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Landau Damping and the Onset of Particle Trapping in Quantum Plasmas[1]

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The notion of wave-particle interactions, the couplings between collective and individual particle behaviors, is fundamental to our comprehension of plasma phenomenology. Such is the case when the electrons' thermal energy k_BT is of the order of or smaller than their Fermi energy $E_F=\frac{\hbar^2}{2m}(3\pi^2 n)^{1/3}$ (n and m are the electron density and mass). The physics of quantum plasmas (e.g., of the warm dense matter regime) is a frontier of high-energy density physics with relevance to many laboratory experiments and to astrophysics. The question arises as to how wave-particle interactions are modified when the quantum nature of the electrons can no longer be ignored. Using analytical theory and simulations, we assess the impact of quantum effects on non-linear wave-particle interactions in quantum plasmas. Two regimes are identified depending on the difference between the time scale of oscillation $t_B(k)=\sqrt{m/eEk}$ of a trapped electron and the quantum time scale $t_q(k)=2m/\hbar k^2$ related to recoil effect, where E and k are the wave amplitude and wave vector. In the classical-like regime, $t_B(k)<t_q(k)$, resonant electrons are trapped in the wave troughs and greatly affect the evolution of the system long before the wave has had time to Landau damp by a large amount according to linear theory. In the quantum regime, $t_B(k)>t_q(k)$, particle trapping is hampered by the finite recoil imparted to resonant electrons in their interactions with plasmons.

Reference: J. Daligault, Phys. Plasmas 21, 040701 (2014).

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