EXCITATION OF SOLITARY WAVES IN A BEAM-PLASMA SYSTEM

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Solitary space-charge waves are produced in a plasma-beam system by modulating the beam and by amplifying and transforming the initial spectrum.

As shown in [1, 2], solitary space-charge waves can exist in a bounded plasma. The excitation of such waves by applying a step potential pulse to a grid placed in the plasma was investigated in [2, 3]. In the present paper we investigate the possibility of generating solitons in a beam-plasma system by periodic initial perturbations that are intensified by the beam and are then transformed into a sequence of potential pulses as a result of nonlinear wave interactions. If the distance between them exceeds appreciably the width of the pulse, they constitute in essence a train of solitons.

The spectrum of a periodic train consists of discrete lines of comparable intensity, filling the frequency interval from $\omega_0 \simeq 2\pi v/L$ to $\omega_N \simeq (L/\Delta)\omega_0$, where L and Δ are the distance between the pulses and the pulse width, and v is the propagation velocity. In order to make this spectrum closer in form to the spectrum of the soliton train $a_n^{(s)} = a^{(s)}(\omega_n)$ during the initial stage, when the principal role is played by enhancement of the initial perturbation by the beam, it is necessary that the spectrum of the initial perturbation contain a discrete set of harmonics with amplitudes given approximately by the relation $a_n^{(0)} \simeq a_n^{(s)}\exp(-\gamma\tau_b)$, where γ_n is the growth rate of the n-th harmonic and τ_b is the characteristic time of development of the two-stream instability. Since $\gamma_n = \gamma(\omega_n)$ increases as ω_n approaches the Langmuir frequency ω_p, and then drops off abruptly to zero, the initial amplitudes should decrease with increasing n. The wave interaction becomes appreciable at large amplitudes, since the characteristic interaction time is inversely proportional to the energy of the excited waves. This process is described by the Korteweg - de Vries (KdV) equation [2], for which the initial condition is the result of the two-stream instability. In accordance with KdV, a large class of initial conditions leads to the formation of trains of solitons and oscillation tails [4].

The experiments were performed with an electron beam of annular cross section, injected into a plasma cylinder bounded by metal walls. The average beam energy was 200 eV, the current 3 mA, the magnetic field 400 Oe, the beam diameter 0.5 cm, and the electron-layer thickness 0.05 cm. The beam was velocity-modulated to produce a periodic initial perturbation rich in harmonics. The accelerating-potential modulation frequency was 10 MHz at an amplitude 100 V. The first 50 cm of the electron path was in high vacuum. The electrons were bunched in this section and a sawtooth wave profile was formed. They then entered a chamber in which the pressure was increased to 2×10^{-4} cm [sic!]. There they moved in a plasma produced by them; the plasma density greatly exceeded the beam density. Two-stream instability with the monoenergetic beam was observed at frequencies $\omega < 200$ MHz, and the growth rate had a maximum at 120 MHz. Figure 1 shows the oscillation spectra at a distance 15 cm from the entrance into the chamber, for a beam modulated at various pressures. The thick lines correspond to pressures at which no instability developed, and the thin lines to the amplification regime. In the former case the spectrum corresponds to a sawtooth wave profile. In the amplification regime, the spectrum broadens to 200 MHz and a wave packet is formed with an intensity

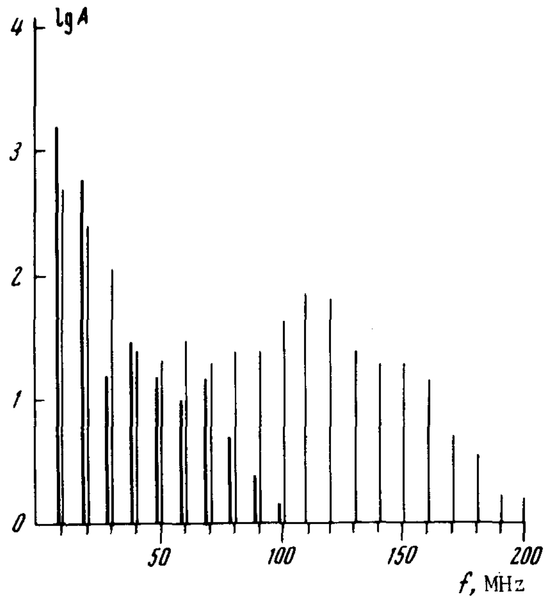
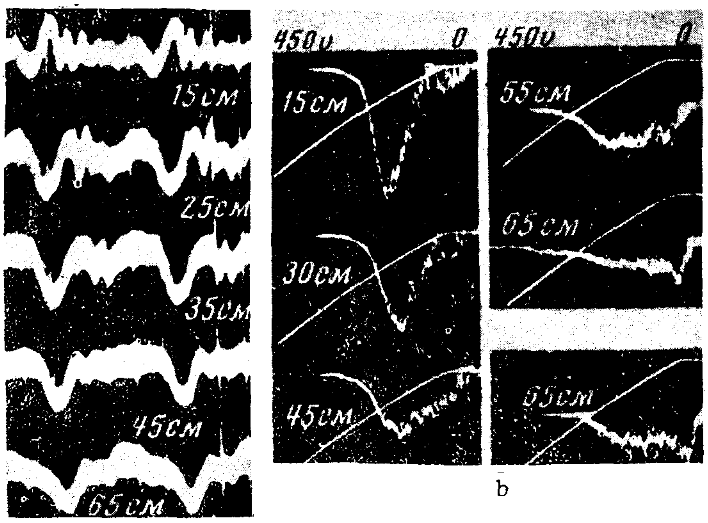


Fig. 1. Oscillation spectra in a plasma-beam system.



a

b

Fig. 2. Evolution of the wave profile (a) and of the energy distribution of electrons (b).

maximum near 120 MHz. The profile of these oscillations is shown in the upper oscillogram (Fig. 2a). During each modulation period (10^{-7} sec), a negative pulse is clearly seen against the background of the oscillations. The oscillations vanish in the course of propagation, and the narrow packet takes the form of a soliton wave. The vanishing of the oscillations is due to the interaction between the harmonics and to a redistribution of the energy over the spectrum, processes that lead to soliton formation. As to the evolution of the energy distribution function f(E), which is shown in Fig. 2, we see that the beam smears out rapidly in the low-energy direction, and a tail of accelerated particles appears in the distribution at the end of the system. For comparison, the last figure shows f(E) obtained when usual two-stream instability develops without beam modulation; in this case there is no high-energy tail.

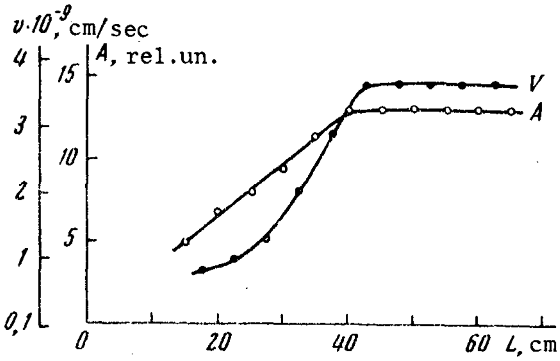


Fig. 3. Amplitude and velocity of solitary wave vs. distance.

As the soliton develops, its amplitude and velocity change (Fig. 3). We see that the velocity increases with increasing amplitude, in agreement with the known solution of the KdV equation. Over a certain length (40 cm) the amplitude and velocity increase, and then remain constant. The maximum velocity of the solitary wave is 4 – 5 times larger than the initial wave velocity.

The results show that a mechanism for the excitation of solitary Langmuir wave exists in a beam-plasma beam. The principal role in this mechanism is played by the beam-plasma instability.

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ELECTRON-ION RECOMBINATION IN AN ELECTRIC FIELD

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The influence of an external electric field on the electron-ion recombination in gases was investigated experimentally. It was observed that the recombination coefficient of electropositive gases (He, N_2) depends on the field intensity.

In the study of phenomena connected with electron-ion recombination in gases it is usually assumed that at fixed values of the temperature and gas pressure the recombination coefficient is constant and does not depend on the external electric field.