DETERMINATION OF CRITICAL ADIABATICITY PARAMETERS FOR DIFFERENT MAGNETIC FIELD GEOMETRIES

A. N. Dubinina and L. S. Krasitskaya

We give the results of some experiments to determine the critical adiabaticity parameter for electrons moving in a mirror-type magnetic trap with different magnetic field geometries. We show that for any configuration of the magnetic field the critical adiabaticity parameter has a constant value of $(3.9 \pm 0.4) \cdot 10^{-2}$.

The determination of the critical adiabaticity parameter $\varepsilon_* = (\rho_L/R)_1$ for electrons moving in a mirror-type magnetic trap was described in [1, 2], where R is the characteristic field dimension and ρ_L is the Larmor radius.

Let m be the electron mass and $v_\perp$ the component of the electron velocity vector perpendicular to the line of force of the magnetic field H. Then, when $\varepsilon < \varepsilon_*$ the magnetic moment $\mu = mv_\perp^2/2H$ is conserved and the particle can remain in the trap for a very long time, i.e., the motion is stable. When $\varepsilon > \varepsilon_*$ the particle soon escapes from the trap.

According to the experiments in [1, 2], the critical adiabaticity parameter $\varepsilon_* = (4.0 \pm 0.5) \cdot 10^{-2}$. In all the experiments referred to in [1, 2] the magnetic field on the axis varied according to the law $H = H_0 + \alpha z^2$, where H_0 is the magnetic field on the axis of the system in the median plane (point z = 0). If the field conforms to some other law, the equation given in [1, 2] will be invalid. The critical value of the adiabaticity parameter (ε_*) determines the boundary between the stable and unstable regions of motion and, hence, the question of whether ε_* is independent of the magnetic field parameters, or the parameters of particles oscillating between the magnetic mirrors, is of great importance. We showed in [1, 2] that ε_* is independent of the energy of the injected particles, the injection angle, and the mirror ratio.

The aim of the experiments described below was to determine the critical adiabaticity parameter for different laws of variations of the magnetic field on the system axis. Variation of the magnetic field was effected by several solenoids placed between the main magnets, which produced a magnetic field of the mirror-trap type (see Fig. 1a). By altering the number of extra solenoids and the direction and strength of the current in them we were able to produce magnetic fields of 30 different configurations. Figure 1b shows some of them [the coordinate origin (z = 0) is in the median plane]. A description of the experimental apparatus and method was given in [4]. The electron injector was an electron gun placed behind the first mirror outside the trap. Injection was effected by a rapid change in the electric field applied to a hollow cylinder mounted in the first mirror.

The trapped electrons were detected from the current on a collector located in the second mirror. In the experiments described in this paper the electron energy varied from 7 to 23.5 keV, and the electron lifetime τ varied from 2 to 12 sec. In this case τ was not defined as the time for reduction of the current pulse by a factor e, but as three times this period. By altering the field strength we determined the lifetime τ of trapped electrons as a function of the field strength. Figure 2a shows some of these curves. The electron lifetime τ in sec is plotted on the y axis and the field strength in oersteds at the center of the magnetic mirror is plotted on the x axis.

Figure 1b illustrates the variation of the magnetic field H on the system axis for which the plot of lifetime of the trapped electron against field strength (Fig. 2a was determined. If the curve of H = H(z) is numbered 1 in Fig. 1b, the relationship $\tau = \tau(H)$ obtained for this magnetic field geometry is also numbered 1 in Fig. 2a.

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 176–178, September–October, 1970. Original article submitted April 7, 1970.

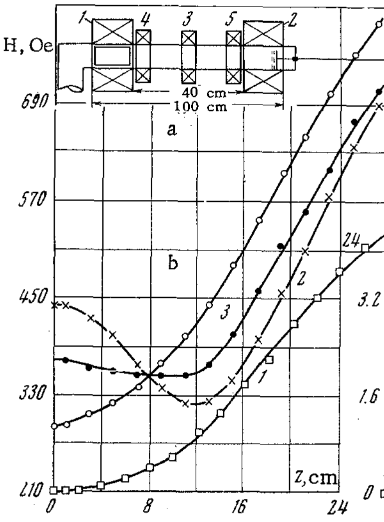

Fig. 1

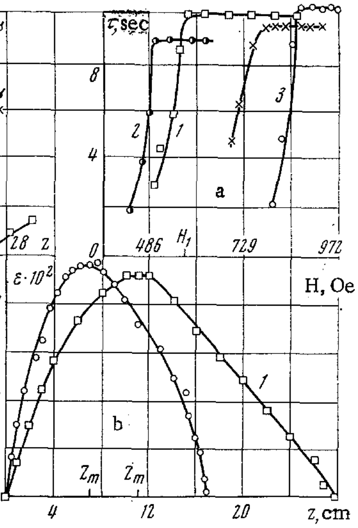

Fig. 2

As the electron oscillates between the magnetic mirrors its r and z coordinates are connected with one another by the motion integral $r^2H(r) = \text{const}$. Hence, the parameter ε, which in the general case is a function of the two coordinates r and z, can be regarded as a function of the variable z alone, i.e., $\varepsilon = f(r(z); z)$. Figure 2b shows this function as a function of z. It is obvious that the picture is symmetric relative to the median plane (z = 0). The regions close to the maximum value ($z = z_m$) are of most interest, since it is here that the requirement of smallness of the adiabaticity parameter may not be satisfied. The lifetime of particles in the trap was determined experimentally as a function of the magnetic field, and the field at which the lifetime τ ceased to depend on the field strength was called the critical magnetic field H_*. The parameter ε calculated for this magnetic field at the point $z = z_m$ was called the critical adiabaticity parameter and was denoted by ε_*.

When the axial variation of the field is given by $H = H_0 + \alpha z_1^2$, the critical parameter can be calculated from the formula

$$\varepsilon_* = \frac{3.4\sqrt{W}}{H_{0*}} \frac{\sqrt{\gamma - 1}}{z_0} F(\theta°).$$

Here W is the energy, γ is the mirror ratio, θ° is the mean injection angle, and $2z_0$ is the distance between the mirrors. In all the other 30 cases we had to find a relationship of the type in Fig. 2b and determine the critical adiabaticity parameter as $\varepsilon_* = \varepsilon_{max}$. When coil 3 alone (Fig. 1a) was switched in, the magnetic field in the median plane increased or decreased and the field in the mirror was practically constant. The result was that in the first case the gradient dH/dz decreased and, as Fig. 2 (curve 1) shows, the field H_* at which a sharp reduction in the time τ occurred was reduced.

When the field in the median plane was reduced by the switching in of coil 3 the gradient dH/dz increased and the reduction in τ occurred at a higher value of the magnetic field (curve 3 in Fig. 2a). As measurements and calculations showed, the field strength H_* increased so that the ratio $H_*^{-2}dH/dz$ remained constant. The switching in of the three additional coils (coil 3 reduced the field strength, coils 4 and 5 increased it) enabled us to produce various field configurations (two of them are shown in Fig. 1b – curves 2 and 3). In this case the parameter ε_* was again found from a figure like Fig. 2b. After treatment of the results of measurements for 30 different magnetic field configurations we found that the critical adiabaticity parameter was $\varepsilon_* = (3.9 \pm 0.4) \cdot 10^{-2}$. Measurements made in a parabolic field for different mirror ratios, energies, and injection angles gave $\varepsilon_* = (4.0 \pm 0.5) \cdot 10^{-2}$.

Thus, the conducted experiments confirm the hypothesis that the critical adiabaticity parameter is a constant characterizing the motion of electrons in inhomogeneous magnetic fields and is, in fact, the boundary of the stable and unstable regions of motion of the charged particles.

The results of similar experiments were given in [5]. The critical parameter, however, was calculated by a method (not described), which lead to a variation of the critical parameter ε_* with the field geometry. Treatment of the experimental curves given in [5] by our method led to the same value of ε_* for the different field geometries.

The authors thank B. V. Chirikov, in whose laboratory the whole program of research was conducted for suggesting the theme of this work and for discussion of the obtained results.

LITERATURE CITED

1. A. N. Dubinia and L. S. Krasnitskaya, "Determination of the adiabaticity parameter $(\rho_L R)_1$ for electron motion in an axially symmetric magnetic trap," ZhÉTF Pis. Red., 5, No. 7, 230 (1967).
2. A. N. Dubinina, L. S. Krasnitskaya (Krasitskaya), and Yu. N. Yudin (Judin), "Motion of charged particles in a magnetic trap with a mirror configuration," Plasma Phys., 11, No. 7, 551 (1969).
3. B. V. Chirikov, "Resonance processes in magnetic traps," At. Energ. 6, 630 (1959).
4. A. N. Dubinina, L. Ya. Trainin, and B. V. Chirikov, "A trap with magnetic mirrors designed for prolonged confinement of electrons," Zh. Éksp. Teor. Fiz., 49, No. 2(8), 373 (1965).
5. V. G. Ponomarenko, K. Ya. Trainin, V. I. Yurchenko, and A. N. Yasnetskii, "An experimental investigation of the motion of individual charged particles in a mirror device," Zh. Éksp. Teor. Fiz., 55, No. 1(7), 3 (1968).