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Fitting Formulas for Perpendicular Closure Coefficients in High-Collisionality Deuterium-Carbon Plasmas

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Plasmas consisting of multiple ion species arise in various contexts, including fusion devices, space plasmas, and plasma processing systems. Their behavior is typically described using fluid equations supplemented by closure relations that account for inter-species Coulomb collisions. A recent study established a theoretical framework for evaluating closure coefficients in high-collisionality regimes, while another provided fitting formulas for deuterium-carbon plasmas, offering parallel closure coefficients (aligned with the magnetic field) with supervised machine learning techniques. [1,2]

In this work, we extend the previous approach by presenting accurate fitting formulas for perpendicular closure coefficients. The results show that the fitting formulas match the closure coefficients within 5% across the parameter space. As a representative example, Figs. 1 and 2 illustrate the accuracy of fitting of closure coefficient $\hat{\alpha}_\perp$ [1] for the frictional force density:

$$\hat{\alpha}_\perp = \frac{\sum_{i=0}^{5} a_i (\ln r)^{\,i}}{(\ln r)^{\,5} + \sum_{j=0}^{4} b_j (\ln r)^{\,j}} \ . \qquad (1)$$

These new expressions enable efficient and reliable modeling of plasma dynamics in the scrape-off layer of tokamak devices. Future work will incorporate additional species such as argon and tritium to further generalize the model.

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References

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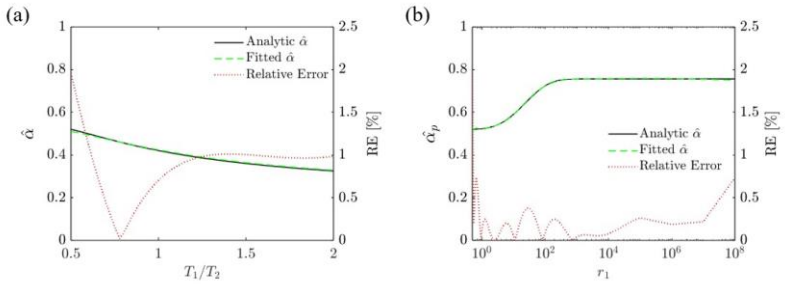

Figure 1. Perpendicular closure coefficient $\hat{\alpha}_\perp$ as a function of (a) T_r ($r_1 = 0.6$) and (b) r_1 ($T_1/T_2 = 0.5$) at $n_1/n_2 = 1$, $T_2/T_e = 0.5, \ln\lambda_{ee} = 19$, and $Z_n = 1$, where Z_n is the effective charge ratio that accounts for both the ion charge states and their density ratio, and $\ln\lambda_{ee}$ denotes the Coulomb logarithm. The subscripts 1 and 2 refer to deuterium and carbon, respectively. The coefficients obtained from the analytic calculation are shown as black solid lines, while those from the fitting results are shown as green dashed lines. The relative error between the analytic and fitted values is indicated by the red dotted line.

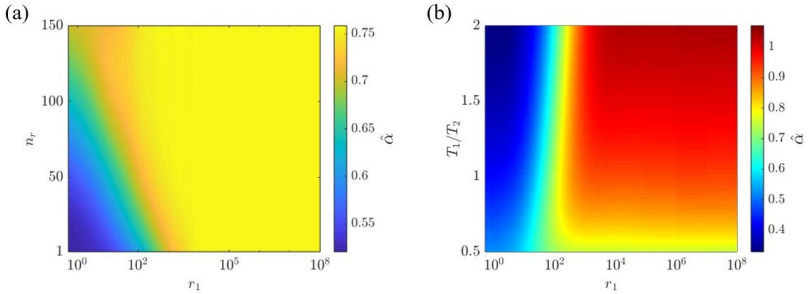

Figure 2. Perpendicular closure coefficient $\hat{\alpha}_p$ in (a) the n_1/n_2-r_1 space ($T_1/T_2 = 0.5$) and (b) the T_1/T_2-r_1 ($n_1/n_2 = 1$) space when $T_2/T_e = 0.5$, $\ln\lambda_{ee} = 19$, $Z_n = 1$.