Langmuir probe. The plasma potential is negative, pointing to a predominant outflow of the ions. At a density $\sim 10^{11}$ cm^{-3} we have $U_f \simeq 20 - 25$ V, and with increasing laser energy the potential decreases by a factor 3 - 4 (Fig. 3). Measurements have shown that the steady-state gas pressure increases with increasing laser-pulse energy (see Fig. 2), reaching 5×10^{-5} Torr at 5 J (the initial pressure in the chamber is $\sim 5 \times 10^{-7}$ Torr). It can be assumed that the main source of the neutral particles is the gas absorbed by the walls of the vacuum chamber. A very important characteristic of the captured plasma is the ion temperature, but no direct measurements of the ion temperature have been performed as yet. An estimate of the ion energy, based on measurement of the plasma stream velocity during the filling of the trap, has shown that the translational energy is of the order of several hundred eV and increases with the laser energy. Experiments were performed on the study of the connection between the density of the captured plasma and the dimension of the focal point on the target (0.3 - 3 mm), the position of the target relative to the boundary magnetic surface (±10 mm), and the magnetic field intensity (3 - 10 kOe). None of these factors influence greatly the plasma parameters; for example, when the magnetic field is changed by a factor 3 - 3.5 the captured-plasma density changes by a factor 2 - 2.5.

Thus, we have demonstrated the possibility of using a laser plasma to fill a toroidal magnetic trap, the high capture efficiency, and the possibility of varying the parameters of the captured plasma in a wide range.

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INFLUENCE ON CORRUGATION OF THE MAGNETIC FIELD ON THE EXPANSION AND COOLING OF A DENSE PLASMA

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As one of the variants of the thermonuclear reactor of the future, we consider a direct system with dense plasma1).

It is assumed that the radial thermal conductivity of the plasma is suppressed by a longitudinal magnetic field, and the radial pressure of the plasma is balanced either by the pressure of the magnetic field or by the pressure of the walls.

If the plasma is produced in the center of the installation, without contact with the ends, then the time of its cooling is determined by the velocity of the free expansion along the magnetic field:

$$t_1 \sim L(M/T)^{1/2}, \tag{1}$$

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1)Dense in the sense that the mean free path of the particles λ is small compared with the length of the apparatus L.

where L is the initial length of the plasma, equal in order of magnitude to the length of the apparatus, T the plasma temperature, and M the ion mass. On the other hand, if the plasma is in contact with the ends, then the time of cooling is determined by the electronic thermal conductivity

$$t_2 \sim \frac{L^2}{\lambda}\left(\frac{m}{T}\right)^{1/2} \sim t_1 \frac{L}{\lambda}\left(\frac{m}{M}\right)^{1/2} \tag{2}$$

(m is the electron mass).

At a plasma density $n \sim 10^{18}$ cm^{-3} and a temperature $T \sim 10^4$ eV, formulas (1) and (2) give approximately equal estimates of the length L necessary to obtain a positive energy yield: $L \sim 200$ m (the transverse dimension and the value of the magnetic field depend on the character of the transverse thermal conductivity). A setup with such parameters, owing to the high plasma pressure ($\sim 10^4$ atm) and the high energy needed for the heating, is apparently at the very borderline of present-day technical capabilities. It would become realizable in practice were it possible to decrease by a factor 5 - 10 both its length and the plasma concentration.

In the present article we propose a method for decreasing the thermal conductivity and the velocity of escape of the plasma along the field; this method apparently solves our problem. The gist of the method is that we change over to a corrugated magnetic field with a corrugation period ℓ much shorter than the mean free path λ (but, as before, $L > \lambda$). The system is transformed into a set of probkotron mirror machines with interconnected ends. Each mirror machine contains captured particles executing a finite motion between the mirrors, and if $\ell < \lambda$ then the captured particles can execute several oscillations from mirror to mirror in the time between two successive collisions. Under such conditions, the transfer of matter and energy along the axis of the system can be effected only by the transiting particles. This circumstance, as will be shown below, leads to the desired effect.

Let us examine the influence of corrugation on the expansion of the plasma, assuming first the corrugation not to be too strong (the mirror ratio k is of the order of unity). The transport of matter is accompanied by friction of the transiting particles against the trapped ones. The latter in turn transfer the acquired momentum to the magnetic field. Consequently one can say in some sense that the plasma experiences friction against the magnetic field.

The friction force per particle is estimated at $F_{fr} \sim M\nu_{ii}v$, where ν_{ii} is the frequency of the ion-ion collisions and v is the velocity of the translational motion of the transiting particles, which in the case of $k \sim 1$ coincides in order of magnitude with the macroscopic plasma velocity. Equating the quantity nF_{fr} to the plasma pressure gradient $\partial nT/\partial z$, we obtain the expansion velocity $v \sim (T/M)^{1/2}(\lambda/L)$. We see therefore that introduction of even not too strong a corrugation leads to a noticeable decrease of v. This changes the character of the motion itself: the inertial expansion gives way to a diffusion "leakage" of the plasma from mirror machine to mirror machine, and the pressure gradient is balanced by the friction of the plasma against the magnetic field 2).

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2) The effect remains in force also at large corrugation scales ($\ell > \lambda$). In this case it is due to the longitudinal viscosity. The rate of leakage is of the order of $(T/M)^{1/2}(\ell^2/\lambda L)$. The deceleration is appreciable until $\ell \sim (\lambda L)^{1/2}$ is reached.

If the radial pressure of the plasma is assumed to be balanced by the wall pressure, then it is desirable to have the wall profile the same as that of the magnetic surface. The longitudinal plasma pressure is then also taken up by the walls, and the magnetic pressure can be made small even in the mirrors: $H^2/8\pi \lesssim nT$.

An increase of the mirror ratio causes a further decrease of the expansion rate. The reason lies both in the reduction of the number of transiting particles and in the decrease of their effective mean free path. The latter effect is connected with the fact that to be captured in the mirror machine it suffices at $k \gg 1$ for the transiting particle to be scattered through a small angle $\Delta\theta^2 \sim 1/k$, so that the effective mean free path becomes of the order of λ/k[3]. The concrete dependence of the expansion velocity on the mirror ratio is determined by the profile of the magnetic field. Calculations show that in the case when the mirror length is small compared with the corrugation period, the velocity decreases by a factor k^2. As a result we obtain the following estimate for the free-expansion time:

$$t_1' \sim \left(\frac{M}{T}\right)^{1/2}\frac{k^2L^2}{\lambda} \sim t_1\frac{k^2L}{\lambda}. \tag{3}$$

A noticeable decrease of the electronic thermal conductivity can be attained only by strong corrugation, since the transport of energy has a diffuse character even in a smooth magnetic field. The thermal flux at $k \gg 1$ and at a small mirror length decreases by a factor k^2. The cooling time increases accordingly:

$$t_2' \sim \left(\frac{m}{T}\right)^{1/2}\frac{k^2L^2}{\lambda} \sim t_1\frac{k^2L}{\lambda}\left(\frac{m}{M}\right)^{1/2}. \tag{4}$$

It is interesting to note that whereas for a smooth tube there exist ranges of lengths and concentrations in which heat-conduction regime is more convenient than the free expansion regime, in a corrugated magnetic field it is always more convenient to have free expansion (see formulas (3) and (4)).

By expanding in the kinetic equations for the electrons and ions in terms of the parameter λ/L, we can obtain a closed system of equations for the change of the temperatures and concentrations of the electrons and ions. The complete results of the corresponding calculations are voluminous and will be published separately. By way of illustration let us consider the problem of expansion of a plasmoid with length $L \gg \lambda(M/m)^{1/4}$. It can be shown that under this condition the heat exchange between the electrons and the ions heats their temperatures equal: $T_e = T_i = T$. The thermal conductivity ensures constancy of the temperature along the plasmoid. The plasma temperature does not depend on the time, since the plasma does not perform work, and the escape velocity acquired by it is small. The foregoing means that the entire information concerning the expansion of the plasma is contained in the equation for the concentration, which, as shown by calculations, takes the following form:

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[3] For the same reason, smallness of the mirror-machine length in the case of strong corrugation should be understood in the sense of $\ell < \lambda/k$.

$$\frac{\partial n}{\partial t} = a\frac{\partial^2 \ln n}{\partial z^2}, \qquad a = \frac{0{,}91\,T^{5/2}}{M^{1/2}k^2\Lambda e^4}, \tag{5}$$

where e is the electron charge and Λ the Coulomb logarithm. For an initial condition in the form $n = n_0(1 + z^2/a^2)^{-1}$ the solution of Eq. (5) is

$$n = n_0(1 + 2at/a^2n_0)[z^2/a^2 + (1 + 2at/a^2n_0)^2]^{-1}.$$

QUANTUM SIZE-EFFECT SEMIMETAL-SEMICONDUCTOR TRANSITION IN ULTRATHIN BISMUTH FILMS

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A semimetal-semiconductor transition in films with decreasing thickness was theoretically predicted in [1, 2]. If the film potential is approximated by a square well, then this transition in bismuth films should occur at thicknesses $L_t \sim 300$ Å for textured samples [3] and $L_t \sim 200$ Å for non-textured samples [4].

Textured Bi films were investigated down to a thickness $L \sim 170$ Å [5, 6], but no semimetal-semiconductor transition was observed. The shift of the red absorption edge in Bi films [7] is no evidence of a transition, owing to the large temperature smearing ($T = 300$°K). The indicated existence of a transition in cleaved $Bi_8Te_7S_5$ [8] cannot be regarded as convincing, since the carrier concentration was not determined in the cited paper, and the resistance does not increase as $T \to 0$.

The absence of a transition down to a thickness 170 Å is apparently connected with the inaccuracy of the film-potential model. Allowance for the electron interaction should lead to a lowering of the film levels, i.e., to a decrease of the expected L_t [9].

We have investigated the thickness dependences of the conductivity σ, of the Hall coefficient R, and of the magnetoresistance $\Delta\rho/\rho_0$ in ultrathin Bi films at $T = 4.2$°K, for the purpose of observing the semimetal-semiconductor transition. We used for the measurements non-textured polycrystalline films with thicknesses from 60 to 400 Å, obtained by electric explosion on glass substrates, using a previously described procedure [4]. The critical film thickness was decreased by using extremely high condensation rates (up to 10^3 μ/sec) [10]. The solidity of the films was determined by electron microscopy, and also by the absence of a sharp growth in the resistivity down to $L \sim 50$ Å. The film thickness was determined photometrically by optical absorption, with absolute standardization by the interferometer method of bands of equal chromatic order [11], with accuracy ±5 Å. Measurements of σ, R, and $\Delta\rho/\rho_0$ were made by a null method, the sample was placed directly in the liquid helium, and the magnetic field intensity was 5000 Oe.

A decrease of the gap with decreasing L was not observed earlier [4], apparently because of the temperature smearing, which at temperatures 78 - 300°K is of the order of the band overlap in Bi, $\Delta = 4.3 \times 10^{-14}$ erg. At $T = 4.2$°K the temperature smearing is negligible.