feature of pulsed saturation at the line center is the vanishing of the phonon avalanche as can be clearly seen in Fig. 2.

An avalanche-like growth of the number of phonons was observed for the first time (by another method) in inversion of the populations of the Zeeman levels of the Fe^{2+} ion in a MgO crystal by adiabatic fast passage [5]. It may seem strange at first glance that the occurrence of a phonon avalanche was observed by us in simple saturation. On the other hand, it was shown theoretically and experimentally [6, 7] that in the case of saturation on the wing of a homogeneously broadened line there arises a region of stimulated emission, the maximum of which lies beyond the saturation point, this being due to the appreciable difference between the temperatures of the dipole-dipole reservoir and the Zeeman system [8]. The presence of such a region of stimulated emission leads apparently to the appearance of the phonon avalanche observed by us. This is confirmed also by the fact that there is no phonon avalanche in the case of saturation of the line center, when the dipole-dipole reservoir is disconnected from the Zeeman system.

A more detailed exposition of the experimental results and of their theoretical analysis will be published elsewhere.

In conclusion, the authors are sincerely grateful to I.L. Fabelinskii and A.S. Borovik-Romanov for a discussion of the results.

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RESONANCES OF ANOMALOUS MICROWAVE HEATING OF ELECTRONS IN A MAGNETIZED PLASMA

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Submitted 1 April 1971
ZhETF Pis. Red. 13, No. 10, 539 - 543 (20 May 1971)

So far, no one has succeeded in relating the mechanism of anomalous heating of electrons in a magnetized plasma with some plasma instability in a microwave field [1]. To ascertain the nature of this phenomenon, we have studied the dependence of the effectiveness of the heating on the value of the magnetic field and the concentration of charged particles.

The experimental setup was similar to that used [1], but the round waveguide was replaced by a rectangular one. Plasma with $T_e = 6$ eV was generated by a spark gun and moved along a homogeneous magnetic field, flowing in and out through the narrow walls of the waveguide. A TE_{10} wave was excited in the waveguide, with the electric-field vector perpendicular to the constant magnetic field. The plasma density, the fast-electron current, and their radial

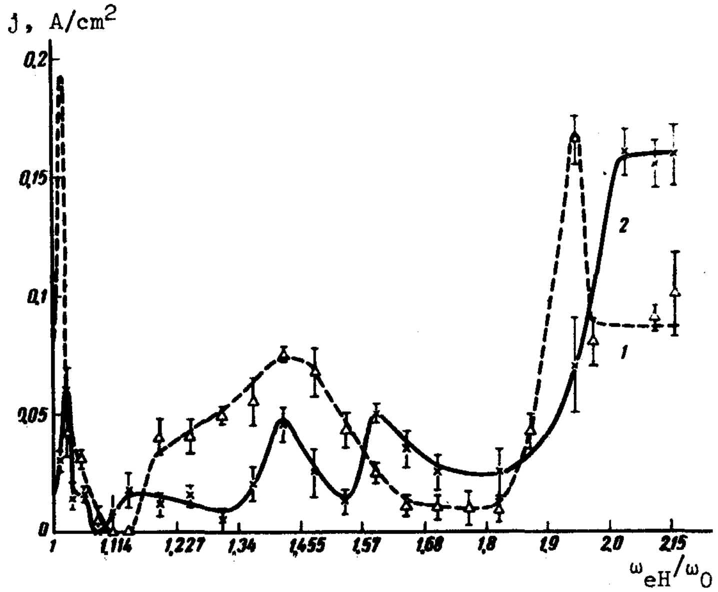

Fig. 1. Fast-electron current vs. the magnetic field: 1 - $n_i/n_{cr} = 0.3$, E = 3 kV/cm, T_e = 70 eV; 2 - $n_i/n_{cr} = 0.1$, E = 4.8 kV/cm, T_e = 50 eV. n_i - ion density, n_{cr} - critical density of ions, E - intensity of microwave field in waveguide, T_e - electron energy.

distributions in the plasma column were measured with a multigrid probe having an input diaphragm of 2 mm diameter.

The measurements have shown that the dependence of the fast-electron current on the magnetic field is not monotonic if only sufficiently fast electrons are registered, i.e., in the case when a sufficiently large negative potential is applied to the probe (Fig. 1). The intensity of the current of electrons of energy T_e = 70 eV at $n_i/n_{cr} = 0.3$ has three maxima, at $\omega_{eH}/\omega_0 = 1$, 1.4 - 1.5, and 1.9 - 2. A decrease of the plasma density leads, as seen from a comparison of curves 1 and 2, to a shift of the peaks towards stronger magnetic fields. At $\omega_{eH}/\omega_0 = 2$, the magnitude of this shift corresponds to the condition $(2\omega_0)^2 = \omega_{eH}^2 + \omega_{Le}^2$, i.e., to equality of the upper hybrid frequency to the second harmonic of the external frequency. It is also seen from the behavior of the curves that the peaks at $\omega_{eH}/\omega_0 = 1$ and 1.5 also shift towards larger magnetic fields with decreasing density.

Such a resonant dependence of the fast-electron current on the magnetic field is connected with the change of their spectrum when the magnetic field is changed. From the delay curves shown in Fig. 2 we see that a detuning of only 10% from resonance $(2\omega_0)^2 = \omega_{eH}^2 + \omega_{Le}^2$ with the magnetic field decreases the maximum particle energy by a factor of 2. Thus, the generation of electrons with highest energy occurs in a rather narrow interval of the magnetic field values.

The dependence of the fast-electron current on the plasma density also has a resonant character. This dependence can be clearly seen in the distribution, shown in Fig. 3, of the electron current over the cross section of the plasma jet. The current distribution turns out to be axially symmetrical. The maximum value of the current, as seen from Fig. 3, occurs at a density close to critical. This occurs both at resonant magnetic fields ($\omega_{eH}/\omega_0 = 2$) and far from resonance ($\omega_{eH}/\omega_0 = 2.5$), i.e., the value of the plasma density corresponding to the maximum of the current is practically independent of the value of the magnetic field.

The observed nonmonotonic dependence of the fast-electron current on the magnetic field and on the plasma density makes it possible to connect the

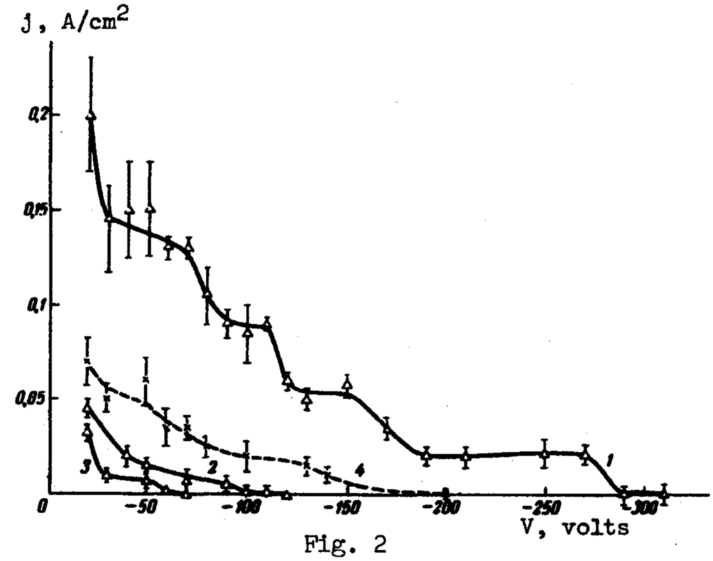

Fig. 2

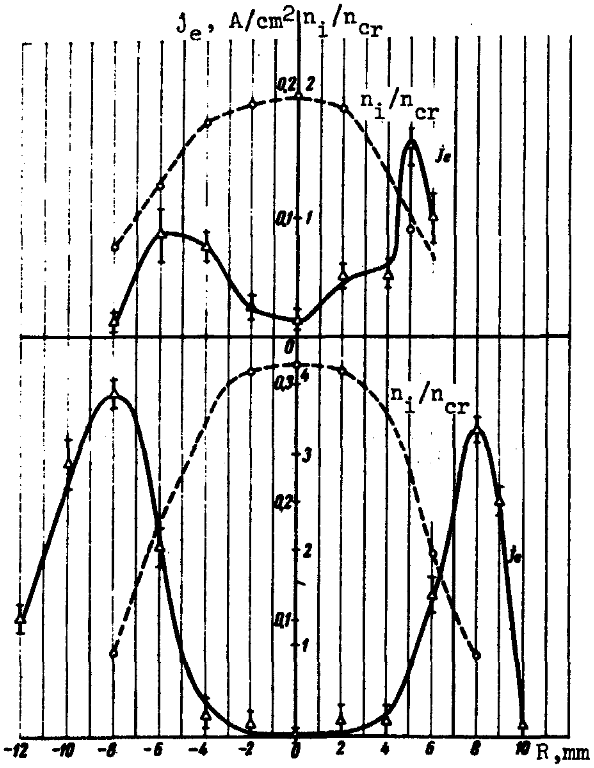

Fig. 3

Fig. 2. Dependence of electron current on the retarding potential of the probe: 1 - $\omega_{eH}/\omega_0 = 2$, E = 3 kV/cm; 2 - $\omega_{eH}/\omega_0 = 2$, E = 1.5 kV/cm; 3 - $\omega_{eH}/\omega_0 = 2$, E = 0.8 kV/cm; 4 - $\omega_{eH}/\omega_0 < 2$ by 10%, E = 3 kV/cm; ω_{eH} - electron cyclotron frequency, ω_0 - frequency of external field.
Fig. 3. Distribution of fast-electron current over cross section of the plasma column: a - $n_i/n_{cr} = 2$, $\omega_{eH}/\omega_0 = 2.5$, T_e = 110 eV, E = 4.8 kV/cm; b - $n_i/n_{cr} = 4$, $\omega_{eH}/\omega_0 = 2$, T_e = 100 eV, E = 4.2 kV/cm.

generation of the fast electrons in anomalous heating with parametric excitation of potential waves in the plasma [2]. As is well known, such an instability arises if the harmonic of the frequency of the external field is equal to the frequency of the longitudinal high-frequency waves in the plasma. For the second harmonic, such a resonance is possible in an interval $[4 - (\omega_{Le}^2/\omega_0^2)]^{1/2} \le \omega_{eH}/\omega_0 \le 2$. It is precisely in this region that the resonant increase of the fast-electron current is observed. The maximum value of the current is observed at resonance of the second harmonic with the upper hybrid frequency, as is confirmed by the shift of the resonance towards stronger magnetic fields with decreasing density. The electronic peak near $\omega_{eH}/\omega_0 = 1.5$ may be connected with the resonance on the third harmonic of the external frequency with the second harmonic of the Bernstein mode [3], i.e., $3\omega_0 = 2\omega_{eH} + \omega_{ri}$ (ω_{ri} is the lower hybrid frequency). We note that in this region it is possible to excite the upper and lower hybrid resonances at the second harmonic of the external field [4], when $2\omega_0 = \omega_{Le} + \omega_{eH}$. With decreasing plasma density, the Bernstein-oscillation frequency at $3\omega_0 = 2\omega_{eH}$ remains essentially unchanged, whereas the resonance for the simultaneous excitation of the upper and lower hybrid frequencies should shift towards larger ω_{eH}/ω_0. It is possible that this leads to the splitting of one resonance current into two.

In the region $\omega_{eH}/\omega_0 \simeq 1$ we also encounter generation of electrons, owing to nonlinear effects, since the broadining of the region of the generation of the electrons to $\omega_{eH}/\omega_0 = 1.1$ cannot be attributed to broadening due to Coulomb collisions, the Doppler effect, or linear transformation of the waves in the inhomogeneous plasma. This is confirmed also by the dependence of the electron current on the power of the incident wave, namely, when the power is decreased by two orders of magnitude the heating of the electrons in the region $\omega_{eH}/\omega_0 \simeq 1$ ceases, but the heating is clearly seen in the region of the upper hybrid frequency $\omega_{eH}^2 = \omega_0^2 - \omega_{Le}^2$, when the effect of heating due to linear wave transformation is possible.

If the density exceeds the critical $n_{max} > n_{cr}$, then parametric resonance is possible at the lower branch of the longitudinal electron waves. With increasing density, for the aperiodic instability, the threshold field decreases, and the growth increment of the oscillations increases [5]. One could therefore expect a continuous increase of the current and of the electron energy with increasing density. Actually, however, a maximum occurs near $\omega_0 \simeq \omega_{Le}$. This is apparently connected with the fact that the largest acceleration of the electrons gives rise to waves that propagate along the magnetic field, and this occurs exactly at $\omega_0 \simeq \omega_{Le}$.

Thus, the observed resonant peaks of generation of fast electrons lie near the resonances of the parametric excitation of the longitudinal electron waves in the plasma. Apparently, this agreement is not accidental, and is a reflection of the nature of the phenomenon, since a computer experiment [6] reveals a group of fast electrons accelerated by the field of the Langmuir waves. Therefore the results obtained above make it possible to point out the frequencies at which nonlinear excitation of plasma oscillations should be sought.

The authors are deeply grateful to V.A. Silin for help with the work, and to Yu.M. Aliev, N.E. Andreev, L.M. Gorbunov, and A.Yu. Kirii for a fruitful discussion.

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