KINETIC AND FLUID CALCULATIONS OF WAVE PROPERTIES IN A MAGNETO-PLASMA WITH ANISOTROPIC PRESSURE PERTURBATIONS

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Two basic approaches are generally adopted for analysing wave phenomena in plasmas. A kinetic, microscopic analysis, in which the evolution of the velocity distribution function through the Vlasov equation is calculated, yielding complex refractive indices that indicate wave damping or growth. Numerical solutions are complicated and time consuming, and the amount of information generated concerning wave parameters is limited. In the fluid, macroscopic approach a set of balance (evolution) equations is written for successive moments of the distribution function, which is usually truncated by neglecting third order heat flux and higher order tensors. This method, by using velocity averaged quantities, misses the microscopic interactions between waves and particles responsible for Landau damping and cyclotron resonances, but readily yields polarization ratios, energy densities and Poynting fluxes of both electromagnetic and acoustic components. In earlier papers the perturbation pressure tensor was usually assumed to be isotropic, since use of an anisotropic perturbation pressure tensor led to very large matrices, which had to be inverted. Suchy and Altman (1997) have shown that the pressure evolution equation can be simplified if the tensor pressure perturbation is split into its trace and tracefree parts, $\mathbf{p}=p\mathbf{I}+\mathbf{p}^{o}$, which can then be solved explicitly for $\mathbf{p}^{o}$ with the aid of a set of 5 orthogonal 4th order tensor projectors (cf. Suchy, 1997). The background pressure, p_0, is assumed to be isotropic. A dispersion equation, a fifth degree polynomial in the square of the refractive index, n, is obtained, yielding two electromagnetic modes, and for low and medium wave-normal angles a third longitudinally polarized electrostatic Langmuir mode and two acoustic modes with high refractive indices. For perpendicular propagation the third, electrostatic, solution is the low-n Bernstein mode. In the dispersion equation the temperature parameter, $\tau := KT/mc^2$, appears up to third power. If the second and third powers of τ are neglected the dispersion quintic is reduced to a cubic, the two high-n acoustic modes are lost and the third, Langmuir or Bernstein, mode is preserved but slightly modified. The electrostatic mode is characterized by wavefield vectors, $\boldsymbol{E}$ and $\boldsymbol{v}$, essentially parallel to the propagation vector $\boldsymbol{k}$; by vanishingly small magnetic energy densities, $\mu_0 H^2 << \varepsilon_0 E^2$, and the energy flux vector is largely acoustic with the trace, $p\mathbf{I}$, and tracefree part, $\mathbf{p}^{o}$, of the pressure tensor contributing equally: $p^*\boldsymbol{v} \sim \mathbf{p}^{o*}{:}\boldsymbol{v} >> \boldsymbol{E}^*\times\boldsymbol{H}$. As to the high-$n$ acoustic modes, the energy densities and flux vectors are due essentially to the tracefree component of the pressure tensor $\mathbf{p}^{o}$, and these modes are thus missed when this pressure component is ignored.

To test the domain of validity of the generalized fluid approach, we have reprogrammed the dispersion equation using the dielectric tensor for a Maxwellian magnetoplasma (cf. Akhiezer et al., 1975). All five modes predicted in the fluid analysis are found in the kinetic calculations, the Langmuir mode having negligible attenuation, but the first acoustic mode is strongly damped, and the high-n acoustic mode is almost purely evanescent. When the attenuation is low (phase velocity much greater than thermal velocity, $v_p >> v_t$), the Langmuir fluid refractive indices (quintic or cubic) closely match the kinetic values, but for decreasing v_p/v_t, Landau damping becomes increasingly important, the quintic root becomes progressively larger and the cubic smaller than the kinetic value. In the Bernstein domain the third fluid mode corresponds fairly well to the the low-n kinetic value only in the first harmonic band, but the match is poor for the high-n Bernstein mode. In polar plots $n(\theta)$ for a cool plasma, $KT/m \approx 0.5$ eV, at frequencies below the upper hybrid frequency, $\omega < \omega_{UH}$, $(\omega_{UH}{}^2 := \omega_p{}^2 + \omega_c{}^2)$ the fluid and kinetic refractive indices overlap and merge with the cold-plasma values on the infinite asymptote, where $\cos\theta = (\omega/\omega_p\omega_c)\sqrt{(\omega_{UH}{}^2 - \omega^2)}$, but for warmer plasmas, typically $KT/m \approx 50$ eV, the overlapping fluid and kinetic values differ appreciably from those of the cold-plasma with the kinetic values diverging slightly from the fluid values as $\theta \to 90°$, due to the contribution of cyclotron resonance effects.

An expansion of the full kinetic dielectric tensor in terms linear in the temperature parameter has sometimes been used (cf. Sitenko and Stepanov, 1957; Allis, Buchsbaum and Bers, 1963). Polar plots of $n(\theta)$ show this method to be marginally better than our fluid calculations for perpendicular propagation, but performs poorly for Langmuir (parallel) propagation if there is slight absorption, e.g. if $\omega_p{}^2/\omega^2 \leq 0.9$.