Poloidal Velocity of Impurity Ions in Neoclassical Theory*

S.K. Wong[1], V.S. Chan[2], and W.M. Solomon[3]

[1]San Diego Mesa College, San Diego, California, USA
[2]General Atomics, P.O. Box 85608, San Diego, California 92186-5608, USA
[3]Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA

A recent measurement [1] of the poloidal velocity of the ion C^{+6} in a deuterium plasma disagrees in both magnitude and direction with the calculation from the computer code NCLASS. The code implements the moment approach of Hirshman and Sigmar [2], which assumes that the toroidal velocities of all ions are much smaller than their respective thermal speeds. This is not true for the C^{+6} ions in the core of the observed plasmas. We have derived a formula for the poloidal velocity of impurity ions in a two-species plasma from neoclassical theory in the banana regime, with corrections from the boundary layer separating the trapped and transiting ions. The formula is applicable to plasmas with toroidal rotations that can approach the thermal speeds of the ions. Applying it to the experiment leads to agreement in direction in the central region, thus alleviating the reported disagreement, although the magnitude still falls short. We have also compared the analytic calculation with the numerical work of Hinton and Moore [3] in the small rotation cases as well as an independent implementation of the moment approach for a two-species plasma that does not make the assumption of much heavier impurity mass as an oft quoted reference [4] does. Our implementation employs quantities for large aspect ratio circular cross-section flux surfaces close to the conventional kinetic approach so as to facilitate comparison of the theoretical bases of the approaches. We have found significant differences that necessitate more refined numerical calculations in the future.

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