20PA-032

Validation of Braginskii Thermal Conductivity in Laser Ablation Region
レーザーアブレーション領域における Braginskii の電子熱伝導率の検証

Takashi Asahina[1], Hideo Nagatomo[1], Atsushi Sunahara[2], Tomoyuki Johzaki[3], Masayasu Hata[1] and Yasuhiko Sentoku[4]
朝比奈隆志[1]，長友英夫[1]，砂原淳[2]，城﨑知至[3]，畑昌育[1]，千徳靖彦[4]

[1]*Institute of Laser Engineering, Osaka University*
2-6 Yamadaoka, Suita, Osaka 565-0871, Japan
大阪大学レーザーエネルギー学研究センター 〒565-0871 大阪府吹田市山田丘 2-6
[2]*Institute for Laser Technology*
2-6, Yamadaoka, Suita, Osaka 565-0871, Japan
レーザー技術総合研究所 〒565-0871 大阪府吹田市山田丘 2-6
[3]*Graduate School of Engineering, Hiroshima University*
1-4-1, Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8527, Japan
広島大学工学研究科 〒739-8527 広島県東広島市鏡山 1-4-1
[4]*University of Nevada at Reno*
1664, North Virginia Street, Reno, NV 89557, USA
ネバダ大学リノ校

In order to improve the reliability of magnetized implosion simulation for laser fusion, the accuracy of thermal conductivity model in magnetic fields, such as Braginskii's transport model, need to be validated. In this study, electron thermal conduction driven by temperature gradient in magnetized plasma is evaluated by Particle-In-Cell simulation. By comparing the simulation with and without 0.1 kT external magnetic field, the supression of electron heat flux due to the cyclotron motion of electrons is reproduced by the simulations.

1. Introduction

In fast ingition scheme, it is essential to improve the core heating efficiency in order to achieve high core temperature. Recently, a technique to generate kT-class magnetic field has been developed[1] and its utilization for fast ignition scheme has been discussed as an electron beam collimator. Such strong magnetic fields also affect the implosion dynamics. In particular, the cyclotron motion of electrons reduces the electron thermal conductivity in the direction perpendicular to the magnetic field. It has been shown by the implosion simulation with imposed external magnetic field that the anisotropic electron thermal conductivity causes the Rayleigh-Taylor instability in the ablation region. In the simulation, Braginskii's model[2] was adopted as the electron thermal conductivity model in magnetized plasmas. Since the reliability of the simulation depends on the accuracy of the conductivity coefficients, the model needs to be validated.

Taking account of magnetic field $\boldsymbol{B}$, Braginskii's transport coefficients were originally derived by solving Fokker-Planck equation approximately. In regard to the electron thermal conduction, the relation of electron heat flux $\boldsymbol{q}_\mathrm{e}$ and temperature gradient ∇T_e are described of the form

$$\boldsymbol{q}_\mathrm{e} = -\kappa_\parallel \nabla_\parallel T_\mathrm{e} - \kappa_\perp \nabla_\perp T_\mathrm{e} - \kappa_\wedge \boldsymbol{b} \times \nabla T_\mathrm{e} . \qquad (1)$$

Thermal conduction coefficients $\kappa_\parallel$, $\kappa_\perp$, and $\kappa_\wedge$ are denoted by

$$\kappa_\parallel = \frac{n_\mathrm{e} T_\mathrm{e} \tau_\mathrm{e}}{m_\mathrm{e}} \gamma_0 , \qquad (2)$$

$$\kappa_\perp = \frac{n_\mathrm{e} T_\mathrm{e} \tau_\mathrm{e}}{m_\mathrm{e}} \frac{\gamma_1' \chi^2 + \gamma_0'}{\chi^4 + \delta_1 \chi^2 + \delta_0} , \qquad (3)$$

$$\kappa_\wedge = \frac{n_\mathrm{e} T_\mathrm{e} \tau_\mathrm{e}}{m_\mathrm{e}} \frac{\chi \left(\gamma_1'' \chi^2 + \gamma_0'' \right)}{\chi^4 + \delta_1 \chi^2 + \delta_0} , \qquad (4)$$

where m_e, n_e, and τ_e are the electron mass, density, and electron-ion collision time. $\chi = \omega_\mathrm{ce} \tau_\mathrm{e}$ is the Hall parameter where $\omega_\mathrm{ce} = eB/m_\mathrm{e}$ is the electron cyclotron frequency. Coefficients γ_0', γ_1', γ_0", γ_1", δ_0, and δ_1, which are dependent on ion charge state Z, are tabulated for $Z = 1, 2, 3, 4, \infty$[2].

Epperlein and Haines[3] showed that some Braginskii coefficients are not accurate for some χ by solving the Fokker-Planck equation numerically. For $\kappa_\perp$ and $\kappa_\wedge$, Braginskii's values are in error up to 65% in their study.

Ji and Held[4] also calculated the transport coefficients for both electron and ion by solving Fokker-Planck equation using the moment method. Their solution with up to 160 moments provided more accurate formulas for wide ranges of χ and Z.

Since the previous studies of transport coefficients in magnetized plasma are based on the solution of Fokker-Planck equation, the results should be checked in other methods. In this study, the accuracy of Braginskii and other models are investigated by Particle-in-Cell (PIC) simulation in the plasma with temperature gradient and uniform density.

2. Simulation Method

In order to simulate the system of plasma with temperature gradient, a one-dimensional electromagnetic PIC code ‘PICLS1D’[5] is used. In this code, the plasma particles have three-dimensional velocity and binary collision model is included. Simulation configuration is shown in Fig. 1. In order to maintain the x-direction temperature gradient, the plasmas on the left and right side of the system are kept to be Maxwellian distribution of temperatures T_H = 1 keV and T_L = 600 eV. In the middle of the system, the plasma temperature is initially uniform T_0 = 800 eV. The system length is set to be the mean free path of electrons with energy $\varepsilon = 10T_H$. The electron density is initially uniform $n_e = 10^{22}$ cm^{-3}. Ion charge state and mass are $Z = 4$ and $m_i = 1288m_e$, which are constant in the whole simulation. The system is composed of 1350 meshes including the constant-temperature regions on the left and right side (5 meshes for each region). 8192 and 1024 particles are used for electrons and ions. The simulation is performed with and without external magnetic field B_{ext} = 0.1 kT perpendicular to x axis.

The system is split into 100 divisions as shown in Fig. 2. Temperature is evaluated in each division by $T = m_e\langle v^2\rangle/3$ (bracket denotes the average quantity over the particles). Electron heat flux is evaluated in the divisions shifted by a half, as shown in Fig. 2, by $q = m_e n_e\langle v^2 v_x\rangle/2$. Assuming the temperature in the shifted division to be the mean value of the temperatures in the adjacent two divisions, one can obtain the relations between the local temperature, temperature gradient, and heat flux.

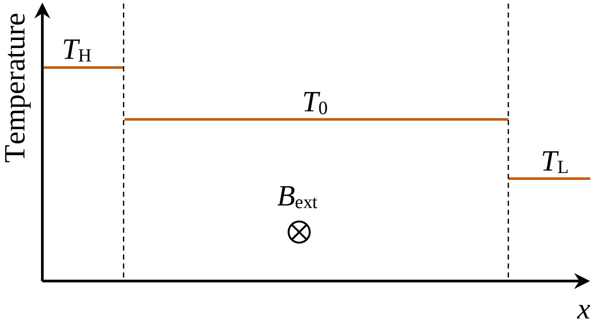

Fig. 1. Initial configuration of the simulation.

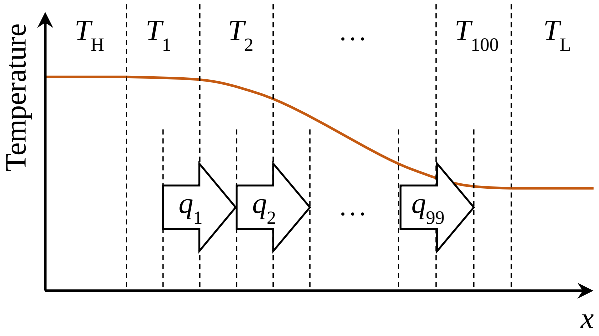

Fig. 2. Divisions introduced to evaluate temperature T and heat flux q.

3. Results

Electron heat flux q is plotted in Fig. 3 as a function of temperature scale length $L = T(dT/dx)^{-1}$ normalized by electron mean free path λ. Here heat flux is normalized by the free-streaming limit $q_F = n_e T(T/m_e)^{1/2}$. The heat flux supression due to external magnetic field is observed. For the gentle-gradient low-flux case, obtained values vary widely because of the limited number of particles. Comparisons with the heat conduction models and improvement of simulation accuracy are ongoing.

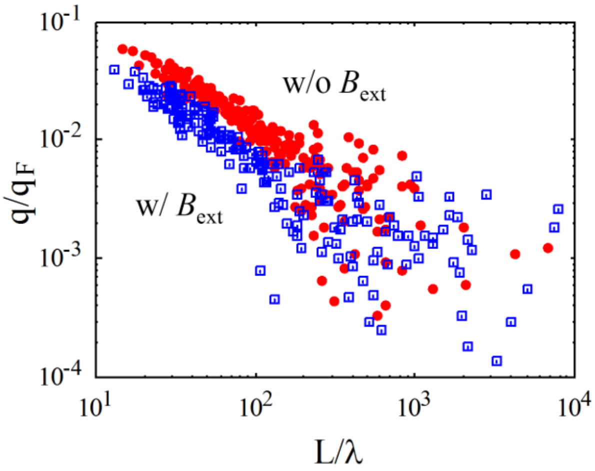

Fig. 3. Evaluated electron heat flux. Red dots and blue squares show the results with and without B_{ext} respectively.

References

[1] S. Fujioka, Z. Zhang, K. Ishihara, K. Shigemori, Y. Hironaka, T. Johzaki, A. Sunahara, N. Yamamoto, H. Nakashima, T. Watanabe, H. Shiraga, H. Nishimura and H. Azechi: Sci. Rep. **3** (2013) 1170.

[2] S. I. Braginskii: Transport Processes in Plasmas in Reviews of Plasma Physics (Consultants Bureau, New York, 1965), Vol. 1, p. 205.

[3] E. M. Epperlein and M. G. Haines: Phys. Fluids **29** (1986) 1029.

[4] J.-Y. Ji and E. D. Held: Phys. Plasmas **20** (2013) 042114.

[5] Y. Sentoku and A. J. Kemp: J. Comput. Phys. **227** (2008) 6846.