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Kinetic Theory of Instability-Enhanced Collisional Effects[1]

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A generalization of the Lenard-Balescu collision operator is derived which accounts for the scattering of particles by instability amplified fluctuations that originate from the thermal motion of discrete particles (in contrast to evoking a fluctuation level externally, as is done in quasilinear kinetic theory) [1]. Emphasis is placed on plasmas with convective instabilities. It is shown that an instability-enhanced collective response results which can be the primary mechanism for scattering particles, being orders of magnitude more frequent than conventional Coulomb collisions, even though the fluctuations are in a linear growth phase. The resulting collision operator is shown to obey conservation laws (energy, momentum, and density), Galilean invariance, and the Boltzmann $\mathcal{H}$-theorem. It has the property that Maxwellian is the unique equilibrium distribution function; again in contrast to weak turbulence or quasilinear theories. Instability-enhanced collisional effects can dominate the physics of low-temperature plasmas. For example, this theory has been applied to two outstanding problems: Langmuir's paradox [2] and determining Bohm's criterion for plasmas with multiple ion species. Langmuir's paradox is a measurement of anomalous electron scattering rapidly establishing a Maxwellian distribution in gas discharges with low temperature and pressure. This may be explained by instability-enhanced scattering in the plasma-boundary transition region (presheath) where convective ion-acoustic instabilities are excited. Bohm's criterion for multiple ion species is a single condition that the ion fluid speeds must obey at the sheath edge; but it is insufficient to determine the speed of individual species. It is shown that an instability-enhanced collisional friction, due to streaming instabilities in the presheath, determines this criterion.

[1] S.D. Baalrud, J.D. Callen, and C.C. Hegna, Phys. Plasmas **15**, 092111 (2008).
[2] S.D. Baalrud, J.D. Callen, and C.C. Hegna, Phys. Rev. Lett. (to appear June 2009); preprint UW-CPTC 09-4 at www.cptc.wisc.edu.

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