Estimates made with the aid of the formula for the absorption coefficient of infrared laser radiation show that the plasma temperature is approximately 14,000°K (the temperature will be lower in gases having an ionization potential larger than that of xenon).

The described experiment is of fundamental significance in that the question of producing an analogous stable spatially-localized plasma in free air, as well as the question of increasing the plasma dimensions, now reduces essentially only to the question of increasing the power of the supply laser (in our experiment the power was quite modest).

It is important that once the discharge is ignited, it can be moved continuously in space at a sufficiently slow motion of the plasma-feeding beam. The rate of this motion need be only lower than a certain limit dictated by the existence of a "normal discharge propagation velocity," analogous to the flame velocity in ordinary combustion [6].

The results of the measurements and of the theoretical calculations of the phenomenon will be presented in later papers.

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ION ENERGY BALANCE IN THE PLASMA OF A TOKAMAK MACHINE

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It was shown in [1, 2] that when the ratio of the external magnetic field intensity H_z to the intensity of the field H_ϕ produced by the current flowing in the plasma of a closed Tokamak magnetic trap is large enough, it is possible to produce a macroscopically stable plasma loop that retains well the energy accumulated in it. This has made it possible to heat electrons to a temperature $T_e \sim 1 \times 10^3$ eV and ions to a temperature $T_i \sim 5 \times 10^2$ eV in hydrogen and $T_i \sim 4 \times 10^2$ in deuterium.

The most important research problem performed with the Tokamak is to establish and explain the laws governing the thermal and diffusion processes in the plasma. Let us consider part of this general problem, namely the energy balance of the ionic component. Measurements of the neon temperature by analysis of the energy spectrum of the charge-exchange atoms show that, other conditions being equal, T_i increases with increasing plasma concentration and decreases with increasing ion mass (when the hydrogen is replaced with deuterium). These facts favor the assumption that the ions are heated principally as a result of heat exchange with the electrons in Coulomb collisions. We take this assumption as our working hypothesis and neglect the other possible sources of heating of the ion component. The energy q transferred from the electrons to the ions per second and per cm^3 is determined by the well-known expression

$$q = 1{,}1 \cdot 10^{-19} n^2 f(T_e/T_i) \frac{1}{A} T_i^{-1/2},$$

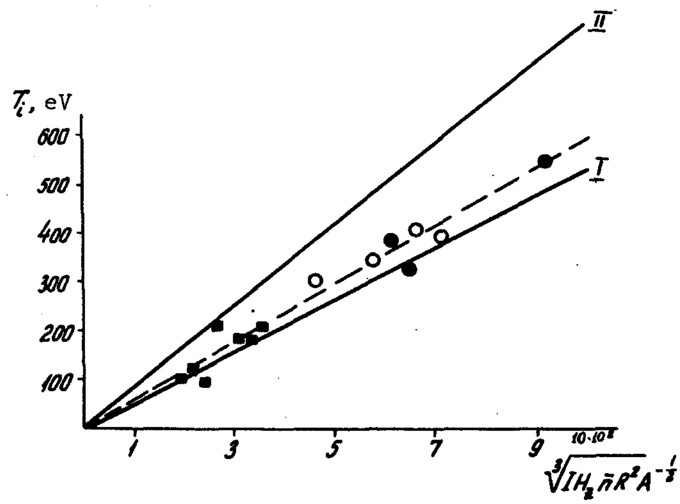
where A is the atomic weight of the medium and n is the electron concentration, and

$$f(T_e/T_i) = \left(\frac{T_e}{T_i} - 1\right)\left(\frac{T_e}{T_i}\right)^{-3/2}.$$

When T_e/T_i changes from 1.6 to 10, the change of $f(T_e/T_i)$ does not exceed 15% of its mean value 0.33. Under the experimental conditions, the ratio T_e/T_i lies practically al-ays within the indicated limits. We can therefore put as an approximate estimate $q = 3.7 \times 10^{-20} n^2/AT_i^{1/2}$. This expression does not contain T_e. Therefore, under ordinary conditions in the Tokamak apparatus, the ion energy balance can be analyzed independently of the electron energy balance.

The ion thermal losses can be caused by three different phenomena: heat conduction, diffusion, and charge exchange. An analysis of the experimental data shows that the diffusion and charge exchange together account for not more than 20% of the total heat loss. We can therefore assume in first approximation that the ions lose energy through heat conduction. The existing theories propose two main mechanisms for ion heat conduction: 1) classical heat conduction by the trapped particles [3], and 2) the energy loss due to development of temperature-drift instability [4]. The theory of heat conduction by trapped particles yields the necessary formulas for the heat-conduction coefficient, as applied to different experimental condutions. By using these formulas and the expression for q, we can show by dimensional analysis that in the Tokomak machines the ion temperature of the plasma loop in the stationary state (i.e., when equilibrium is established between the heat influx and the heat loss) should be proportional to $(IH_zR^2\bar{n})^{1/3}A^{-1/2}$, where I is the current, R the radius of the toroidal system, and $\bar{n}$ the average concentration. The proportionality coefficient can be determined by solving the heat-conduction equation at a given current and concentration over the cross section of the loop.

The figure shows the results of the measured maximum ion temperature in the Tokamak machines T-3 and TM-3. In these machines, R = 100 and 40 cm, respectively, and a (the radius of the plasma loop cross section) equals 15 and 8 cm, respectively. The ordinates represent the ion temperatures T_i on the axial line of the plasma turn in the state of thermal equilibrium (i.e., at the instant when it reaches the maximum). The abscissas represent the quantities $(IH_zR^2\bar{n})^{1/3}A^{-1/2}$, where $\bar{n}$ is the average electron density as determined from radio-interferometer data. (In the case when n has a parabolic distribution over the cross section, $\bar{n}$ is equal to 2/3 of the concentration on the axial line). The measured values of T_i were obtained at values of $\bar{n}$ from 1.5×10^{13} to 3.8×10^{13} cm^{-3}, of I from 60 to 110 kA, of H_z from 25 to 38 kOe, for the T-3 apparatus and of $\bar{n}$ from 1×10^{13} to 3×10^{13} cm^{-3}, I from 19 to 37 kA, and H_z = 27 kOe for the TM-3 apparatus. In the indicated density ranges, it can be assumed that the Coulomb heating predominates in both T-3 and TM-3. The black circles represent the experimental data for hydrogen in the T-3 apparatus, the light circles are for deuterium in T-3, and the squares are for TM-3



(hydrogen). We see that the measurement results are in good agreement fith the $(IH_z R^2 \bar{n})^{1/3}$ dependence. The theoretical dependence of T_i on the ion mass is also well satisfied. The lines I and II in the figure represent the variation of T_i calculated on the basis of the classical theory under two different assumptions concerning the distribution of the current density and the concentration in the plasma. Line I corresponds to the assumption that the current density j(r) and the concentration n(r) are constant over the cross section, n being assumed equal to the value $\bar{n}$ measured by radio-interferometry. Line II was calculated for the case when j and n vary parabolically, i.e., $j = j_0(1 - r^2/a^2)$ and $n = n_0(1 - r^2/a^2)$. The line approximating the experimental plot of T_i (dashed) lies in the interval between I and II. It follows from the figure that when $(IH_z R^2 \bar{n})^{1/3} A^{-1/2}$ varies in the range from 1.9×10^8 to 9.2×10^8 (I is in amperes, H_z in Oersteds, R in centimeters, and $\bar{n}$ in $cm^{-1/2}$), the following relation holds true:

$$T_i = (5{,}9 \pm 0{,}5) \cdot 10^{-7} \sqrt[3]{IH_z R^2 \bar{n}}\, A^{-1/2}. \qquad (1)$$

This result favors the assumption that the processes of heat transfer in the plasma loop, in the range of variation of the physical parameters considered here, are due mainly to the classical mechanism.

We note that the interpretation of the presented data is not completely unambiguous, since we arrive at the relation $T_i \sim (IH_z a^2 \bar{n}^{1/3} A^{-1/2}$ by using the theory of temperature-drift instability and assuming that all the heat is carried away as a result of the "anomalous" heat conduction. It is difficult to distinguish between this relation and the relation $T_i \sim (IH_z R^2 \bar{n})^{1/3} A^{-1/2}$, since the ratios a/R are practically the same in the T-3 and TM-3 machines. However, the indicated theory does not make it possible to estimate the absolute value of the thermal conductivity. In addition, it must be borne in mind that the "anomalous" thermal losses can play a major role only in the external layers of the plasma loop, where there is a sufficiently large temperature gradient.

Everything mentioned above pertained to the ion temperature at the phase when this temperature reaches a maximum. It is also possible to analyze the energy balance of the ions over the extent of the discharge pulse. Such an analysis shows that the time variation of T_i can also be readily explained within the framework of the theory of heat conduction by the trapped particles.

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CONCERNING ONE POSSIBILITY OF MEASURING THE REGENERATION PHASE

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In connection with the new experiments performed with the accelerator of the High-energy Physics Institute [1] and the possible violation of the Pomeranchuk theorem, measurement of the phase of regeneration of K^0 mesons at high energies [2] has become very important. This quantity plays an important role also in the measurement of the parameters that characterize violation of CP-invariance.

We propose to use, for a direct observation of the regeneration phase, the interference between beams of long-lived neutral K mesons, one attenuated and the other coherently regenerated from K_1^0.

Proceding in the standard manner (cf., e.g., [3]), we can write down the wave function of the K^0 meson in the following manner:

$$|K^0> \sim e^{-iM_1 t}\left\{e^{-i(M_1 t_1 + M_1'\tau)} + \rho e^{-i(M_2 t_1 + M_2'\tau)}\right\}|K_1^0> +$$
$$+ e^{-iM_2 t}\left\{e^{-i(M_2 t_1 + M_2'\tau)} + \rho e^{-i(M_1 t_1 + M_2'\tau)}\right\}|K_2^0> ,$$

where t_1, τ, and t are the times of flight of the particle from the source to the front edge of the regenerator, inside the regenerator, and from the rear edge of the regenerator to the decay point, respectively,

$$\rho = \frac{\pi N}{m}\frac{f - \bar{f}}{M_2 - M_1}\left(1 - e^{i(M_2 - M_1)\tau}\right).$$

N is the number of nuclei per cm^3 of the regenerator, $M_{2,1} = m_{2,1} - i\Gamma_{2,1}/2$, $m_{2,1}$ and $\Gamma_{2,1}$ are the masses and widths of the K_2^0 and K_1^0 mesons, and f and $\bar{f}$ are the forward elastic scattering amplitudes of the K^0 and $\bar{K}^0$ mesons in the substance. The difference $f - \bar{f}$ is the regeneration amplitude,

$$M'_{2,1} = M_{2,1} - \frac{\pi N}{m}(f + \bar{f}), \text{ a } m = \frac{m_1 + m_2}{2} .$$

Far behind the regenerator, the intensity of the $K_2^0 \to F$ decay (where F is an arbitrary channel) is given by

$$I(K_2^0) \sim \Gamma_2(F)\, e^{-\Gamma_2(t+\tau)}\left\{e^{-\Gamma_2 t_1} + |\rho|^2 e^{-\Gamma_1 t_1} + 2|\rho|\, e^{-\Gamma_1 \frac{t_1}{2}}\cos(\phi_\rho + \Delta m t_1)\right\}$$

$\Delta m = m_2 - m_1$, and $\phi_\rho \equiv \arg \rho$.