Quasi-soliton Langmuir oscillations localized in density "wells" of a magnetized plasma

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Localized formations of the type of a one-dimensional Langmuir soliton, measuring ~25 Debye radii and with a lifetime ~10^4 oscillation periods, were observed in experiments on the buildup of Langmuir oscillations by an external electric field in artifically produced density "wells" of a magnetized collisionless plasma.

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We report here the results of a first stage of experiments aimed at producing a one-dimensional Langmuir soliton[1,2] by an external RF electric field, and of an investigation of its dynamics in a magnetized plasma. Starting from the requirements of weak collision damping of the oscillations and the possibility of observing Langmuir solitons that are immobile or are stopped relative to the plasma, we chose for the experiments the regime of a flowing collisionless plasma. In the experimental setup (Fig. 1a) such a regime was produced by passing a pulsed (~ 20 μsec) electron beam through a discharge chamber filled intermittently with hydrogen. The produced plasma, bypassing the neutral-gas delay line 3,[3] propagated at ion-sound velocity $c_s \approx 2\times 10^6$ cm/sec along a

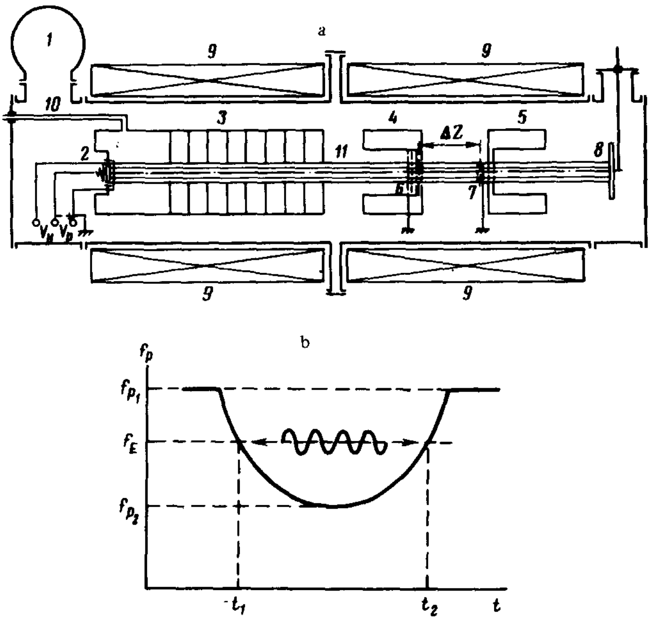

FIG. 1. a) Experimental setup: 1—vacuum pump, 2—electron gun, 3—gas delay line, 4—pump resonator, 5—diagnostic resonator, 6—exciting grids, 7—Langmuir probe, 8—collector, 9—magnetic-field coils, 10—gas supply, 11—plasma pinch. b) Langmuir oscillation trapped in plasma-density well; t_1 and t_2—start of pumping and instant of reflection of waves from the density barrier.

homogeneous magnetic field $H=(1.5-2)\times 10^3$ Oe, passing through the working volume and striking the collector 8.

The working parameters of the hydrogen plasma were the following: electron density $n_e \approx 3\times 10^9$ cm^{-3}, temperature $T_e \approx 10$ eV, plasma-pinch diameter 4 cm, and neutral-gas pressure $p \lesssim 5\times 10^{-6}$ mm Hg. The buildup of the Langmuir oscillations was produced by a longitudinal (relative to H) RF electric field at a frequency $f_E = 495$ MHz, excited in a quarter-wave pump resonator 4 by a generator with pulse duration 1 μsec; the ends of the resonator were covered with grids of 95% transmission each, and the gap between grids was 2 mm. To permit the oscillations of frequency f_E to be trapped in the plasma, the initial density was chosen to satisfy the condition $f_p > f_E$, where $f_p = (n_e e^2/\pi m)^{1/2}$ is the frequency of the electron Langmuir oscillations. To allow the electric field of frequency f_E to penetrate into the plasma in this case, a plasma-density "well" was produced at the instant of the pumping in the gap of the resonator 4 by a voltage pulse (of negative polarity) of 5 μsec duration, applied to a pair of grids 6 located 0.5 cm directly in front of the resonator grids. The leading front of this pulse coincided approximately with the instant when the pump generator was turned on. The pump power in the plasma was several watts. The density "well" propagated along H with a velocity $\sim c_s = 2\times 10^6$ cm/sec. Thus, at the instant of pumping the local (in the resonator gap) Langmuir fre-

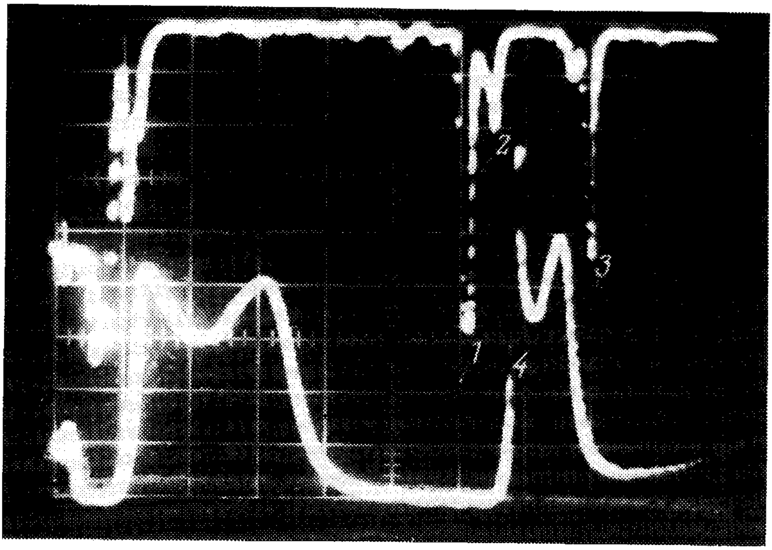

FIG. 2. Oscillograms of packets of Langmuir waves and plasma-density "wells"; sweep 10 μsec/div.

quency was scanned in time from a value $f_{p_1} > f_E$ to a value $f_{p_2} < f_E$; the results (see below) show that the pumping took place at $f_p \approx f_E$ ($n_e \approx 3 \times 10^9$ cm^{-3}), and the Langmuir oscillation excited in the plasma-density "well" turned out to be "trapped" between the leading and trailing edges of the "well"—Fig. 1b. The obtained formation (the density "well" and the packet of Langmuir waves localized in it) traveled next past a Langmuir probe 7 (made from a grid of 2 cm diameter with 90% transparency). This probe was connected to a diagnostic resonator 5 and to a tunable pulsed receiver, the signal envelope of which was fed to an oscilloscope. The diagnostic resonator was analogous in principle to the pump resonator, but operated at a higher frequency; it was fed by a weak cw generator and was tuned in such a way that at the corresponding density and at the instant of the passage of the "well" it produced a (detected) pulse. The Langmuir probe and the diagnostic resonator were mechanically interconnected (the distance between them was 3 cm) and could be moved along the installation during the experiments.

The most general result of the experiments is shown in Fig. 2, where trace 1 shows the pump-resonator pulse at the frequency $f_E = 495$ MHz, 2 and 3 show the pulses (packets) of Langmuir oscillations at 492 MHz, registered at a distance 15 cm from the pumping point, and 4 shows the plasma-density "well." It is seen that packets 2 and 3 are located on the leading and trailing edges of the "well," in qualitative agreement with the character of the spatial distribution of the RF field intensity of the wave trapped in the "potential well"[4] (Fig. 1b). (The difference between the velocities of the leading and trailing edges of the "well" is connected with its forward and backward spreading with a velocity $\sim C_s$.[1]) Particular attention is called to the fact that the packet 3 has a "lifetime" ~ 20 μsec in the plasma, amounting to 10^4 periods of the

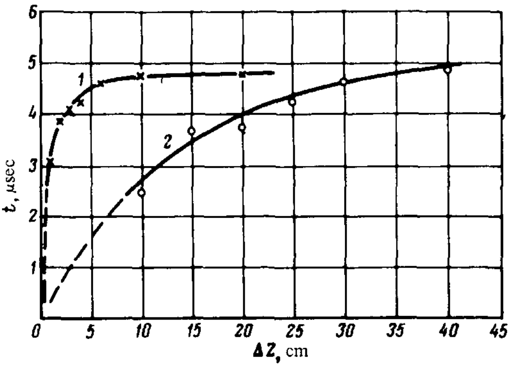

FIG. 3. Delay (relative to the instant of pumping) of the arrival of the wave packet connected with the leading front of the "well" vs the distance between the Langmuir probe and the pump resonator.

plasma oscillations, and spans not more than 0.7 cm, which is at least one-sixth the diameter of the plasma pinch. Packet 2 moves about five times faster than packet 3 and has a width, 3—4 cm, comparable with the plasma-pinch diameter.

The lifetime of the wave packets localized in the plasma is limited only by the condition for their trapping: $f_p > f_E$, where f_p is the Langmuir frequency of the plasma outside the density "well." In our experiments, the density of the plasma, as the latter propagates from the point at which it is produced, decreases (as a result of longitudinal spreading), and the indicated trapping condition ceases to be satisfied. The packets of the Langmuir waves then "jump out" of the "wells" and reach the Langmuir probe practically instantaneously. Depending on the initial margin with which the condition $f_p > f_E$ is satisfied in the region of the pump resonator, the "free path" of the Langmuir packet together with the "well," naturally, turns out to be different. This is shown in Fig. 3, where the initial density in case 2 is larger than in case 1. Accordingly, in case 2 the Langmuir packet traverses, together with the "well" (at the velocity of its leading front $\sim 2c_s$) about 30 cm, and in case 1 only ~ 5 cm.

The most important result, in our opinion, is that even though the external pumping of the oscillations takes place only on the leading edge of the "well," the oscillations are observed predominantly on its trailing edge, where they persist more than 20 μsec after the end of the pump pulse (Fig. 2), when there is no longer a leading density barrier for the oscillations (inasmuch as, according to Fig. 3, this barrier exists for not longer than 6 μsec). This gives grounds for assuming that the indicated oscillations are localized in "their own" density well produced by the pressure of their electric field, i.e., they constitute a formation of the type of a quasi-one-dimensional Langmuir soliton measuring ~ 25 Debye radii and having a lifetime larger than 10^4 oscillation periods. To observe this proper "well," which is self-consistent with the trapped electric field, it is necessary to increase the sensitivity of the diagnostic resonator.

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)The spreading of the "well" is due to the fact that the initial energy density of the Langmuir waves excited in the "well" is insufficient to equalize the difference between the thermal pressures of the plasma outside and inside the "well"; the relative depth $\delta n_e/n_e$ of the density "well" was several per cent.

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