Impact of magnetic field on the parallel resistivity

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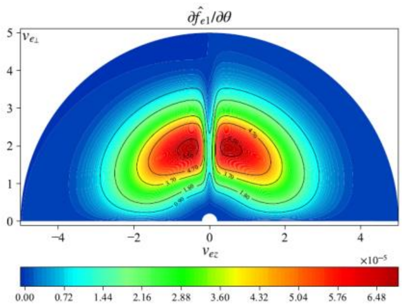
The impact of magnetic field (MF) on the parallel resistivity $\eta_\parallel$ is studied for strongly magnetized plasmas with the electron thermal gyroradius ρ_{the} smaller than the Debye length λ_D but much larger than the Landau length λL. Two previous papers [P. Ghendrih et al., Phys. Lett. A 119, 354 (1987); S. D. Baalrud and T. Lafleur, Phys. Plasmas 28, 102107 (2021)] found $\eta_\parallel$ to increase monotonically with MF. Unfortunately, both works used predetermined electron distribution functions and are thus not self-consistent.

A self-consistent study is conducted for the impact of MF on $\eta_\parallel$ in this paper. Contrary to previous results, $\eta_\parallel$ is found to decrease monotonically with the MF, which is expected to have a notable impact on various plasma physics problems associated with $\eta_\parallel$, particularly on the resistive in-stabilities and transport phenomena.

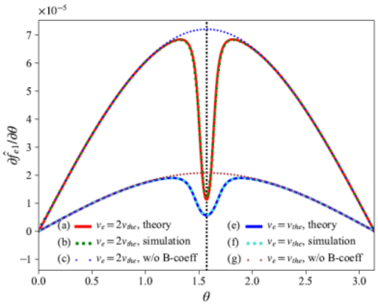
The MF influence on the electron dynamics has been considered during the collision process while its influence on the ion dynamics is ignorable. For simplicity, the electrons are supposed to collide only with background ions and not with other electrons. Since the current is mainly carried by the electrons, we can ignore the ion response to E and take its velocity distribution function f_i to be Maxwellian. Under these conditions, the evolution of the electron distribution function f_e is governed by a magnetized Fokker-Planck (FP) equation. The first- and second-order magnetized FP coefficients can be obtained in the static screening approximation. The f_{e1} can be solved self-consistently from the electron magnetized FK equation in a Lorentz gas-like approximation. From the f_{e1} expression, we have

$$\frac{\partial f_{e1}(\mathbf{v}_e)}{\partial\theta} = \frac{\beta v_e^4 \sin\theta\, f_{e0}(v_e)}{2v_{the}^2[1+\alpha' v_e \mathcal{D}(v_e\cos\theta)]}$$

Figure 1 shows the contour map of $\partial f_{e1}/\partial\theta$ in the quasistatic state obtained numerically and the black contour lines from the theoretical result with $m_i/m_e = 3672$ and $\alpha = 0.2$. A good agreement between the numerical and theoretical results is achieved.



The change of $\partial f_{e1}/\partial\theta$ with θ is plotted in Fig. 2 for the two cases $\hat{v}_e = 1$ and $\hat{v}_e = 2$. The theoretical results represented by the solid curves and the numerical results by the dashed curves are in good agreement.



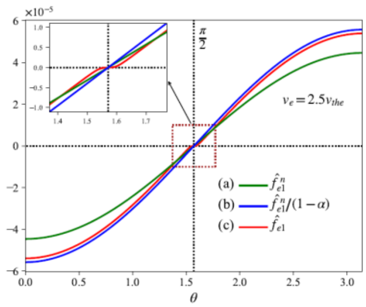
The parallel current J_z is given by

$$J_z = -e\int v_{ez} f_e(\mathbf{v}_e,\, t)\, d^3\mathbf{v}_e = \frac{64\sqrt{2\pi}\varepsilon_0^2(k_BT_e)^{3/2}}{Ze^2\sqrt{m_e}\ln(\rho_{the}/r_L)}E$$

from which we finally obtain the parallel resistivity as

$$\eta_\parallel = \frac{E}{J_z} = \frac{Ze^2\sqrt{m_e}}{64\sqrt{2\pi}\varepsilon_0^2(k_BT_e)^{3/2}}\ln\left(\frac{\rho_{the}}{r_L}\right)$$

It is shown that only difference from the conventional parallel resistivity is the replacement of λ_D in $ln\,\Lambda$ by ρ_{the}. To explain the MF dependence of $\eta_\parallel$, we compare f_{e1} with MF for $m_i/m_e = 3672$ and $\alpha = 0.2$, and $v_e = 2.5v_{the}$ with its value f_{e1}^n without MF in Fig. 3.



The MF influence on $\eta_\parallel$ is significant in the white dwarf atmospheres and the ultracold neutral plasmas with the relative corrections close to 90%. For the Alcator C-Mod tokamak scrape-off layer plasmas, the relative correction is about 10%. In the future, as the MF of tokamaks increases, its influence on $\eta_\parallel$ may become more pronounced.

References

[1] Cohen, Spitzer, and Routly, Phys. Rev. 80, 230 (1950); Spitzer and Härm, *ibid*. 89, 977 (1953).
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