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Observation of apparent magnetic charges carried by ferromagnetic particles in water droplets

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Abstract. The behaviour of water droplets condensed on ferromagnetic particles of submicron sizes, which are falling in a gaseous medium, is investigated. Under intensive lighting a number of droplets move in a magnetic field similarly to objects having magnetic charge. The mean value of this charge coincides with the value of the Dirac monopole charge.

This work continues the series of the experiments devoted to investigation of the magnetic charge effect (MCE)† on ferromagnetic aerosols (Mikhailov 1983, 1985, 1987).

The results obtained earlier were interpreted in terms of the magnetic charge concept, and this allowed us to explain consistently all the regularities obtained experimentally. However, there is another approach to the problem—an attempt to relate the MCE to forces of a radiometric nature (Ford and Wheeler 1959). It is evident that to achieve this one needs a certain structural non-uniformity of the particle surface that strongly correlates with the particle magnetic moment (Mikhailov and Mikhailova 1987). These requirements may be readily satisfied in the case of a solid particle.

However, a liquid surface cannot contain any stable non-uniformities and it is also difficult to imagine the gas-kinetic mechanism imitating the MCE at a liquid drop.

So we decided to surround a ferromagnetic particle with a liquid shell and, as a consequence of this, to eliminate contact of its surface with the surrounding gas. The absence of the MCE under observation of such objects would show unambiguously that a magnetic monopole does not participate in this effect.

Thus, the primary aim of this experiment is to search for additional arguments in favour of either alternative.

A trivial way to surround a solid particle by liquid is to condense saturated vapour on its surface in a diffusion chamber (figure 1). For an appropriate particle surface (we use Fe_3O_4) the condensed drop enclosed it completely and it falls together with the particle in gravitational field at a speed which can be made convenient for observation.

If such an object still shows the properties responsible for the MCE, the magnetic field $\boldsymbol{H}$ perpendicular to the gravity force will deflect its trajectory from the line of free fall.

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† The essence of the effect is as follows. Under intensive illumination the separate gas-suspended ferromagnetic particles move in the magnetic field along its lines of force: reversal of the field vector $\boldsymbol{H}$ also causes a reversal of the particle motion, and reducing the field to zero causes them to stop. An increase in field strength or light intensity causes a rise in particle velocity, while decreasing these quantities results in a reduced particle velocity. The number of particles moving in the direction of $\boldsymbol{H}$ is, within statistical variations, equal to the number of particles moving in the opposite direction.

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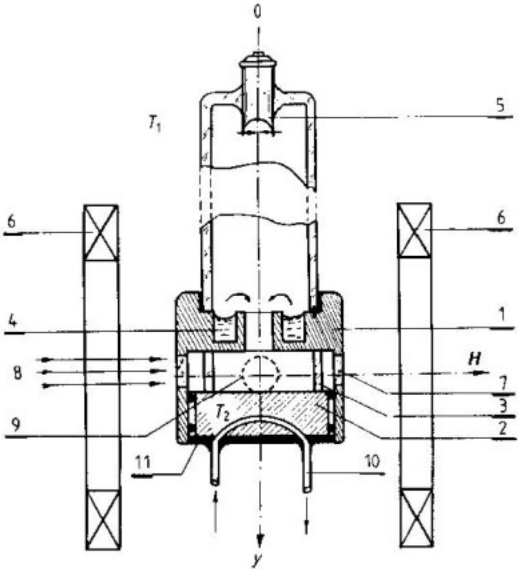

Figure 1. Scheme of experimental apparatus. 1 is the body of diffusion chamber (copper), 2 is the cold bottom of the chamber (copper), 3 is the cylinder (glass), 4 is the working liquid, 5 is the electric spark (aerosols source), 6 is the electromagnet coil (Helmholtz coil), 7 is the optical glass, 8 is the light beam (the gas laser: $\lambda = 4400$ Å, $P = 25$ mW, flux density ~ 100 W/cm^2), 9 is the optical glass for observation, 10 is the refrigerant, 11 is the thermal insulation, T_1 is the external temperature, T_2 is the temperature of the chamber bottom (in our experiment $T_1 = +23°$ C, $T_2 = +2°$ C, $\Delta T/\Delta y = 30°/\text{cm}$).

To avoid ambiguities when identifying tracks, it is expedient to carry out the periodic inversion of the field $\boldsymbol{H}$ (scanning). In this way one can reveal and take into account systematic effects (e.g. photophoresis). In our experiment we do this by alternating the current direction in the magnetic coils at a frequency of several Hertz.

Under such conditions a particle showing the MCE will move along the trajectory depicted in figure 2.

The first observations made in the diffusion chamber have shown that the MCE is still present. Ferromagnetic particles (increased in mass due to the saturated water vapour condensation by six orders of magnitude) fall into the field of view of a

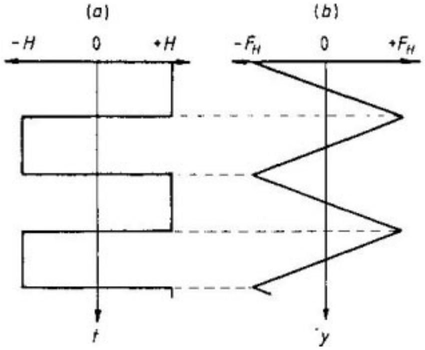

Figure 2. (a) is the time diagram of the magnetic field. (b) is a trajectory of a particle: $\circ Y$ is a line of the free fall. The scanning frequency in this experiment is $\nu = 5$ Hz.

microscope—in accordance with figure 2.† The photograph of such a particle trajectory is given in figure 3.

Thus the apparent magnetic charge effect is confirmed by these observations.

The charge is found as follows.

For Stokes' motion the speed of a falling droplet is

$$v_S=\frac{2a^2\gamma}{9\eta}\rho \tag{1}$$

where a is the drop radius, γ is the free fall acceleration, η is viscosity, ρ is the drop density.

The magnetic field $\boldsymbol{H}$ acts on the magnetic charge g with the force

$$\boldsymbol{F}=g\boldsymbol{H}. \tag{2}$$

According to Stokes' law

$$gH=6\pi\eta a v_H \tag{3}$$

where v_H is the drop speed in the direction of $\boldsymbol{H}$.

From (1) and (3) we obtain

$$g=\frac{18\pi}{H}\sqrt{\eta^3/2\gamma\rho}\;v_H\sqrt{v_S}. \tag{4}$$

Since the field scanning frequency and the characteristics of the optical measurement system are known, the speeds v_H and v_S are obtained easily from the particle track

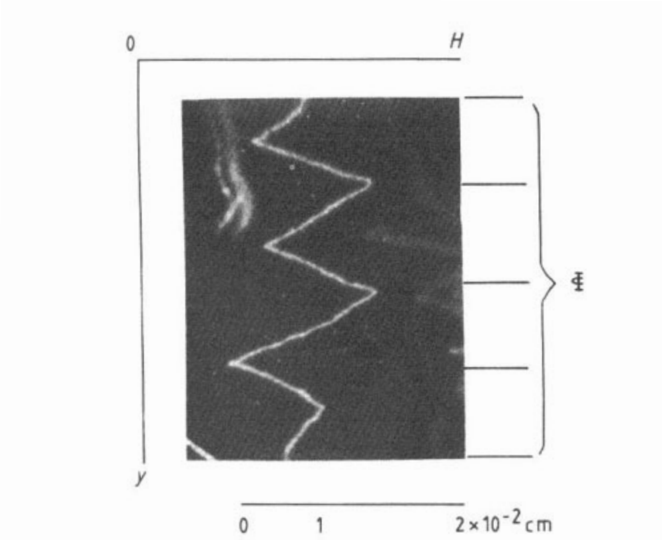

Figure 3. The photograph of the trajectory of the particle. Φ is the light beam, ∘Y is the gravity force direction, ∘H is the force line of the magnetic field. The scanning frequency of the magnetic field $\nu=5$ Hz, $H=2.7$ gauss.

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† A control experiment on particles of Pt (paramagnetic) and Cu (diamagnetic), also enclosed with droplets, showed an absence of the magnetic charge effect. This result is compatible with the results, obtained earlier on 'dry' particles (Mikhailov 1987), and indicates that the droplet itself does not cause the effect.

photographs (figures 2 and 3). This technique was presented in detail previously (Mikhailov 1983, 1987). The values appropriate to this experiment are $a \sim 10^{-4}$ cm, $v_S \sim (10^{-2}\text{-}10^{-1})$ cm s^{-1} at $H \sim (1\text{-}10)$ gauss.

During this experiment the tracks of 428 particles have been photographed and processed. The charge distribution of these particles is shown as a histogram (figure 4). The histogram is approximated by a log-normal distribution (smooth curve) using the minimization program (FUMILI) of Sokolov and Silin (1961). The most probable value of the apparent magnetic charge is

$$g_m = (2.5^{+1.6}_{-1.3})10^{-8} \text{ gauss cm}^2. \qquad (5)$$

It is evident that the charge of Dirac's monopole $g_D = 3.29 \times 10^{-8}$ gauss cm^2 is within the range of (5).

The log-normal distribution suggests that among the observed events are rare cases when a measured value is considerably greater than the mean. This suggests that in our experiment there may be charges which are a multiple of the elementary charge.

Note that the results of this experiment are in accordance with the Lochak theory of magnetic monopole (Lochak 1985a, b). From that theory it follows that observation of Dirac's monopoles under the conditions in our experiment is quite probable as the monopoles are expected to be created by a process of interaction between light and microparticles (see also Akers 1988, Barrett 1989, Daviau 1989).

Further work is necessary to exclude the possibility of systematic errors but from the above numerical result we conclude that the observed effect would be consistent with the presence of Dirac monopoles within the droplet, possibly held as bound states with the magnetic moment of the ferromagnetic particle.

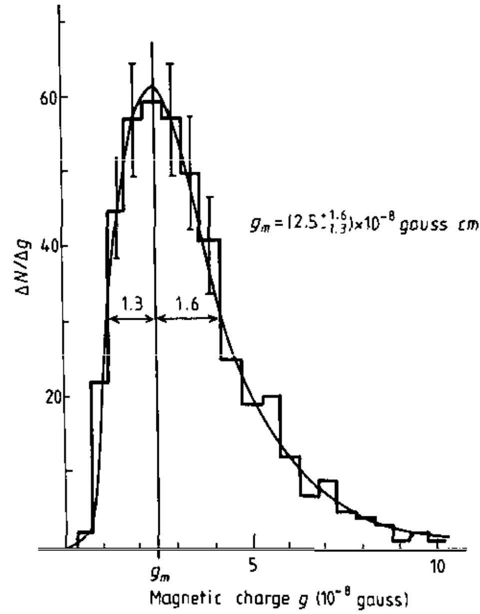

Figure 4. The charge distribution of the particles. The smooth curve is $p(g) = A/(\sigma g \sqrt{2\pi}) \exp[-(\ln g - m)^2/2\sigma^2]$, where $A = 219 \pm 6, 4$, $\sigma = 0.557 \pm 0.006$ and $m = 1.09 \pm 0.01$.

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