An experimental limit on the existence of the electron quasimagnetic (arion) interaction

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The results of a search for an electron quasimagnetic interaction are given. It is found that the quasimagnetic (arion) interaction between electrons does not exceed 10^{-14} of their magnetic interaction. For the arion interaction constant of the electron this is equivalent to the limit $x_e^2 < 2\times 10^{-4}$.

A number of theoretical models (supersymmetric theories, technicolor models, and grand unification models) suggest the possible existence of physical massless or very light particles. The details of the theoretical study of such models are given in the review articles of Ref. 1. The standard model permits the existence of such particles. They are very interesting from the experimental point of view, since they can be detected in experiments at the laboratory scale. Various theoretical models predict the existence of a stable, massless, pseudoscalar particle—the arion.[2] The model-independent features and possible methods of detection of the long-range arion force are studied in greatest detail in Ref. 1. There the analogy between the arion and magnetic fields is studied. Arion exchange between two fermions f_1 and f_2 leads to the potential

$$V(r) = -x_{f_1} x_{f_2} \frac{G_F}{8\pi\sqrt{2}} \frac{1}{r^3} [\vec{\sigma}_1 \vec{\sigma}_2 - 3(\vec{\sigma}_1 \vec{n})(\vec{\sigma}_2 \vec{n})], \qquad (1)$$

where $\vec{\sigma}_1$ and $\vec{\sigma}_2$ are the Pauli spin matrices, $n = \vec{r}/r$, G_F is the Fermi constant and x_f is a parameter which depends on the vacuum expectation values of the fields. This interaction is equivalent, up to a sign, to the interaction of spin magnetic moments with the "magneton" $x_f(G_F/8\pi\sqrt{2})^{1/2}$. The arion field is, like the magnetic field, generated by oriented spins. The main difference is that the arion field is not related to moving electric charges.

Therefore, in its simplest form the goal of a laboratory experiment is, first, to create a system of polarized spins, second, to cancel or screen the magnetic field of these spins by electric currents, and, third, to attempt to detect the presence of a quasimagnetic field in the screened region by means of a "spin" detector. By "spin detector" we mean any magnetometric system based on the interaction of particle spins with the measured field. The result of such an experiment can be written as a ratio $\Delta B / B_0$, where B_0 is the magnetic field of the polarized spin system screened by currents and ΔB is the value of the field measured by the spin detector in the screened region. This ratio is proportional to the arion interaction constant x_{f_1}, x_{f_2}. For example, for electrons[2]

$$\frac{\Delta B}{B_0} = x_e^2 \frac{G_F m_e^2}{2\pi\sqrt{2}\alpha} = 4,7 \cdot 10^{-11} x_e^2. \tag{2}$$

In laboratory experiments the most stringent limits which have been obtained are those of Ref. 3, $|x_e x_q| < 2.5 \times 10^{-3}$, and Ref. 4, $|x_e x_q| < 10^{-2}$ for the arion interaction of electrons and quarks, and also in Ref. 5: $x_e^2 < 10^{-3}$ for the arion interaction of electrons.

The experiment which we have carried out is shown schematically in Fig. 1. As the arion field source we used a massive ferromagnetic screen, magnetized by the switching of a superconducting solenoid. A ferromagnetic rod in a superconducting screen placed along the source axis as close as possible to its face served as the detector. The variation of the magnetic flux inside the rod was measured by means of a SQUID with a flux transformer. As mentioned earlier, the experiment measured the ratio $\Delta B / B_0$ in the screened region. It is therefore necessary to create the maximum possible B_0 and then to be able to suppress it to a level smaller than ΔB, i.e., such that

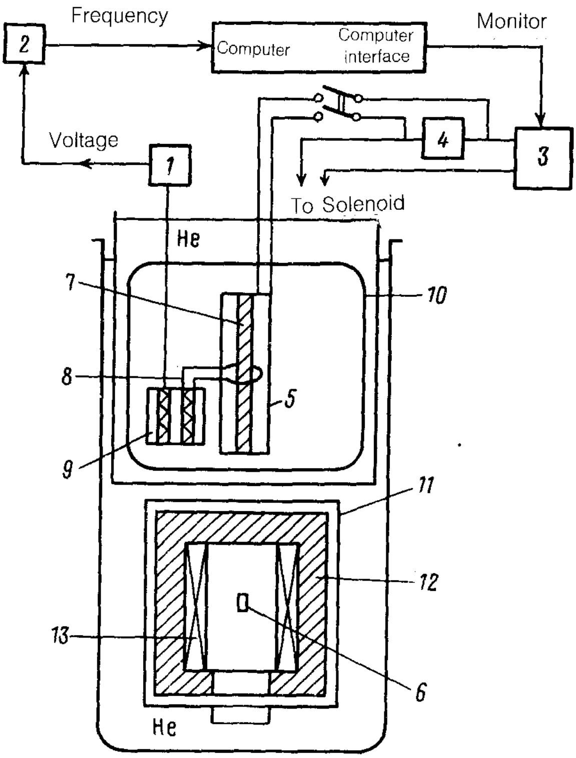

FIG. 1. 1—Magnetometer, 2—voltmeter, 3—power amplifier, 4—shunt, 5—calibration coil, 6—Hall probe, 7—ferromagnetic rod, 8—flux transformer, 9—Zimmerman SQUID, 10—lead screen, 11—niobium screen, 12—ferromagnetic screen, 13—superconducting solenoid.

the screening coefficient satisfy $K > B_0/\Delta B$. In our experiment the screening coefficient can be represented as the product of three coefficient: $K = K_f K_n K_l$, where K_f is the screening coefficient of the ferromagnetic screen, K_n is the screening coefficient of the niobium screen, and K_l is the screening coefficient of the lead screens. Each of these coefficients was measured: $K_f > 10^2$, $K_n \approx 10^5$, and $K_l \approx 10^8$. Altogether, we have $K > 10^{15}$. Therefore, the search for the effect can be extended to the level $\Delta B / B_0 \sim 10^{-15}$. In addition, the screening coefficient of the lead screens imposes certain requirements on the value of the magnetic field leaking from the current lead: $\Delta B_c < \Delta B K_l$. The field leakage was monitored by a quantum magnetometer on an optical pump. For a current of ≈ 15 A ($B_0 \sim 200$ Oe) we obtained $\Delta B_c < 10^{-6}$ Oe. For this field leakage and screening coefficient $K_l \approx 10^8$ the effect can be sought down to the level $\Delta B / B_0 \sim 10^{-16}$. Let us now consider the actual measurement technique. The setup operated in the following manner in the measurement mode. A computer controls the feeding of a current from an electronic module to the control winding of the power amplifier, which feeds a superconducting solenoid. The magnetic field of the solenoid is controlled by a Hall probe. The current in the solenoid circuit is controlled by the voltage on the measuring shunt. As usual, the contribution from slow drift was suppressed by changing the current polarity in the sequence $+ - - + - + + - - + + - + - - +$. The duration of this set of measurements is 15 sec. The output voltage from the SQUID magnetometer is transformed to a frequency by a digital voltmeter and then fed to counters which continuously operate an array of N_i^+ and N_i^- counters for the corresponding polarity of a single set of measurements. The difference $\Delta N_i = N_i^+ - N_i^-$ is proportional to the desired arion field. The data collection continues until the computer buffer is filled (a measurement cycle consists of 27 sets). The preliminary analysis of the cycle is then carried out: $N_2^+ = \Sigma N_i^+$, $N^- = \Sigma N_i^-$ $(i = 1,...,27)$, $\Delta N = (N^+ - N^-)/27$, $\sigma^2 = \Sigma(\Delta N_i - \Delta N)^2/26 \times 27$. To rescale ΔN to the arion interaction constant, it is necessary to calibrate the measuring system. This can be done by supplying a known magnetic field to the rod. The voltage from the measurement shunt is fed to the calibration coil. The same program used to make the measurements is then used to determine the calibration constant $\Delta N_k = N^+ - N^-$. If we denote the amplitude of the gauge field by H_k, we then can write

$$\frac{\Delta B}{B_0} = \frac{\Delta N \pm \sigma}{\Delta N_k} \frac{H_k}{B_0}. \tag{3}$$

According to the calibration results, $\Delta B / B_0 = |5.7 \times 10^{-15} (\Delta N \pm \sigma)|$. For the interaction constant we find

$$x_e^2 = \frac{\Delta N \pm \sigma}{\Delta N_k} \frac{H_k}{4,7 \cdot 10^{-11} B_0} \approx |(\Delta N \pm \sigma) 1,2 \cdot 10^{-4}|. \tag{4}$$

Nearly two hundred measurement cycles were carried out. The total set of statistics was ≈ 28 hours of data acquisition time. The histogram of ΔN_i is shown in Fig. 2. According to the Pearson criterion, the hypothesis of a normal distribution is satisfied at a significance level $q = 0.1$ ($\chi_n^2 \approx 8.7$, $\chi^2 \approx 11.7$, $\chi_b^2 \approx 27.6$). The combined analysis of the full set of measurements gives the result

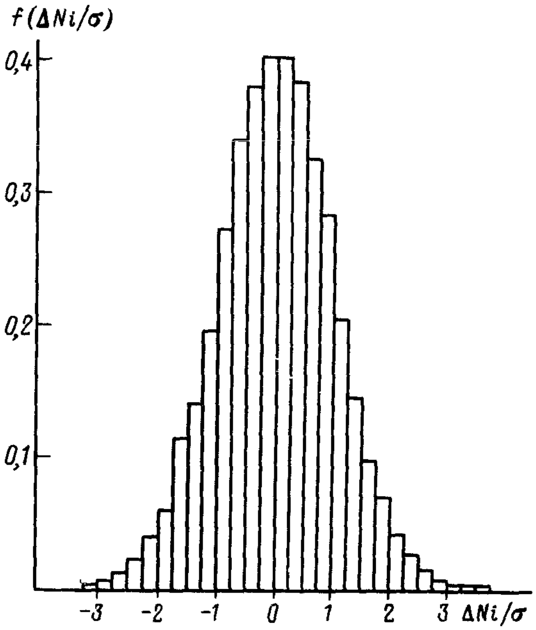

FIG. 2. Histogram of the distribution of the deviation from the mean value ΔN_i normalized to its rms deviation.

$$\Delta N = (-0,7 \pm 7,9) \cdot 10^{-1}. \tag{5}$$

The measured effect lies within the error. At the 95% confidence level we obtain the limit

$$\frac{\Delta B}{B_0} < 8,5 \cdot 10^{-15}. \tag{6}$$

Therefore, in the experiment we have attained a screening coefficient of $\approx 10^{14}$ and have shown that at this level the polarized electron interaction energy does not have any "quasimagnetic" corrections. This leads to the following limit on the arion interaction parameter of electrons at the 95% confidence level:

$$x_e^2 < 2 \cdot 10^{-4}. \tag{7}$$

This is five times more stringent than the limit of the earlier study of Ref. 5. It should be noted that the method can be improved further so that the sensitivity is increased by 1–2 orders of magnitude.

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