

A two-fluid analysis of waves in a warm ion-electron plasma

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Following the work presented in [1–3], we discuss waves in a warm ideal two-fluid plasma consisting of ions and electrons, adopting a two-fluid approach, assuming charge neutrality and a homogeneous background at rest. The resulting dispersion relation was detailed in [4]. The plasma itself is governed by four characteristic quantities: the electron (resp. ion) magnetisation E (I) and the squared electron (resp. ion) sound speed v^2 (w^2). Finally, a fifth parameter to describe different wave types is the parameter λ describing the angle between the propagation vector \mathbf{k} and the magnetic field \mathbf{B} [4]. A plasma described by these parameters supports 6 wave types, which we refer to as the S, A, F, M, O and X modes, following the labelling scheme introduced in [1–3].

Exploiting λ , it is shown that the frequencies of these waves obey an ordering at all oblique propagation angles for all wavelengths. Hence, for each mode long and short wavelength limits can be computed, identifying cutoffs and resonances.

This ordering, however, is violated at parallel and perpendicular propagation. This implies that the modes no longer connect the long and short wavelength limits in the same way as in the oblique case. Thus, at these angles, modes cross. These crossings can be identified and lead to avoided crossings at oblique angles such that the ordering is satisfied there. The ordering, combined with the crossings at parallel and perpendicular propagation, offer a complete picture of the wave types in an ion-electron plasma.

With this knowledge of the different wave modes, the dispersion relation is then utilised to analytically quantify the phase and group speed of each mode. Although significant simplification occurs in the long and short wavelength limits, they are easily visualised for intermediate wavelengths in phase and group speed diagrams, revealing intricate behaviour. These phase and group speed diagrams also serve as a warm plasma alternative for CMA diagrams [6–7].

Furthermore, parallels can be drawn to published results, including the recovery of the Hall-MHD dispersion relation [5], a generalisation of the Appleton-Hartree relation to a warm plasma [7] and a comparison to results obtained in kinetic theory [6–7].

References

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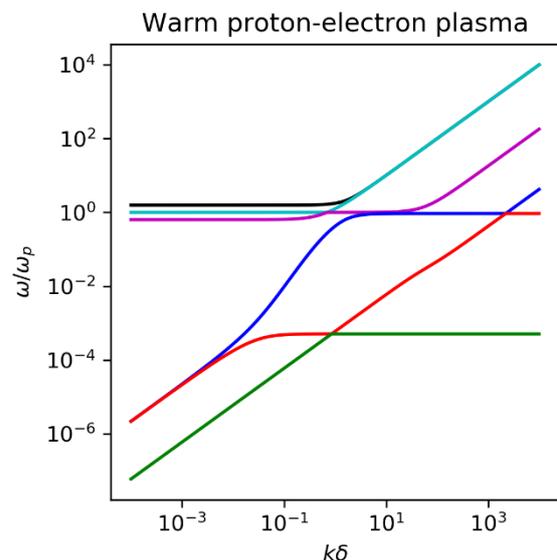


Figure: Six wave modes (each one in a different color), in a plot of the frequency as a function of the wavenumber, at nearly-parallel propagation, showing avoided crossings.