Two types of Langmuir solitons

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We show that at a velocity slower than the thermal ionic there exist two types of solitons which differ from each other by the sign of their potentials.

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Both the standing soliton—the potential hump with velocity $u \ll v_{Ti}$ —and the traveling soliton—the potential well, $u \gg v_{Ti}$ —were already considered in the first study of the Langmuir solitons.[1] In that and subsequent works, the ions were described by the equations of hydrodynamics, and while the velocity region near the thermal ionic region could not be considered, it was implied that the standing and traveling soliton solutions in this region were transitive.

In this work we confirm, on the basis of kinetic studies, that extending the solution for the traveling soliton into the region of small velocities results in its being a potential well for the ions, and the standing soliton identified in Ref. 1 constitutes a separate branch.

The Langmuir waves are conveniently described by the Schroedinger equation,[2] where variations of the plasma density are substituted for the potential

$$\delta n/n = \int f_i(v)\left(v/\sqrt{v^2 - 2e\phi/M} - 1\right) dv \tag{1}$$

and it is assumed that no ions were captured, and the distribution function is represented in a coordinate system that travels together with the soliton. Expanding the above equation in terms of the small parameter $(e\phi/T_i)^{1/2}$, we find

$$\delta n/n = -f_i(0)\,2\sqrt{-2e\phi/M} + \frac{e\phi}{M}\int \frac{1}{v}\frac{\partial f}{\partial v}\,dv, \tag{2}$$

where the integral is considered as the principal value. In the region $u \lesssim v_{Ti}$ we get

$$\frac{e\phi}{M} = -\frac{1}{8}\left(\frac{\delta n}{n}\right)^2 f_i^{-2}(0) \cdot \tag{3}$$

The potential above is small in comparison with the high-frequency pressure acting on the electrons and, therefore, the two types of solitons coincide in every respect except for the interaction with the ions.

In the event of a slow deceleration of a soliton-well (for instance, due to the plasma density gradient)[3] $\delta n/n$ remains practically invariant, $f_i(0)$ increases and, consequently, the well depth decreases. Particles are no longer trapped in the shallowest well and, therefore, Eqs. (2) and (3) hold up to the point at which the soliton stops. As the soliton velocity increases the potential well deepens resulting in ion capture. The number of captured ions differs for a given soliton velocity and, in this sense, the soliton-well has a continuous spectrum. In the case of uniform motion, deceleration due to ions fails to take place even near v_{Ti}, whereas the soliton-hump is strongly retarded when scattered by ions and, in fact, it becomes totally immobile.[4]

The soliton-well of the potential may hopefully be identified in experiments of the type done in Ref. 5 by examining two features: (1) the soliton-well may also move in the case $T_i \gtrsim T_e$ and (2) transition from soliton-well to soliton-hump should occur as a result of turbulent instability during a period of the order of nonlinear frequency shift in the soliton.

In conclusion, we should point out that the foregoing also applies to the electroacoustic solitons.[6]

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