Determination of the critical value of the adiabaticity parameter for electrons moving near the midplane of a magnetic bottle

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(Submitted May 6, 1974)
ZhETF Pis. Red. **19**, 755–757 (June 20, 1974)

The numerical critical value of the adiabaticity parameter is obtained for electrons injected in the midplane of a magnetic bottle with the aid of crossed fields E and H and pitch angles $\alpha \sim 90°$.

An experimental investigation of the stability of motion of electrons in an axially-symmetrical magnetic trap, as a function of the adiabaticity parameter $\chi = R_L/R_c$ (R_L is the Larmor radius, R_c is the curvature radius of the magnetic force line) was carried out in a number of studies.[1-4] The numerical critical value of the parameter χ_*, which separates the stable motion from the unstable motion, was obtained in[1] for electrons having small pitch angles in the midplane of the bottle. It was noted in[3,4] that for electrons with larger values of the orbital angular momentum the manifestation of nonadiabatic effects in motion begins at large χ. However, the value of χ_* was not determined. In the present paper we investigate the nonadiabaticity of the motion of an electron near the midplane of a dipole trap (the plane passing through the center of the field perpendicular to the symmetry axis).

The dipole plane was produced by a permanent magnet in the form of a homogeneously-magnitized sphere. We used magnets of 8 cm diameter with magnetic moments $M \approx 2\times10^4$ G cm^3 and diameter 16 cm with $M \approx 2.6\times10^5$ G cm^3. The choice of a field with this configuration was governed by the following considerations. Near the midplane, the dipole trap is similar to an ordinary trap with magnetic mirrors. In addition, an investigation of the motion in a dipole trap is of great interest for cosmic physics.

The maximum vacuum in the working volume was $P \sim 5\times10^{-10}$ Torr; the method of obtaining this vacuum was described in detail in[2]. The injector was an incandescent filament placed between two plane-parallel plates. The plate dimensions ranged from 10×10 to 20×20 mm, and the distance between them was 1–2 cm. The electrons were injected into the bottle by applying to the plate rectangular pulses of amplitude up to 500 V and duration ~1 μsec. The electron source was located in the central plane in a magnetic field $\overline{H} \approx 80$ Oe. The "breakaway" of the electrons from the source was due to the drift in the crossed fields E and H. The choice of the optimal experimental conditions was effected with the aid of an electric probe. The signals from the probe constituted a sequence of pulses with decreasing amplitude and with equal delay between them, determined by the period of the azimuthal drift.

The trapped electrons were registered with a KÉU channel electron multiplier.[5] The input to the multiplier, together with the system of grids and diaphragm, was placed along the force lines at an angular distance ~20° from the midplane. The magnetic field intensity in

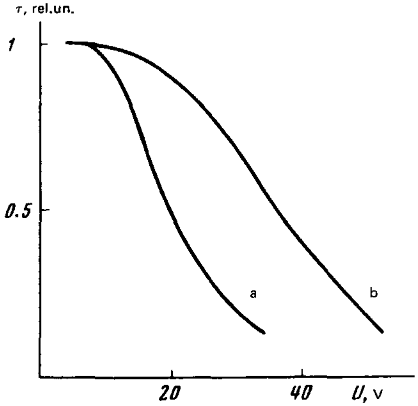

FIG. 1. Dependence of the duration of the pulse train on the voltage on the blocking grid of the channel electron multiplier: a—τ for a magnet with $M = 2\times10^4$ G cm^3, b—τ for a magnet with $M = 2.6\times10^5$ G cm^3, $E = 300$ V/cm, $P \sim 10^{-9}$ Torr.

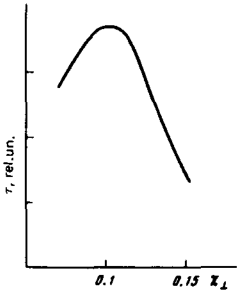

FIG. 2. Dependence of the containment plane on the transverse adiabaticity parameter; $P \sim 5 \times 10^{-10}$ Torr.

the midplane was $H = 44$ Oe. The oscillogram of the electron current to the multiplier took the form of a ridge of pulses, from the duration of which it was possible to estimate the containment time τ. The maximum value of τ was determined by the scattering by the residual gas and amounted to $\sim 10^{-1}$ sec ($\sim 10^{7}$ Larmor periods of revolution).

Figure 1 shows the dependence of τ on the blocking voltage on the grid of the electron multiplier for the large and small magnets. If the containment time were to depend on the vacuum then, by virtue of the practical identity of the spectra in both cases, the $\tau(U)$ plots would not differ. Actually, a strong discrepancy is observed for $U \gtrsim 10$ V, corresponding to χ_{*} $(\alpha = 90°) = \chi_{\perp *}$ ~ 0.1. For a more accurate determination of the critical value of $\chi_{\perp *}$, we plotted τ against the electron energy W.

Figure 2 shows a plot of $\tau(\chi_{\perp})$, from which it follows that at $\chi_{\perp} \lesssim 0.1$ the containment time is determined by the scattering by the gas, since the value of τ increases with increasing $W (\chi \sim W^{1/2})$. At larger values of $\chi_{\perp}$, nonadiabatic escape of the electrons from the dipole trap takes place. An analysis of the plots of $\tau(U)$ and $\tau(W)$ leads to the following numerical critical value of the adiabaticity parameter

$$\chi_{\perp *} = \frac{R_L}{R_c} = \frac{3R_L}{R_s} \approx 0.1 \pm 0.02,$$

where R_s is the distance from the center of the magnet to the force line in the midplane. The competing mechanism that extracts the electrons from the drift sheath is the result of diffusion across the magnetic field and the ionization losses at $W \gtrsim 15$ V do not play an essential role. Estimates show that $\tau_{\perp} \sim D_{\perp}^{-1} \gg \tau$ at $P \lesssim 10^{-7}$ Torr, and that the time between the two ionization acts is $\tau_i \gtrsim 10\tau$ at $P \lesssim 10^{-6}$ Torr.

The authors are grateful to S. N. Vernov for a discussion of the results.

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