Solenoidal electric dipole moment

L. A. Mikaélyan

I. V. Kurchatov Institute of Atomic Energy

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A macroscopic experiment aimed at finding the solenoidal electric moment p_s is proposed and realized. The upper bounds obtained for the moment are $p_s < 5\times 10^{-27}$ and $p_s < 2\times 10^{-22} e$ cm for the electron and the Fe^{57} nucleus, respectively.

By "solenoidal electric dipole moment (EDM)" $\mathbf{P}_s$ is meant a moment that produces a time constant solenoidal electric field $\mathbf{e}$ with closed force lines, just as the lines of the field $\mathbf{b}$ produced by the magnetic dipole moment $\vec{\mu}$ are closed. More accurately speaking, a particle has a moment $\mathbf{p}_s$ if the field $\mathbf{e}$ coincides, apart from a factor, with the field $\mathbf{b}$ of the magnetic moment $\vec{\mu}$. The solenoidal field $\mathbf{e}$ might be produced, for example, by circular currents of magnetic poles (monopoles).

If a macroscopic sample contains oriented moments $\mathbf{p}_s$, so that the solenoidal moment per unit volume $\mathcal{P}_s$ differs from zero, then a macroscopic electric field E_s should be produced, with a closed-circuit circulation (emf) different from zero. Indeed, it follows directly from the foregoing that the macroscopic equations for the considered case coincide, apart from the notation, with the equations of magnetostatics (in the absence of conduction currents):

$$\begin{aligned} \operatorname{rot} E_s &= 4\pi \operatorname{rot} \mathcal{P}_s, & \oint \mathbf{E}_s\, d\mathbf{r} &= \oint 4\pi \vec{\mathcal{P}}_s\, d\mathbf{r}, \\ \operatorname{rot} B &= 4\pi \operatorname{rot} M, & \oint \mathbf{B}\, d\mathbf{r} &= \oint 4\pi \mathbf{M}\, d\mathbf{r}. \end{aligned} \tag{1}$$

We describe below an attempt to observe the solenoidal EDM of an electron in a macroscopic experiment based on the assumption that the moments p_s and μ of the electron are rigidly connected with each other and with the direction of the electron spin. By magnetizing an iron sample, a macroscopic orientation of the moments μ of the magnetic electrons of the iron atoms was produced, and by the same token an orientation of the moments p_s of these electrons.

The electric circuit for the measurement of the emf (see the figure) consisted of a thin iron wire of length $l = 7\times 10^4$ cm and resistance 635 Ω, wound into coil, and a dc measuring instrument. The wire was magnetized by the field of direct current flowing along the coil axis. For convenience, the circuit included also a section with $r = 10$ Ω, on which a voltage drop $\pm 50\times 10^{-6}$ V was produced. We emphasize that the premise that an emf is

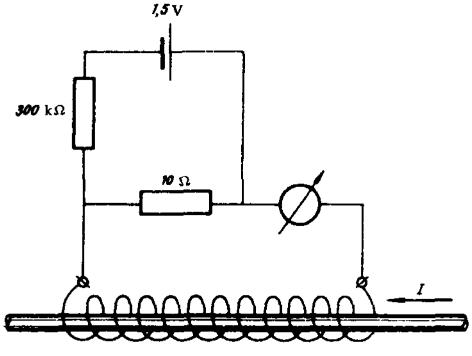

FIG. 1.

produced when the iron is magnetized is based only on the assumption that there is a rigid correlation between the directions of $\mathbf{p}_s$ and $\vec{\mu}$, and on the superposition principle. Indeed, if each electron produces in addition to the solenoidal field **b** of the magnetic moment also a solenoidal electric field **e**, then $\mathbf{e} = (p_s/\mu_B)\mathbf{b}$, where μ_B is the electron Bohr magneton. The macroscopic field E_s, equal to the averaged sum of the individual fields e, satisfies the conditions

$$\oint \mathbf{E}_s\, d\mathbf{r} = \oint \Sigma \mathbf{e}\, d\mathbf{r} = \frac{p_s}{\mu_B}\oint \mathbf{b}\, d\mathbf{r} = \frac{p_s}{\mu_B} 4\pi \oint \mathbf{M}\, d\mathbf{r} \approx \frac{p_s}{\mu_B} Bl\,, \tag{2}$$

i.e., the emf with the coefficient $4\pi(p_s/\mu_B)$ is equal to the circulation of the magnetization of the sample (it is assumed that the entire magnetization of the iron is of spin origin).

In the experiment, magnetization of the iron to $4\pi M = \pm 10^4$ has established an upper bound for the emf, namely $\oint \mathbf{E}_s \cdot d\mathbf{r} < 10^{-6}\ \mathrm{V} = 3.3\times 10^{-9}$ cgs esu. The absence of an emf of this magnitude permits, with (2) taken into account, an estimate of the solenoidal moment of the electron. With the aid of obvious relation we obtain also an estimate for the Fe^{57} nucleus

electron $p_s < 5\cdot 10^{-29}\ e\cdot\mathrm{cm}$,
Fe^{57} $p_s < 2\cdot 10^{-21}\ e\cdot\mathrm{cm}$

The low sensitivity to the moment of Fe^{57} is due to the fact that the nuclear polarization under the experimental conditions (room temperature, natural isotope mixture) was quite low.

Expression (2) and the estimate of p_s should be corrected for the following factors. Actually the solenoidal character of the field **e** becomes manifest only if there is a direct contact between the conduction electron and the moment p_s. A rough allowance for the Coulomb repulsion between the conduction electron and the magnetic electron of the iron worsens the estimate of the electron moment by approximately two orders of magnitude, while the attraction of the conduction electron to the nucleus improves the estimate of the nuclear moment by approximately one order of magnitude. As a result we obtain the following estimates:

electron $p_s < 5\cdot 10^{-27}\ e\cdot\mathrm{cm}$.
Fe^{57} $p_s < 2\cdot 10^{-22}\ e\cdot\mathrm{cm}$

We note that the correlation between the electric dipole moment and the spin of the particle is possible only with nonconservation of P and T-parity. The experimental bound obtained in the present study on the moment of the electron is better by approximately three orders of magnitude than in[1]. Theoretical estimates of the maximum possible value of the moment can be obtained by methods analogous to those of[2].

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