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DETERMINATION OF THE ADIABATICITY PARAMETER ρ_L/R FOR AN ELECTRON MOVING IN AN AXIALLY-SYMMETRICAL MAGNETIC TRAP

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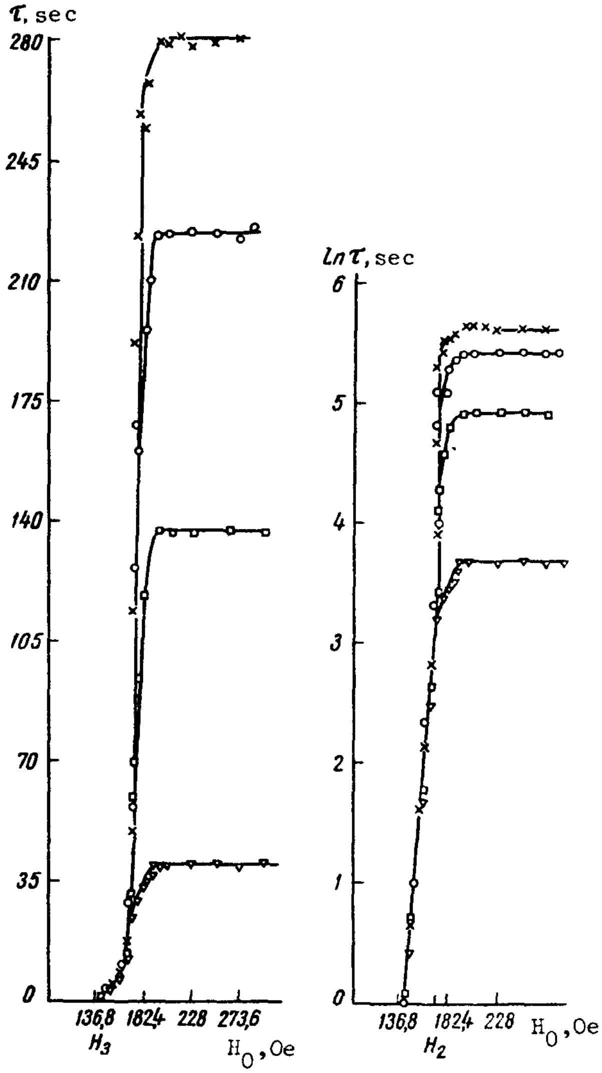
We have investigated experimentally the dependence of the lifetime τ, of electrons captured in a magnetic trap, on the magnetic field. S. N. Rodionov [1] has shown that at certain magnetic-field configurations the electron lifetime is large (~10^7 oscillations). However, the physical picture of the motion of a charged particle in a magnetic trap over very long time intervals remained quite unclear. Chirikov [2,3] was among the first to investigate this picture, and found it to be, in the most general outline, as follows: There exists a certain critical value $(\rho_L/R)_1$ at which the motion becomes stochastic, and when $\rho_L/R < (\rho_L/R)_1$ the motion is stable, i.e., it differs little from the motion with constant magnetic moment (ρ_L - Larmor radius, R - radius of curvature of the force line). However, the question of how long stability is maintained during the course of the motion remained open.

Hope of rigorously explaining this question was raised by the papers of Kolmogorov [4] and Arnol'd [5], in which the conditions were obtained for absolute stability, i.e., for stability at a finite value of ρ_L/R. Arnol'd [5] formulated a theorem that at a certain finite value of the adiabaticity parameter (ρ_L/R in our case) the charged particle should exist in the trap forever, i.e., it should never leave the volume, if there are no additional loss sources. However, the theory could not determine the value of the parameter $(\rho_L/R)_1$. In our experiments we attempted to find the numerical critical value of the parameter $(\rho_L/R)_1$.

The maximum lifetime during the time of our experiments, at $\rho_L/R < (\rho_L/R)_1$ was 410 sec (5×10^{11} Larmor revolutions) and was determined by scattering by the residual gas.

The experimental setup was a magnetic trap of mirror configuration. The maximum magnetic field at the center of each of the mirrors reached 1500 Oe at a mirror ratio ranging from 2.66 to 4.44. A detailed description of the apparatus is given in [6].



The injector was an electron gun situated outside the working volume behind one of the mirrors (No. 1), in the center of which was placed a special electrode in the form of a hollow cylinder. The electrons were injected by rapidly varying the electric field applied to the electrode. The captured electrons were observed by measuring the current to a collector placed in mirror No. 2. The energy of the injected electrons was varied from 7 to 35 kV. The vacuum in the system was varied from 4×10^{-6} to 7×10^{-10} mm Hg. During the time of the experiments we obtained 65 plots of the lifetime against the magnetic field at different electron energy W, mirror ratio γ, and angle $\bar{\theta}_0$.

We denote by τ_g the time of scattering by the residual gas, and by τ_m the time of scattering by the magnetic-field inhomogeneities. As seen from the figure, at magnetic field values $H \leq H_3$ the lifetime of the electron is so small that at the scale used in the figure the $\tau = \tau(H)$ plot almost merges with the OH axis. With increasing magnetic field, when τ_m is still much smaller than τ_g, the electron lifetime is independent of the residual gas and is given by the formula $\tau = Ae(B/(\rho_{\perp}/R))$. This is seen most clearly from the $\ln \tau = f(H)$ curves. The experimental curves make it possible to determine the coefficients A and B, namely $A \cong 10^{-8}$ sec and $B = 0.8 - 0.9$. With increasing magnetic field, the electron lifetime followed an exponential law only after a certain magnetic field value H_2. When plotting $\tau = \tau(H)$, we could vary H in steps of 5.7 Oe. As seen from the figure, at such a measurement accuracy τ had at $H = H_2$ different values bounded from above by τ_g - the time determined by the scattering by the residual gas.

Thus, according to the figure, the $\ln \tau = f(H)$ plot approaches an asymptote determined by the field H_2. This result agrees with Arnol'd's theory: At magnetic fields $H > H_2$, when the parameter $\rho_{\perp}/R$ becomes sufficiently small, the particle goes over into the region of absolute confinement, i.e., in the region where it executes a tremendous number of Larmor revolutions (up to 5×10^{11} in our experiments) and does not leave the working volume.

As the electron moves in the trap, the values of ρ_L, R, and ρ_L/R change with changing coordinate z. The decisive factor in the motion of the electron is the maximum value of ρ_L/R. We obtained the coordinate z (the oz axis coincides with the symmetry axis of the system) at which the parameter ρ_L/R reaches a maximum value, equal to

$$\left(\frac{\rho_L}{R}\right)_{1\max} = \frac{3{,}4\sqrt{W}}{H_{01}}\,\frac{\sqrt{\gamma-1}}{z_0}\sqrt{1-\sin^2\bar{\theta}_0\left[1+\frac{f(\bar{\theta}_0)}{4}\right]}\,\frac{\sqrt{f(\bar{\theta}_0)}}{\left[1+\frac{f(\bar{\theta}_0)}{4}\right]^2},$$

where

$$f(\bar{\theta}_0) = \frac{3-\sin^2\bar{\theta}_0-\sqrt{9(1-\sin^2\bar{\theta}_0)^2+4\sin^2\bar{\theta}_0}}{\sin^2\bar{\theta}_0},$$

H_{01} is the value of H_0 at $\rho_L/R = (\rho_L/R)_1$, γ is the mirror ratio, $2z_0$ is the distance between mirrors, and $\bar{\theta}_0$ is the angle between the velocity vector and the field H in the median plane.

We took account here of the fact that, in accord with the measurements, the magnetic field on the system axis varied like $H = H_0 + \lambda z^2$. The value of $(\rho_L/R)_{1\max}$, calculated from curves plotted in accord with the foregoing formula, was found to be $\cong 4 \times 10^{-2}$. If the geometry of the magnetic field and the injection conditions are maintained constant, then the Larmor radius ρ_L also remains practically constant when the electron energy is varied.

In conclusion, the authors are deeply grateful to B. V. Chirikov for suggesting the topic, for interest, and for valuable advice that contributed to the performance of the work.

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TEMPERATURE DEPENDENCE OF THE MAGNETOSTRICTION CONSTANTS OF SINGLE-CRYSTAL LITHIUM FERRITE

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The nature of the magnetostriction of ferrites with magnetic ions in S-states is still unclear at present [1]. It is therefore important to investigate experimentally in detail the magnetostriction of such ferrites. Lithium ferrite is of special interest in this respect, being a material capable of existing in different ionic-ordering states, depending on the heat treatment [2]. In addition, this material is promising from the point of view