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The Plasma-Sheath Boundary in Two-Ion-Species Plasmas[1]

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The Bohm criterion is among the most important results in plasma physics because it provides the ion flow speed at the sheath edge under common plasma conditions. This is a useful boundary condition for modeling plasma-materials interactions, as well as for global plasma models. However, a difficulty arises when multiple ion species are present because the Bohm criterion provides only one constraint in as many unknowns as there are ion species. Conventional theory assumes that the ion species are decoupled, which leads to the prediction that each obtains its individual sound speed at the sheath edge: $V_i = \sqrt{T_e/m_i}$. However, experiments in Ar-Xe and He-Xe mixtures have revealed that the ion speeds can merge toward a common speed under typical low-temperature plasma conditions [1]. This merging of ion speeds suggests that ion-ion friction may be playing a role, but standard Coulomb collisions are far too weak to explain the measurements. In this work, we discuss how the experimental results can be understood by accounting for wave-particle collisions from ion-ion two-stream instabilities. These instabilities arise when the differential flow speed between the ion species exceeds a threshold value that depends on the ion species concentrations and the electron-ion temperature ratio. When this threshold is exceeded, wave-particle interactions rapidly increase the collision rate leading to an ion-ion friction force that effectively "locks" the differential flow speed to the instability threshold. This provides a second constraint that can be used to determine the speed of each ion species at the sheath edge. We present numerical calculations of the instability threshold, and new particle-in-cell simulations that show the presence of both the instabilites and enhanced friction force. Only by accounting for the instabilites can theory predict the simulated ion speeds at the sheath edge.

[1] Hershkowitz, Yip, Severn, Phys. Plasmas 18, 057102 (2011); and references therein.

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