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# Effect of finite temperature in counter differential rotation equilibrium of two-fluid plasma

Y. Nakajima[1], T. Okada[1], H. Himura[1] and A. Sanpei[1]
[1] Department of Electronics, Kyoto Institute of Technology
e-mail (speaker): m0621027@edu.kit.ac.jp

Recently, the interesting works by using the non-neutral plasma for which all particles have the same sign of charge are not only to study itself but also to apply to production and confinement of multi-component plasma. There are some projects using two non-neutral plasmas such as efforts to create electron–positron pair plasma or to confine two-fluid plasma consisting of lithium ion ($Li^+$) plasma and electron ($e^-$) one. [1]

In my presentation, the property of the two-dimensional (2D) counter differential rotation equilibria[2] of $Li^+$ plasma and $e^-$ one with finite temperatures $T_i$ and $T_e$ confined cylindrically by a single trap in the uniform magnetic field $\boldsymbol{B}$ is described. In the equilibrium, $Li^+$ and $e^-$ plasmas exhibit corresponding rigid rotations around the plasma axis with the different angular velocities $\omega_{ri}$ and $\omega_{re}$ like a two-fluid plasma. It is previously shown that cold two-component plasma support in the differential rotation equilibrium. If the ion and $e^-$ plasma have low temperature $T_i$ and $T_e$ of near 0 eV, the pressures are negligible, and so the rotation is simply driven by $\boldsymbol{B}$ and the self-electronic potential $\phi_s$ or electronic field $\boldsymbol{E} = -\nabla\phi_s$ which the difference between the uniform density of ion plasma $n_{i0}$ and $e^-$ plasma $n_{e0}$ produces. Considering $\boldsymbol{E}\times\boldsymbol{B}$ drift $v_\phi$, it is consistent that the ion plasma and $e^-$ plasma rotate in same direction. This is such a simple case that each of $\omega_{ri}$ and $\omega_{re}$ can be calculated by $n_{i0}$ and $n_{e0}$. However, the unrealistic assumption of $T_i = T_e = 0$ eV is required to achieve the equilibrium. No solutions to the 2D differential rotation equilibrium with the finite temperature of $T_i$ and $T_e$ have been published yet, in our knowledge.

As shown in Figure 1, we obtain one of the solutions of the equilibrium equation calculated numerically. In the calculation, $n_e$ is always larger than $n_{i0}$, which means the system considered in this work is still a kind of non-neutral plasmas. Resultantly, a bell-shaped negative potential well exists in the plasmas; $\boldsymbol{E}$ is also non-uniform in the whole system. Nonetheless, both $Li^+$ and $e^-$ plasmas exhibit cornesponding rigid rotations around the plasma axis with different velocities like a two-fluid plasma. Another remarkable thing is that the $e^-$ plasma rotates in the same direction as that of $\boldsymbol{E}\times\boldsymbol{B}$, while the $Li^+$ plasma counter-rotates overall, as shown in Figure 2. This counter-rotation is attributed to the contribution from the diamagnetic drift of the $Li^+$ plasma $v_{di}$ owing to its finite ion pressure.

References

[1] H. Himura, *Nucl. Instrum. Methods. Phys. Res. B*, **811**: 100-107 (2016).
[2] Y. Nakajima, H. Himura, A. Sanpei, submitted to *J. Plasma Phys.* (2021).

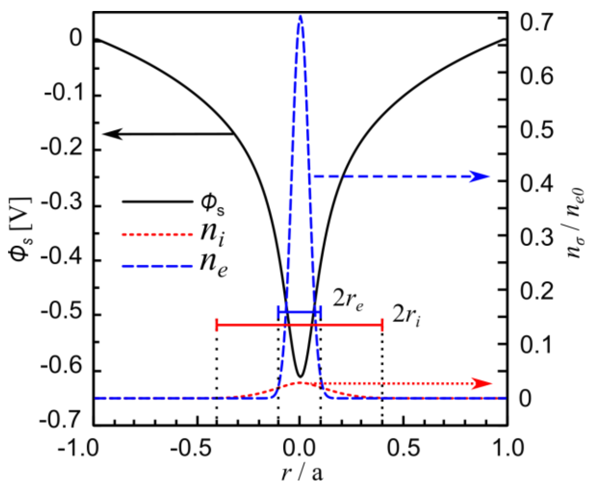


**Figure 2.** Radial profiles of $\phi_s(r)$ and $n_\sigma(r)$ for a set of equilibrium solutions. The conducting wall is at $r = a$.

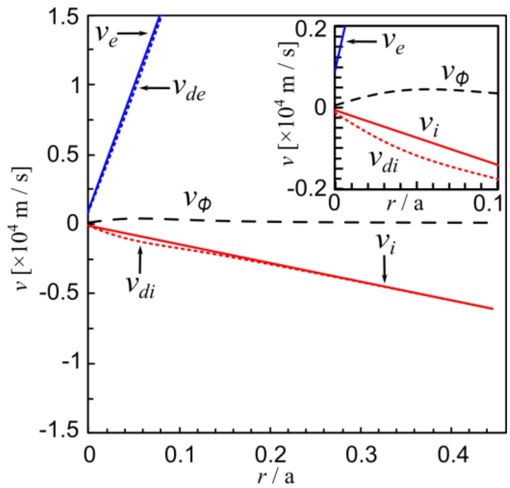


**Figure 1.** Radial profiles of the azimuthal components of $v_\phi$ (black dashed curves), $v_{d\sigma}$ (red dotted curves for $Li^+$ plasma and blue for $e^-$ plasma), and $v_\sigma$ (two solid red and blue lines) for the set of solutions shown in Figure 1.