ibid. <u>14</u>, 979 (1965).

ELECTRON HEATING IN THE TN-1 INSTALLATION

P. I. Blinov, B. I. Gavrilov, L. P. Zakatov, and P. A. Cheremnykh

Submitted 7 September 1965

Turbulent heating of a plasma by means of a high-frequency shock circuit has been the subject of many papers [1-5]. It is shown in them that when certain conditions are satisfied (in particular, $a = u_a/4\nu$ and $\tilde{H} = H_0$) it is possible to heat a plasma to temperatures $(T_e + T_i) = \xi\tilde{H}^2/8\pi nK$, where ξ reaches a value 0.3. Here a is the radius of the plasma column, u_a the Alfven velocity, ν the frequency of the circuit, and $\tilde{H}$ the amplitude of the alternating magnetic field. The TN-1 installation, a diagram of which is shown in Fig. 1, was constructed to heat the electronic component of a plasma by this method. The quasistatic field H_0 reached a maximum within 5 μsec, after which it decreased with a 20 msec time constant. The mirror ratio was 2, the maximum value of the field H_0 in the center of the trap was 8 kOe. The plasma was injected in the trap by a coaxial injector with electrodes made of deuterium-impregnated titanium. By varying the injector voltage it was possible to vary the plasma density from $n_e > 2 \times 10^{13}$ cm^{-3} to $n_e < 10^{11}$ cm^{-3}. A single-turn loop with frequency $\nu = 3.5$ Mc at a voltage $u_c = 120$ kV on a capacitor $C_c = 3 \times 10^{-8}$ F produced a field of H = 900 Oe. By varying the time interval between the operation of the high-frequency loop and the application of the magnetic field, it was possible to study the heating of the electrons at different $\tilde{H}/H_0$. It was expected that the electrons with $n_e = 2 \times 10^{12}$ cm^{-3} would be heated to $T_e = 3$ keV, and that further adiabatic compression would raise the temperature to ~30 keV.

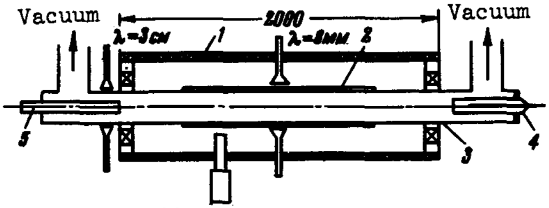

Fig. 1. Diagram of TN-1 installation. 1 - Solenoid, 2 - high-frequency shock circuit, 3 - vacuum glass chamber, 4 - plasma injector, 5 - grid probe or x-ray detector.

The experiment has shown that the cold plasma filling the trap chamber decayed as a result of recombination with a time constant $\tau_c = 300$ μsec. When the circuit was closed, a radial magnetohydrodynamic wave propagated in the plasma. From the readings of a magnetic probe mounted on the chamber axis, it is seen (Fig. 2) that for a compression wave (i.e., when the variable magnetic field is added to the quasistatic field), the wave front increases by 2 - 4 times steeper than the wave in vacuum. (The increase in slope of the combined wave was first observed in [6].) After the termination of the discharge in the circuit, the electron density increased by several time, and then decreased with a time constant $\tau_e = (0.25 - 0.5)\tau_c$. The average electron energy, determined from grid-probe data [7], is ~200 eV at $\tilde{H} = H_0$, corresponding to $nT \leq 10^{15}$ eV/cm^3. Consequently, not more than 10% of the high-frequency field energy goes into plasma heating, i.e., $\xi \leq 0.1$. Measurements of the logarithmic damping decrement have shown that in the presence of the plasma the additional energy loss in the circuit does not exceed 10%. Thus, our data have so far not confirmed the conclusion that turbulent heating of a plasma by means of a shock circuit is highly effective. The discrepancy may possibly be due either to the choice of circuit frequency, which in our case is 2.5 times smaller than in [1-5], or to other factors which have not yet been made clear.

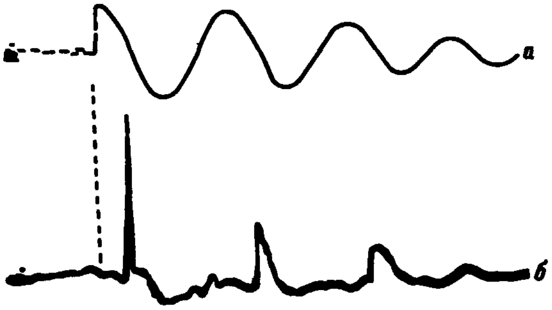

Fig. 2. Oscillograms of the magnetic probe signal. a - Without plasma, b - with plasma. $\tilde{H}$ = 800 Oe, $n_e = 10^{13}$ cm^{-3}, H_0 = 500 Oe. Sweep duration 1 μsec.

When the trap was filled with the aid of an injector of the button type, used in [3-5], it was possible to deduce from the readings of the microwave interferometer that the trap is filled with plasma in a highly uneven fashion. In this case, x-rays of energy ~20 keV were emitted from the chamber after the closing of the circuit. The duration of the x-radiation reached 25 msec, but the electron density decreased in this case from $n_e = (2 - 5) \times 10^{12}$ cm^{-3} to a level below 10^{11} cm^{-3} within not more than 20 μsec. When a coaxial injector was used, prolonged x-radiation was observed only upon injection of a non-uniform plasma jet (for which purpose an asymmetrical discharge was produced in the injector), or else when the density was close to 10^{11} cm^{-3}. For this purpose, however, it was necessary that the amplitude of the second half-wave of the alternating magnetic field be larger than the field H_0. Estimates show that when the magnetic field passes through zero and during the subsequent rapid magnetic compression, the electrons can acquire as a result of the betatron acceleration mechanism an energy of several times 10 keV, producing the bremsstrahlung registered by a lateral pickup. Figure 3 shows the dependence of the lateral x-radiation on the ratio $\tilde{H}/H_0$ (curve a). We see that the x-radiation is observed in the region where $\tilde{H}/H_0$ exceeds unity. When $\tilde{H}/H_0 > 1.7$, the escape of plasma through the ends of the installation increases, as is evidenced by curve b, which shows the outgoing electron flux through the mirrors, and the lateral x-radiation decreases sharply. Thus, the x-radiation is due to the presence of an accelerating mechanism and does not prove the existence of high electron temperatures.

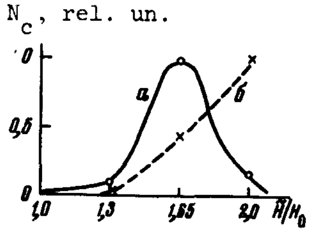

Fig. 3. Intensity of lateral x-radiation (curve a) and electron flux through the mirror (curve b) vs. $\tilde{H}/H_0$. $n_e = 10^{11}$ cm^{-3}, H_0 = 450 Oe, $H_{0\ max}$ = 8 kOe.

The authors thank E. K. Zavoiskii for suggesting the topic and interest in the work, and L. I. Rudakov, G. V. Sholin, A. V. Gordeev, and L. V. Korablev for useful discussions.

[1] M. V. Babykin et al., JETP 43, 411 (1962), Soviet Phys. JETP 16, 295 (1963).
[2] M. V. Babykin et al., JETP 43, 1547 (1962), Soviet Phys. JETP 16, 1092 (1963).

[3] M. V. Babykin et al., JETP 43, 1976 (1962), Soviet Phys. JETP 16, 1391 (1963).
[4] M. V. Babykin et al., JETP 46, 511 (1964), Soviet Phys. JETP 19, 349 (1964).
[5] E. K. Zavoiskii, Atomnaya energiya 14, 57 (1963).
[6] S. P. Zagorodnikov et al., JETP 47, 1717 (1964), Soviet Phys. JETP 20, 1154 (1965).
[7] D. G. Bulyginskii et al., JETP 44, 183 (1963). [sic!]

EXCITATION FUNCTION OF THE REACTION $S^{36}(p\gamma)Cl^{37}$ IN THE INTERVAL E_p = 1.4 - 2.1 MeV

A. A. Koval', E. G. Kopanets, Yu. S. Korda, L. N. Sukhotin 1), and S. P. Tsytko

Submitted 7 September 1965

The Cl^{37} nucleus has 20 neutrons and 17 protons and belongs to the group of nuclei with shell 1d2S. The spin and parity $3/2^+$ of the ground state of this nucleus follow from the predictions of the shell model and of the Nilsson scheme, according to which they are determined by the last odd proton on the $1d_{3/2}$ orbit [1]. These predictions of the models do not contradict any experimental facts, but the spin and parity of the ground state of Cl^{37} has not yet been directly determined in an experiment.

Experimental data on the excited levels of Cl^{37} are very scanty. They were obtained in a study of β decay of S^{37} in [2], the results of which were confirmed in [3], after which Stribel [4] determined more accurately the energy of the γ rays accompanying the β decay.

The most accurate and reliable observations of the excited states were made in [5], in a study of the reactions $Cl^{37}(p, p'\gamma)Cl^{37}$. The authors of that paper used protons accelerated to 7 MeV and analyzed the inelastically scattered protons with a magnetic spectrometer. The observed groups of inelastically scattered protons pointed to the existence in Cl^{37} of levels with excitation energies 0.838, 1728, 3.087, and 3.105 MeV. All the energies were determined accurate to ±0.005 MeV.

The same nuclear reaction, but with a target enriched with Cl^{37}, was investigated in [6] in a proton energy interval 4.6 - 5.6 MeV. However, only one Cl^{37} level was observed, with excitation energy 1.73 ± 0.010 MeV.

To obtain new experimental data on the excited states of Cl^{37}, it would be very attractive to use the hitherto unobserved radiative proton capture reaction $S^{36}(p\gamma)Cl^{37}$. The energy released in this reaction is $Q_m = 8.401 \pm 0.009$ MeV. Thus, one could hope to obtain more knowledge with the aid of this reaction on the excited states of Cl^{37}, up to 12 MeV, using protons accelerated to 3.5 MeV.

The present work is an attempt to investigate the $S^{36}(p\gamma)Cl^{37}$ reaction.

Natural sulfur contains only 0.014% S^{36}. Therefore one of the first important methodological problems to be solved was to prepare a thin isotopic S^{36} target sufficiently enriched to make radiative capture of a proton by S^{36} observable. The target was prepared in an electromagnetic separator by knocking S^{36} ions into a tantalum base. The method of preparation of such targets is described in [7]. The target used in our experiments was approximately 3 keV