Fusion Plasma Theory II. 2019

Week 15

24.3 PHYSICAL MEANING OF LANDAU DAMPING

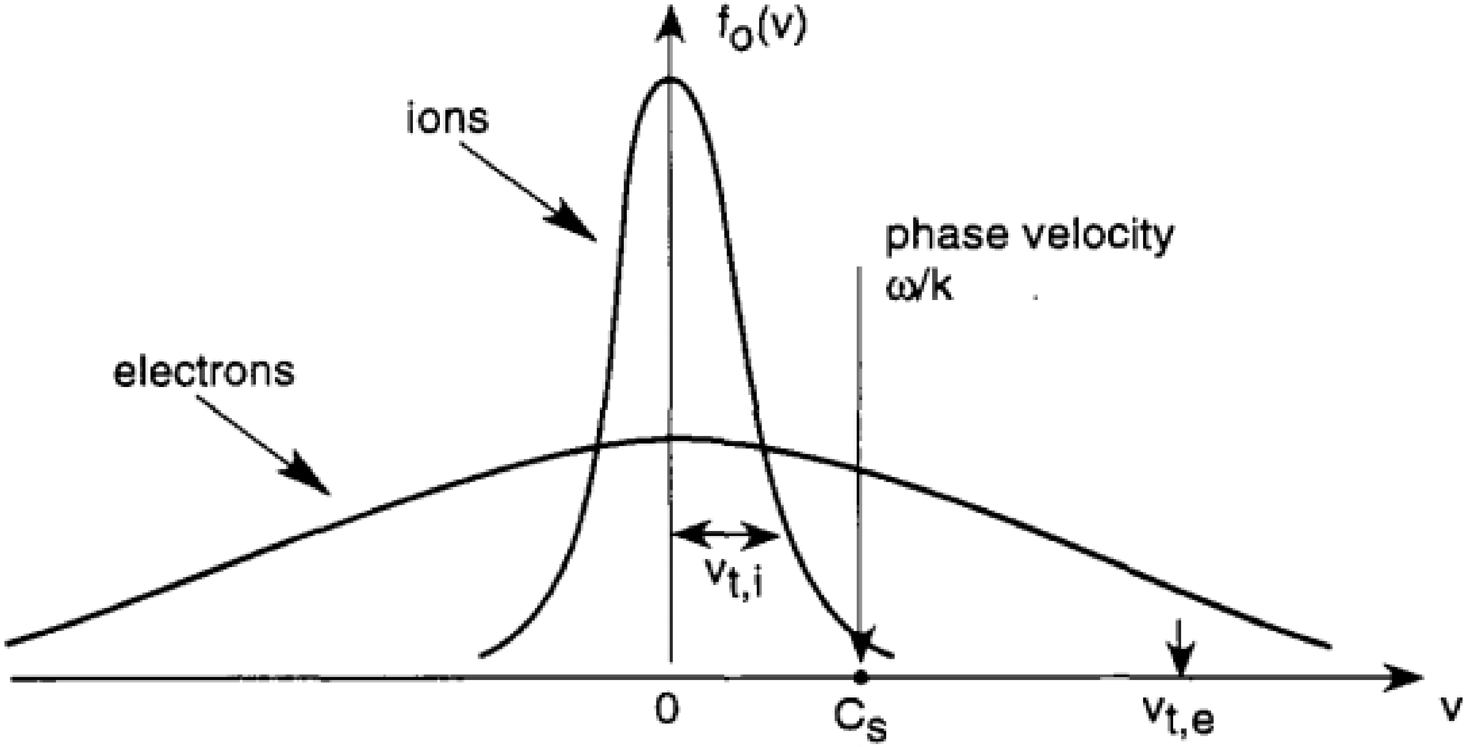
Physically, it is clear that Landau damping is associated with those particles in the distribution that have a velocity nearly equal to the phase velocity of the wave, ω/k, since the contribution to the dispersion function, equation (24.18), that gives rise to Landau damping is the term in $(\partial f_0/\partial v)|_{\omega/k}$. These may be called 'resonant particles'. Resonant particles travel along at almost the same speed as the wave and tend to see a relatively static electric field, rather than a rapidly fluctuating one. They can, therefore, exchange energy very effectively with the wave.

The electrons with $v \approx \omega/k$, which are nearly resonant with the plasma wave in the Landau problem, are analogous to the resonant particles in the mapping problem of Chapter 5. They see an essentially steady electric field, which can be positive or negative depending on their phase relative to the wave. Thus, some nearly resonant particles are accelerated by the wave, while others are decelerated. A resonant individual particle has an equal chance of being accelerated or decelerated, after averaging over all possible phases. Thus the population of particles that was originally moving slightly faster than ω/k is *mixed* with the population that was moving slightly slower.

However, a Maxwellian distribution has *more slower electrons than faster ones*. Consequently, there are more particles being accelerated on average by this mixing process than being decelerated. Since this results in a net transfer of energy from the wave to the particles, the wave is damped.

As particles with velocities near the phase velocity ω/k are speeded-up or slowed down in this way by the wave, the distribution $f(v)$ (averaged over wave phase) tends to be 'flattened' in this region. Effectively, there arises a wave-induced diffusion in velocity space, concentrated in the region around the phase velocity ω/k. The new, modified distribution function contains the same number of particles, but it has gained a little energy at the expense of the wave. Strictly, this flattening of the distribution function is a *nonlinear* effect, because it is quadratic in the amplitude of the perturbation. For infinitesimal perturbations, the flattening would be imperceptible, but it is sufficient to account for the loss of wave energy, which is also quadratic in the perturbation amplitude. For larger wave amplitudes, such as those arising from unstable modes of perturbation, wave-induced velocity diffusion can often be the dominant nonlinear effect, as in the 'quasi-linear theory' discussed in the next Chapter.

23-17.



We saw in Chapter 16 and again in Chapter 23 (see Problem 23.3) that, when finite-T_i corrections are retained in the dispersion function, for $k\lambda_D \ll 1$ the dispersion relation for ion acoustic waves remains $\omega \approx kC_s$, but the sound speed is modified to $C_s = [(T_e + 3T_i)/M]^{1/2}$, although this result was limited still to the case $T_i \ll T_e$ in the kinetic treatment of Chapter 23. If, nonetheless, we use this result to obtain an order-of-magnitude estimate for the ion Landau damping in the case $T_i \approx T_e$, by substituting $\omega/k = C_s \sim 2(T/M)^{1/2}$ into the second term on the right-hand side on the first line of equation (24.33), we obtain $\gamma/\omega \sim 0.2$. Such a large value of the damping decrement, γ, indicates that the ion acoustic wave is essentially non-existent in such a plasma.

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