Tech. Phys. 14, 1 (1969)]; N. E. Andreev, Zh. Tekh. Fiz. 39, 1560 (1969) [Sov. Phys.-Tech. Phys. 14, 1171 (1970)]; Yu. M. Aliev and D. Zyunder, Zh. Eksp. Teor. Fiz. 57, 1324 (1969) [Sov. Phys.-JETP 30, 718 (1970)]; N. E. Andreev and A. Yu. Kiriĭ, Kratkie soobshcheniya po fizike (Brief Communications on Physics), No. 1 (1970).

[9]R. R. Ramazashvili, Zh. Eksp. Teor. Fiz. 53, 2168 (1970) [Sov. Phys.-JETP 26, 1225 (1968)]; Yu. M. Aliev and E. Ferlingi, Zh. Eksp. Teor. Fiz. 57, 1623 (1969) [Sov. Phys.-JETP 30, 877 (1970)]; V. I. Domrin and R. R. Ramazashvili, Kratkie soobshcheniya po fizike (Brief Communications on Physics), No. 7, 62 (1970).

[10]K. F. Sergeĭchev and I. R. Gekker, Transactions of the 8th International Conference on Phenomena in Ionized Gases, Vienna, 1967, p. 394; K. F. Sergeĭchev, Zh. Eksp. Teor. Fiz. 52, 575 (1967) [Sov. Phys.-JETP 25, 377 (1967)]; K. F. Sergeĭchev, Transactions of the 9th International Conference on Phenomena in Ionized Gases, Bucharest, 1969, p. 540; K. F. Sergeĭchev, Zh. Eksp. Teor. Fiz. 58, 1157 (1970) [Sov. Phys.-JETP 31, 620 (1970)].

[11]I. R. Gekker and O. V. Sizukhin, ZhETF Pis. Red. 9, 408 (1969) [JETP Lett. 9, 243 (1969)]; I. R. Gekker and O. V. Sizukhin, Transactions of the 9th International Conference on Phenomena in Ionized Gases, Bucharest, 1969, p. 542; I. R. Gekker, Physik und Technik des Plasmas, Physikalishe Gesellschaft der DDR, 1970, p. 56; K. F. Sergeĭchev and V. E. Trofimov, ZhETF Pis. Red., (1971) (in press); H. Dreicer, J. C. Ingraham and D. Henderson, Bull. Am. Phys. Soc., Ser. 11, 15, No. 11, 1427 (1970).

[12]G. M. Batanov, K. A. Sarksyan and V. A. Silin, Transactions of the 9th International Conference on Phenomena in Ionized Gases, Bucharest, 1969, p. 541; V. I. Barinov, I. R. Gekker, O. V. Sizukhin, and É. G. Khachaturyan, Kratkie soobshcheniya po fizike (Brief Communications on Physics), 1971 (in press); R. A. Demirkhanov, G. L. Kharasanov, and I. K. Sidorova, Zh. Eksp. Teor. Fiz. 59, 1874 (1970) [Sov. Phys.-JETP 32, 1013 (1971)].

V. E. Golant. Ultrahigh-frequency Methods of Plasma Heating

As is well known, one of the main problems of controlled thermonuclear fusion is the heating of a plasma to "thermonuclear" temperatures. Interest in the search for suitable methods of heating has particularly deepened in connection with the advances made in the confinement of plasma for prolonged periods in quasi-stationary toroidal magnetic traps. We discuss in this report the possibility of the application in such systems of high-frequency methods of heating. In order to reduce the influence of these methods on the confinement of the plasma to a minimum, it is desirable to accomplish them at the smallest possible values of the power fed into the plasma, and to employ linear absorption mechanisms.

As is shown by analysis (see[1,2]), the most effective conditions for linear absorption of high-frequency waves can be realized if we excite in the plasma longitudinal waves with a large refractive index (the so-called plasma waves). A direct excitation of longitudinal waves is difficult to accomplish. However, an effective mechanism exists in a nonuniform plasma for the conversion of externally introduced transverse waves into longitudinal plasma waves. Such a conversion in a plasma, confined by a magnetic field can occur in the regions of the upper hybrid frequencies $\omega = \sqrt{\omega_p^2 + \omega_{He}^2}$ and lower hybrid frequencies

$$\omega = \left[\omega_{He}\omega_{Hi}\,\frac{\omega_p^2+\omega_{He}\omega_{Hi}}{\omega_p^2+\omega_{He}^2}\right]^{1/2}$$

(ω_{He} and ω_{Hi} are the electron and ion cyclotron frequencies, and ω_p is the plasma frequency)*. A theoretical analysis shows that the efficiency of the linear conversion can, under suitable conditions, be fairly high[1-3]. It is important that the efficiency then turns out to be practically independent, under a wide range of conditions, of the plasma temperature and the collision frequency of the charged particles[4]. Thus, the conversion of transverse waves into plasma waves may result in their efficient absorption.

Wide-ranging experimental investigations of the absorption of high-frequency waves, directed towards the establishment of the absorption mechanism, have been carried out at the A. F. Ioffe Physico-technical Institute of the USSR Academy of Sciences (a review of the principal experiments on the absorption is given in[2]). These investigations were carried out in the frequency range 9—10 GHz, 3—4 GHz, and 100—200 MHz at powers of from 1 mW to 20 kW for a wide range of plasma parameters (plasma in H_2, He, and Ar at pressures of 10^{-5}—10^{-1} mm Hg, charged-particle concentrations of 10^{10}—10^{13} cm^{-3}, electron temperatures of 3—10 eV, in specific experiments up to 1000 eV, and magnetic fields of up to 5 kOe; the radius of the plasma was 1—5 cm).

The experiments showed, first and foremost, that effective absorption can be observed within the limits of sharply bounded frequency bands[5-8]. The boundaries of these bands practically coincide with the theoretical boundaries of the frequency regions in which wave conversion is possible.

Further, measurements were made of the high-frequency field distribution (with the aid of probes and from the Stark broadening of the spectral lines), and the localization of the absorption region (with the aid of electrostatic probes)[9,10]. The data obtained as a result of these measurements, are in good agreement with the proposition that the absorption is connected with the conversion of the waves fed into the plasma into slow, strongly-damped plasma waves. In particular, the measurements of the amplitudes of the high-frequency field intensity in the conversion region and the measurements of the attenuation distance of the plasma waves are in agreement with theory.

Finally, we must mention the measurements of the efficiency of absorption of UHF waves and of plasma heating within the limits of the conversion regions[5-8]. In conformity with theoretical predictions, the efficiency of absorption turned out to be weakly dependent on the collision frequency and the energy of the charged particles when these quantities were varied by several orders of magnitude. It also changed little when the

*For the parameters of quasi-stationary thermonuclear installations, both of these regions fall in the ultrahigh-frequency region.

intensity of the high-frequency field was varied within considerable ranges. The maximum values of the absorption efficiency in the region of the upper hybrid frequencies reached 50—90%; the corresponding electron heating was recorded in this frequency range. The absorption efficiency in the lower hybrid frequency band was 20%. Approximately the same heating of the electron and ion components of the plasma was observed in this region. Thus, the experiments confirm the existence of an effective mechanism of absorption by a plasma of high-frequency waves, connected with the linear conversion of the waves, and the possibility of utilization of this mechanism for plasma heating.

Up till now, the experiments on UHF-wave absorption by a plasma and on plasma heating have been carried out on small experimental facilities. On going over to UHF plasma heating in large systems with prolonged plasma confinement, a number of new problems arises[11]. First of all, it is necessary to ensure the elimination or the limitation of the opacity region which impedes the penetration of the wave into the conversion region. Analysis and experiments show that this can be achieved in the region of the upper hybrid frequencies (using a non-uniform magnetic field), as well as in the region of the lower hybrid frequencies (using a longitudinal moderation of the waves fed into the plasma). The question further arises as to the most effective mechanism of absorption of plasma waves. The determination of this mechanism significantly depends on the actual distribution of the magnetic field and the concentration of the charged particles over the volume of the plasma. The most complicated problems to analyze are the problems of the influence of nonlinear effects on UHF heating and of the influence of heating on the confinement of the plasma. The answer to these questions can be given only as a result of experiments. Experiments on UHF plasma heating in toroidal installations of relatively large dimensions are now in progress at the A. F. Ioffe Physico-technical Institute of the USSR Academy of Sciences. It is expected that the results of these experiments will allow us to determine the prospects of the application of UHF heating in quasi-stationary toroidal magnetic traps.

[1] V. L. Ginzburg, Rasprostranenie elektromagnitnykh voln v plazme (The Propagation of Electromagnetic Waves in Plasmas), M., Nauka, 1967 (Eng. Transl., Pergamon Press, New York, 1970).

[2] V. E. Golant and A. D. Piliya, Usp. Fiz. Nauk 104, 413 (1971) this issue, p. 413.

[3] S. S. Moiseev, Proceedings of the Seventh International Conference on Phenomena in Ionized Gases, Vol. II, Beograd, 1966, p. 645.

[4] A. D. Piliya and V. I. Fedorov, Zh. Eksp. Teor. Fiz. 57, 1198 (1969) [Sov. Phys.-JETP 30, 653 (1970)].

[5] A. I. Anisimov, N. I. Vinogradov, V. E. Golant, and L. P. Pakhomov, Zh. Tekh. Fiz. 37, 680 (1967) [Sov. Phys.-Tech. Phys. 12, 486 (1967)].

[6] V. N. Budnikov, V. E. Golant, and A. A. Obukhov, Zh. Tekh. Fiz. 38, 576 (1968); 40, 138 (1970) [Sov. Phys.-JETP 13, 427 (1968); 15, 97 (1970)].

[7] M. V. Krivosheev, Zh. Tekh. Fiz. 39, 816 (1969) [Sov. Phys.-Tech. Phys. 14, 613 (1969)]; V. E. Golant, M. V. Krivosheev, and V. I. Fedorov, Zh. Tekh. Fiz. 40, 382 (1970) [Sov. Phys.-Tech. Phys. 15, 282 (1970)].

[8] B. V. Galaktionov, V. V. D'yachenko, and O. N. Shcherbinin, Zh. Tekh. Fiz. 40, 2317 (1970) [Sov. Phys.-Tech. Phys. 15, 1809 (1971)].

[9] A. N. Anisimov, N. I. Vinogradov, V. E. Golant, and L. P. Pakhomov, Zh. Tekh. Fiz. 41, 696 (1971) [Sov. Phys.-Tech. Phys. 16, 546 (1971)].

[10] V. I. Arkhipenko, A. P. Berezin, V. N. Burnikov, V. E. Golant, K. M. Novik, A. A. Obukhov, A. D. Piliya, V. I. Fedorov, and K. G. Shakhovets, Paper Presented at the 4th International Conference on Plasma Physics and Controlled Thermonuclear Fusion, USA, 1971.

[11] V. E. Golant and A. D. Piliya, Paper at the International Conference on Closed Systems, Dubna, 1969.

D. S. Chernavskiĭ. Elastic and Inelastic Interactions of High-energy Hadrons.

The current state of the physics of strong interactions is characterized by the following. The elastic scattering of hadrons at energies $E_{lab} \lesssim 70$ GeV has been well studied, from the experimental as well as theoretical point of view. The theoretical basis here is the method of complex orbital momenta (the Regge method) (for details, see[1]).

The situation is different with processes of extreme inelasticity; the experimental data on these processes were largely obtained in cosmic rays and are of qualitative nature. On the other hand, owing to the advances made in the construction of accelerators, accurate quantitative data for energies $E_{lab} \approx 50-500$ GeV are expected to be available in the very near future. Several theoretical schemes and models exist which claim to describe inelastic interactions.

Until recently, little attention was paid to the connection between the schemes of the inelastic processes and the properties of the elastic scattering amplitude. Meanwhile, having the scheme of an inelastic process, we practically have the picture of the elastic process, in the same way as knowing the characteristics of an absorbing body, we know the pattern of diffraction scattering. Thus, the theory of inelastic processes should at the same time correctly describe elastic scattering.

A similar program of unified description is being pursued in the theory of peripheral interactions based on the Bethe-Salpeter equation (for details, see[2]). Although the above-mentioned requirement does not make the theory of peripheral interactions closed and unique, it severly limits the arbitrariness and leads to some objective (not depending on the arbitrariness) results. The following is the principal one: from the condition of constancy of the total cross section at high energies arises in the theory a new parameter having the dimensions of mass and equal, in order of magnitude, to $\mathfrak{M} \approx 2-3$ GeV.

This parameter appears in inelastic interactions in the following fashion: the distribution over the invariant masses of the irreducible blocks of the multiperipheral scheme turns out to be fairly broad. The mean value of the mass of a pion cluster turns out to be large—of the order of 2 GeV. On the disintegration of