Plasma theory of phonons in a liquid

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Well known, that a sound oscillations are polarized atoms of a liquid. In the case of a system of strongly interacting atoms, like a liquid, electrons of external atomic level (valency) can be considered as Fermi-liquid. But for simplicity, to obtain a characteristic value of velocities, we consider it as degenerated Fermi-gas and in this model all sorts of ions will be considered as ideal gases too. Then we have a plasma model with neutrality $\sum_a eZ_a n_{a0} = 0$ (Z_a is charge). The Maxwell equation for self-consistent longitudinal (potential) electric field is $\partial\mathbf{E}/\partial t = -4\pi \sum_a eZ_a n_a \mathbf{v}_a$. Component velocity $\mathbf{v}_a$ can be expressed through electric field with the help of linearized continuity and Euler equations for every component in adiabatic process. And after Fourier transformations we obtain a dispersion equation $1 = \sum_a \Omega_a^2/\left(\omega^2 - u_a^2 k^2\right)$, where $\Omega_a^2 = 4\pi e^2 Z_a^2 n_{a0}/m_a$ is a square plasma frequency and $u_a^2 = \left(\partial P_a/\partial n_{a0}\right)_s/m_a$, P_a is a component pressure. The dispersion equation gives in general $(a_{max} - 1)$ phonon modes which correspond to every intermediate frequencies $u_a k \ll \omega \ll u_b k$. The largest frequency between electronic and ionic velocities corresponds to acoustic phonon mode and for $kr_{TFe} \ll 1$ ($r_{TFe} = u_e/\Omega_e$ is Thomas-Fermi radius) gives $\omega = ku_e \sum_i \Omega_i/\Omega_e$, like ion sound. Lets suppose, we have two - light (l) and heavy (h) - ion sorts with the same temperature that, from Vlasov kinetic theory is well known, gives dumping of modes with $ku_l \ll \Omega_l$, but if $u_l/\Omega_l \gg 1/k \gg u_h/\Omega_h$ (between Debye radiuses) then we obtain an optic mode $\omega = \Omega_h$. Lets consider extremely low temperatures and bosonic ions (α-particles - helium II, for example). Then for a condensate part (c) of ions $P_c = 0$ and $u_c = 0$. We suppose that $n_c \ll n_{\alpha-c} \sim n_e/2$, then we obtain not only the first sound with $\omega = ku_e\Omega_{\alpha-c}/\Omega_e$ but also the second sound with $\omega = ku_{\alpha-c}\Omega_c/\Omega_{\alpha-c}$ for $kr_{\alpha-c} \ll 1$ ($r_{\alpha-c} = u_{\alpha-c}/\Omega_{\alpha-c}$ is Bose analogy of r_{TF}). And from Vlasov kinetic theory we know, that condensate part of α-particles does not give Cherenkov damping of sound. If we have a small addition of ^3He, it will absorb the second sound when $u_{^3He} \geq u_{\alpha-c}\Omega_c/\Omega_{\alpha-c}$. This condition gives a critical concentration of ^3He in ideal gas approximation.