Nonlinear Landau damping of electrostatic waves in quantum plasmas

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Landau damping has been a topic of long-standing interest in plasma physics. Waves in plasmas undergo such collisionless damping when they resonantly interact with free and/or trapped particles, i.e., when the particle's velocity approaches the wave phase velocity or group velocity of nonlinear wave envelopes. Such collisionless linear damping was first theoretically predicted by Landau in 1946 [1], and later confirmed experimentally by Malmberg and Wharton in 1964 [2]. In this context, Ott and Sudan [3] theoretically investigated the linear Landau damping of ion-acoustic solitary waves in electron-ion plasmas by means of a Korteweg de-Vries (KdV) equation. The theory was later developed by a number of authors in various plasma environments [4-7].

On the other hand, Ichikawa [8] investigated the effects of nonlinear Landau damping due to resonant particles having the group velocity of electrostatic wave envelopes in electron-ion plasmas. When quantum effects are taken into consideration, there appears new length scale and hence new coupling parameters and new processes that come into the picture. In this scenario, the typical Vlasov-Poisson system is no longer applicable and one has to deal with the Wigner-Poisson equations [9].

In this talk, we review some recent developments of the theory of nonlinear Landau damping of electrostatic wave envelopes in classical [6] and semiclassical [7] plasmas. We also investigate the wave-particle interaction of electrostatic waves in a fully degenerate plasma using the Wigner-Moyal equation coupled to the Poisson equation. In contrast to classical and semiclassical plasmas, the resonant velocity is found to be shifted by the quantity [9] $n\hbar k/2m$, *i.e.*, $v^n_{res}=\omega/k\pm n\hbar k/2m$, where $n=1,2,3,...$; $\hbar$ is the reduced Planck's constant, ω (k) is the wave frequency (number) and m is the particle's mass. It occurs due to the plasmon energy and momentum. We focus on the regimes where the linear Landau damping (one plasmon) is forbidden, however, two- and three-plasmon resonances can be important in the nonlinear wave-particle interactions. The effects of these plasmon and group velocity resonances are also studied on electrostatic wave envelopes in quantum plasmas. Using the multiple scale expansion technique, we show that the evolution of wave envelopes is governed by a nonlinear Schrödinger (NLS) equation with a nonlocal nonlinearity [6,7,9]. In contrast to classical [6] and semiclassical [7] plasmas, such nonlocal term appears due to the three-plasmon and group velocity resonances. Furthermore, the local cubic nonlinear term is also modified by the two-plasmon and three-plasmon resonances. The effects of these multiplasmon and group velocity resonances are examined on the modulation of wave envelopes as well as on the soliton solution of the NLS equation. Finally, applications of our results in laboratory, space and astrophysical environments are discussed.

References

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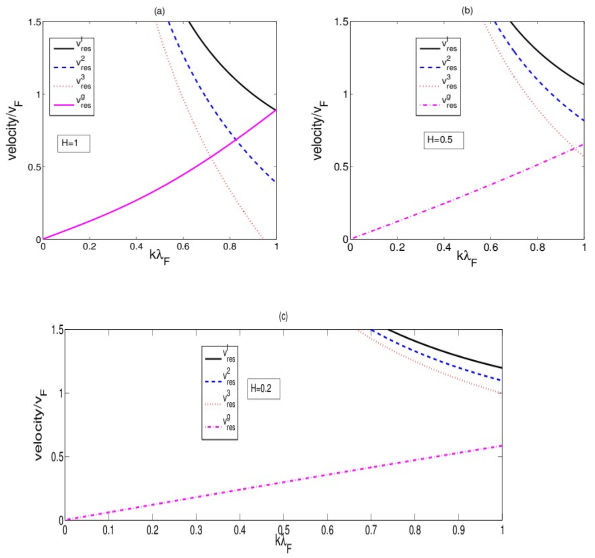

Fig. 1: Two parameter regimes are shown: one where both the multi-plasmon and group velocity resonances are important [subplots (a) and (b)], and other where only the group velocity resonance can be important [subplot (c)].