Extensions and Applications of the Bohm Criterion

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The Bohm criterion [1] is a statement that the ion fluid velocity must be supersonic at the interface between a quasineutral plasma and a non-neutral sheath: $V_i \geq c_s \equiv \sqrt{T_e / m_i}$. It has since been appreciated that the minimum allowed value is typically realized in quiescent weakly collisional plasmas. The Bohm criterion is one of the most well known results in plasma physics because the ion speed at the sheath edge provides a useful boundary condition for modeling plasma-material interactions, as well as global plasma characteristics. A particular utility is that it is insensitive to the sometimes-complicated physics occurring in the presheath region leading up to the sheath edge. In his original derivation, Bohm assumed a two-component plasma consisting of a cold ion fluid and comparatively warm thermal electrons. Much modern work in this area focuses on relaxing these assumptions to formulate a kinetic Bohm criterion valid for arbitrary ion and electron velocity distributions. The conventional kinetic Bohm criterion [2] neglects collisions in the sheath and applies the asymptotic limit $\lambda_D/l \to 0$ where λ_D is the Debye length and l is a characteristic length scale of the plasma. In this work, we present an alternative kinetic formulation in which collisions and the parameter λ_D/l are treated perturbatively rather than in the strict limit where they vanish [3]. This leads to a theory that encompasses a broader class of distribution functions than the conventional theory. One particular benefit is that it applies to realistic experimental conditions where collisions such as ionization might be infrequent in the sheath, but are nevertheless finite. In contrast, the conventional approach diverges in this situation as a result of the distribution functions not being strict Vlasov solutions at the sheath edge.

To illustrate the utility of this new approach, we present two common examples where kinetic effects are significant. The first considers what happens when the sheath potential drop becomes small, as happens near a Langmuir probe biased near the plasma potential. In this case, the electron distribution is far from equilibrium due to loss to the probe, which leads to subsonic values of the ion speed at the sheath edge. The second example considers the role of ionization in the approach to the sheath edge, which generates a non-thermal tail in the ion distribution function. Here it is important to treat collisions as a perturbation rather than take the collisionless limit.

[1] D. Bohm, in *Characteristics of Electrical Discharges in Magnetic Fields,* ed A Guthrie and R K Wakerling (New York: McGraw-Hill) chapter 3.
[2] E.R. Harrison and W.B. Thompson, *Proc. Phys. Soc.* **74**, 145 (1959).
[3] S.D. Baalrud and C.C. Hegna, *Plasma Sources Sci. and Technol.* **20**, 025013 (2011).