where f_c is the threshold value of the amplitude of the external signal. When $f/f_c \gtrsim 1$, the amplitude b increases linearly with f. It is seen from Fig. 2 that these conclusions are in good agreement with experiment.

The expressions for the amplitudes of the Langmuir oscillations near threshold can be represented in the form of an expansion in powers of the amplitude b. Accurate to quadratic terms, we have

$$a_0 \sim 1 - c_0 b^2, \quad a_{\pm} \sim c_{\pm 1} b, \quad a_{\pm 2} \sim c_{\pm 2} b^2,$$

where c_0, $c_{\pm 1}$, and $c_{\pm 2}$ are certain constants that depend on the dynamic parameters, viz., the interaction coefficients, the wave damping, and the detuning. These relations between the amplitudes have been observed experimentally (Fig. 3).

The increase of the external-signal amplitude f beyond threshold leads to excitation of "relaxation" oscillations similar to those described in [6]. These oscillations are characterized by intense diffusion of the plasma to the walls of the tube and by appreciable oscillations of the plasma density and temperature.

Our investigations show that ion-acoustic oscillations are excited in a beam-plasma system starting with a certain threshold value of the Langmuir-oscillation amplitude.

The power of the ion-acoustic oscillations beyond threshold is proportional to the power P of the external high-frequency signal.

The power of the Langmuir oscillations beyond threshold increases like $\sqrt{P}$.

The growth of the ion-acoustic or Langmuir oscillation amplitudes is limited by the excitation of relaxation oscillations.

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EXPERIMENTAL INVESTIGATION OF INDUCED SCATTERING OF PLASMA OSCILLATIONS IN A STRONG MAGNETIC FIELD

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It is known that induced scattering leads to instability of a monochromatic wave of frequency ω_{k_0} and wave vector $\vec{k}_0$ against excitation of long-wave oscillations $(\omega_k, \vec{k}, k < k_0)$ [1]. The purpose of the present study was to investigate experimentally this instability in a plasma placed in a strong magnetic field. The experiments were performed with a one-sided Q-machine placed in a homogeneous magnetic field of intensity $H = 2\times 10^3$ Oe. The system was evacuated to a pressure $(0.5 - 1)\times 10^{-6}$ Torr and filled with a helium plasma of density $(1 - 2)\times 10^9$ cm^{-3}. The plasma-to-cyclotron frequency ratio under the conditions of the experiment, ω_p/ω_H, was equal to 1/10 - 1/15. The electron thermal velocities ranged from 3×10^7 to 4×10^7 cm/sec.

The plasma oscillations were excited with the aid of a system of coaxial probes, and a movable coaxial probe was used to extract the oscillations. A study of the dispersion law of these oscillations has shown that the first radial harmonic of the Langmuir oscillations of the magnetized plasma is excited in the system:

$$\omega = \omega_p \frac{k_z}{\sqrt{k_z^2 + k_\perp^2}} \quad \text{,i.e., } v_{ph} = \frac{\omega}{k_z} = \frac{1}{k_\perp}\sqrt{\omega_p^2 - \omega^2}.$$

Here $k_\perp = \lambda/a$, where a = 1 cm is the plasma radius and $\lambda = 2.4$.

The change of the oscillation amplitude along the system was investigated with the aid of a moving receiving probe, the signal from which was fed to the input of a tuned measuring receiver of the P5-G type, connected to an automatic EPP-09-GM plotter. To investigate the induced scattering, a pump wave (ω_{k_0}, k_{0z}) was excited in the system in addition to the sounding wave (ω_k, k_z). In the absence of the pump wave (the main wave), the absorption of the sounding wave is well described by the formula for the linear Landau damping. The absorption increases when the wave frequency approaches the plasma frequency and the phase velocity of the wave becomes equal to the thermal velocity of the particles. In the study of the induced scattering, the phase velocities of the main and sounding waves were chosen in the interval $(1 - 3)\times 10^8$ cm/sec, for which $v_{ph} \ll v_{ph}^{max} = \omega_p/k_\perp$. In this interval, the linear damping is small enough, but on the other hand the phase velocity of the beats produced as a result of the nonlinear interaction of the main and sounding waves

$$v_{ph}^{\delta} = \frac{\omega_k - \omega_{k_0}}{k_z - k_{0z}} \tag{2}$$

turns out to be of the order of the thermal velocity. The beat frequency is much lower than the plasma frequency, and thus the beats do not belong to the spectrum of the natural plasma oscillations.

Under these conditions the main nonlinear mechanism leading to t-e transfer of energy from the main wave to the sounding wave is the induced scattering due to the resonant interaction of the beats of the difference frequency and the thermal electrons of the plasma. The induced scattering was investigated earlier in detail only for broad wave packets [2, 3], but such a scattering takes place also for monochromatic waves. In the case of a monochromatic wave the scattering causes the wave to be unstable against excitation of sounding waves in the long-wave part of the spectrum. When induced scattering is taken into account, the change of the electric field in the sounding wave along the system is determined from the equation

$$\begin{aligned} \frac{dE_k}{dz} = &-\sqrt{\frac{\pi}{8}}\, \frac{\omega_k \omega_0^2}{k_\perp^2 v_{Te}^3} \exp\left(-\frac{m v_{ph}^2}{2T}\right) E_k - \\ &- \frac{9}{8}\sqrt{\frac{\pi}{2}} \left(\frac{e\phi_0}{m v_{ph}^{0\,2}}\right)^2 \operatorname{sgn}(\omega_k - \omega_{k_0}) \frac{\omega_k \omega_{k_0}^2}{k_\perp^2 v_{ph}^5} v_{ph}^{\delta} v_{Te}\, \alpha\left(\frac{v_{ph}^{\delta}}{v_{Te}}\right) E_k . \end{aligned} \tag{3}$$

In this formula ω_k and v_{ph} are the frequency and phase velocity of the sounding wave, ω_{k_0}, v_{ph}^0, and ϕ_0 are the frequency, phase velocity, and amplitude of the potential in the main wave, $v_{Te} = \sqrt{T/m}$ is the thermal velocity of the plasma electrons, and the coefficient $\alpha(v_{ph}^{\delta}/v_{Te})$ is given by

$$\alpha(v_{ph}^{\delta}/v_{Te}) = \begin{cases} 1 & \text{for } v_{ph}^{\delta} \ll v_{Te} \\ 4(v_{ph}^{\delta}/v_{Te})^4 e^{-\frac{v_{ph}^{\delta\,2}}{2 v_{Te}^2}} & \text{for } v_{ph}^{\delta} \gg v_{Te} . \end{cases}$$

In the derivation of (3), the plasma-particle velocity distribution function was assumed to be Maxwellian.

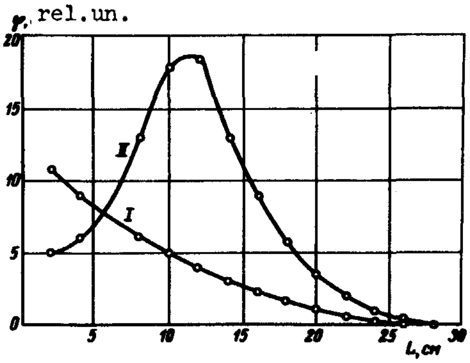

Fig. 1

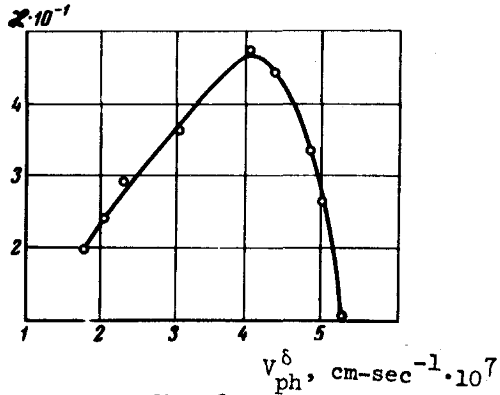

Fig. 2

Fig. 1. Distribution of the amplitude of the sounding wave along the system. I - in the absence of the main wave, II - in the presence of the main wave, whose frequency is higher than that of the sounding wave. The decrease of the amplitude at large z is connected in this case with the attenuation of ϕ_0 to values at which the increment of the induced scattering becomes smaller than the linear decrement of the Landau damping.

Fig. 2. Amplification coefficient of sounding wave vs. the phase velocity of the beats.

The first term in the right side of (3) corresponds to linear Landau damping, and the second to the change of the sounding wave as a result of the induced scattering. The scattering is from the electrons, inasmuch as $v^{\delta}_{ph} >> v_{ti}$, and the contribution of the ions to the polarizability at the difference frequency is small because $|\omega_k - \omega_{k_0}| >> \omega_{0i}$. It follows from the equation that induced scattering can lead to a growth of the amplitude of the sounding wave when $\omega_k < \omega_{k_0}$.

It was observed in the experiments that the sounding wave becomes amplified along the system in those case when the pump frequency excited in the plasma has a higher frequency than the sounding wave (see Fig. 1). On the other hand, if the pump frequency is lower, than the presence of the pump wave in the plasma leads only to an enhancement of the damping of the sounding wave.

The amplification coefficient κ of the wave was determined with the aid of the spatial distribution of the sounding wave shown in Fig. 1. The experiments were performed at main-wave potential amplitudes $\phi_0 = (1 - 3)$b.[1] The dependence of the amplification coefficient on ϕ_0 was quadratic in this case. At large amplitudes, the main wave turns out to be unstable against excitation of low-frequency ionic oscillations. The amplitude of the sounding wave was appreciably lower than $\phi_0 \leq 0.1$b.

The dependence of the gain on the phase velocity v^{δ}_{ph} of the beats (Fig. 2) was obtained by varying the frequency of the main wave at a fixed frequency of the sounding wave. The plot shown in Fig. 3 was obtained at $\omega_p = 2\times10^9$ sec^{-1}, $\phi_0 = 1$b, $v_{ph} = 1.5\times10^8$ cm/sec. The maximum of the amplification coefficient is reached at $v^{\delta}_{ph} = (1 - 1.5)v_{Te}$. The dependence of κ on v^{δ}_{ph} at $v^{\delta}_{ph} < v_{Te}$ and $v^{\delta}_{ph} > v_{Te}$ agrees qualitatively with the theoretical dependence in (3).

The experimental value of the maximum gain, $\kappa^{exp}_{max} = 0.5$ cm^{-1}, is sufficiently close to the theoretical $\kappa^{theor}_{max} = 0.66$ cm^{-1} obtained from (3) at $\alpha = 1$ and $v^{\delta}_{ph} = v_{Te}$.

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TEMPERATURE DEPENDENCE OF THE POSITION AND LINE WIDTH OF CYCLOTRON RESONANCE IN LEAD

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Electron-phonon interaction in metals leads to an increase of the effective mass m^* of the conduction electrons on the Fermi surface [1]:

$$m^* = m_b(1 + \lambda),$$

where m_b is the effective mass due to the band structure, and λ is a coefficient characterizing the electron-phonon interaction. The function $\lambda(T)$ was calculated in [2] for Pb and Hg.

According to this calculation, a change of λ should lead to an increase of m^* by several per cent when the temperature is increased from 0 to about 4°K.

We have used cyclotron resonance (CR) to investigate experimentally the temperature dependence of the effective mass of lead, a metal with a strong electron-phonon interaction [1, 2].

The sample was single-crystal Pb in the form of a disc with the normal oriented along [011], grown by R. T. Mina from the melt in a dismountable crucible mold [3]. The sample, freely lying on a quartz substrate, was placed in a strip resonator tuned to a frequency ~19.2 GHz, connected in the feedback loop of a self-oscillator using a traveling wave tube [4]. We measured either the low-frequency component (at a magnetic-field modulation frequency 12 Hz) of the generation amplitude near threshold, or the frequency deviation of the oscillator [4].

The resonator and sample were placed in a cryostat cooled with liquid He^3. The sample temperature changed less than 0.1°K during the time necessary to record each spectrum. The magnetic field H produced by the electromagnet was applied along the $[0\bar{1}1]$ axis. The field was set parallel to the sample surface with accuracy ~5' as determined by the maximum of the CR amplitude ψ_2 (the notation is the same as in [6, 7]). The magnetic field intensity was measured with a Hall pickup, and the calibration was with a nuclear magnetometer with running water [5] during each measurement of the investigated section of the CR spectrum. The magnetic field measurement accuracy was limited by its modulation and amounted to ~0.1%.

Figure 1 shows CR spectra obtained by the frequency-modulation method [4]. The figure shows three strong resonances: third-order resonances of ψ_2 on a noncentral hole orbit and of χ on a non-lanar orbit passing over the tubes in the third zone, and a first-order resonance of ζ_1 on the central section of the tube. With increasing temperature, the CR lines broaden as a result of the decrease of the relaxation time and shift to the stronger-field region, corresponding to an increase of the effective mass.

The results were reduced for the most intense ζ_1 resonance, since the ψ_2 and χ resonance lines overlap when $T \gtrsim 2$°K, owing to the decrease of the relaxation time τ. The resonant value of the field H_1 and the value of $\omega\tau$ were determined by comparing the experimental line shape with that calculated in accord with [8] for the case corresponding to the minimum effective mass. Since the Q of the strip resonator is not high ($\sim 10^3$), it is impossible to register in the experiments either $\partial X/\partial H$ or $\partial R/\partial H$ alone [9], and we chose in the reduction the combination $\partial X/\partial H + \beta\partial R/\partial H$ or $\partial R/\partial H + \beta\partial X/\partial H$, which describes the experimentally observed line. The parameter β was chosen once for the measurement run, if the tuning of the circuit did not change during the course of the measurements. The values $\beta \approx 0.2 - 0.3$ indicate that the admixture of the other component was not large.