Electronic transport of Lorentz plasma with collision and magnetic field effects*

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The electronic transverse transport of Lorentz plasma with collision and magnetic field effects is studied by solving the Boltzmann equation for different electron density distributions. For the Maxwellian distribution, it is shown that transport coefficients decrease as Ω increases, Ω is the ratio of an electron's magneto-cyclotron frequency to plasma collision frequency. It means that the electrons are possible to be highly collimated by a strong magnetic field. For the quasi-monoenergetic distribution with different widths, it is found that the transport coefficients decrease greatly as $\bar{\varepsilon}$ decreases. In particular when the width approaches to zero the transverse transport coefficients are hardly affected by the magnetic field and the minimal one is obtained. Results imply that the strong magnetic field and quasi-monoenergetic distribution are both beneficial to reduce the electronic transverse transport. This study is also helpful to understand the relevant problems of plasma transport in the background of the inertial confinement fusion.

Keywords: transverse transport coefficients, magnetic field, collision, distribution

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1. Introduction

In the inertial confinement fusion (ICF) study,[1–3] electron transport is an important but difficult problem. For example, for fast ignition (FI) the laser energy is first deposited into fast electrons in the interaction region, which is usually 50 μm–100 μm away from the dense core, and then the energy flux transports into the dense core. Studies[4] showed that electrons with an energy of 1 MeV–3 MeV are optimal for FI. The transport coefficients are usually required for both target design and magnetohydrodynamic codes. Because of its significance, many theoretical and numerical models have been established in search of electron transport features, such as the Spitzer–Härm model,[5,6] the Braginskii model,[7] and the nonlocal electron transport model,[8] and so on.

In laser–plasma interaction physics, in order to obtain accurate electron transport coefficients one must consider two effects, one is associated with the self-generated magnetic field and the other is the plasma collision.[9–13] Certainly the electron distribution[14–16] has also played a key role. The self-generated magnetic field has been studied in laser interacting with plasma over the period of time.[9,17–22] Recently, experimental measurements by Tatarakis *et al.*[23] showed that the self-generated magnetic field, from a few of MGs (1 Gs = 10^{-4} T) to several hundred of MG, can be generated. The corresponding electron cyclotron frequency ω_{Be} lies within $\sim 1.8\times10^{15}$ Hz–1.8×10^{17} Hz. Such a strong magnetic field is believed to have an important impact on electron transport.

Besides, the collision effect on the transport of electrons has been considered and studied in the high density region.[24–26] For example, Kemp *et al.*[27] showed that the collision effect cannot be neglected when the number density is beyond $\sim 10^{23}$ cm^{-3}, due to the collision frequency being close to the plasma frequency. Usually, the number density can be 10^{22} cm^{-3}–10^{26} cm^{-3} in ICF, and the corresponding electron–ion collision frequency ν_{ei} is $\sim 1.5\times10^{15}$ Hz–3.8×10^{17} Hz, which is obviously comparable to ω_{Be}. The most previous studies about the electronic transverse transport coefficients were focused on the calculations of the weak collision, i.e. $\omega_{\mathrm{Be}} \gg \nu_{\mathrm{ei}}$, with a Maxwellian distribution function.[28] However, the combination effect of collision and strong magnetic field for different distributions have not been considered, in particular when ω_{Be} is comparable to ν_{ei}. Therefore, the electronic transverse transport needs to be studied further in these cases.

Plasma consists of electrons and ions. With the condition of assuming the electron temperature equals the ion temperature and the mass of the electrons is much smaller than that of the ions, the speed of electrons is much faster than the speed of the ions. Therefore, it is feasible assuming that electrons are moving while ions are stationary, so that ions are not affected by the collision and electromagnetic field. Besides, for simplicity we just consider the involving problem for the Lorentz plasma,[28–30] in which the electron–electron collision $\nu_{\mathrm{ee}} \sim e^4 N_{\mathrm{e}}$ can be ignored in comparison with the electron–

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ion collision $\nu_{ei} \sim e^4 z_i N_e$, i.e., $\nu_{ee} \ll \nu_{ei}$, where N_e denotes the electron density and z_i is the atomic number. In order to control the divergence of electrons, Robinson *et al.*[31] showed that an electron beam could be collimated well by the self-generated magnetic field in the high-Z material area. Without loss of generality, we can assume that the atomic number is $z_i \gg 1$.[30,32,33]

In this paper, the electronic transverse transport coefficients, such as electric and thermal conductivity, are studied by solving the Boltzmann transport equation for Lorentz plasma with a collision effect in the presence of a magnetic field. The different electrons distribution functions are also considered. The analytical formula is given and the corresponding numerical results are illustrated for the transport coefficients. It is found that the strong magnetic field and quasi-monoenergetic distribution are both beneficial to reduce the electronic transverse transport.

The paper is organized as follows. Section 2 gives the theoretical frame and analytical formula. Section 3 exhibits the results in the presence of both magnetic field and collision for different distribution functions. The results are also analyzed physically. A brief summary and discussion are given in Section 4.

2. Theoretical frame and analytical formula

Assuming that $f(\boldsymbol{r},\boldsymbol{v},t)$ is the electrons distribution function at position $\boldsymbol{r}$, velocity $\boldsymbol{v}$, and time t, then the stationary transport equation of Lorentz plasma in a magnetic field reads[28]

$$\boldsymbol{v}\cdot\frac{\partial f}{\partial \boldsymbol{r}} - e\boldsymbol{E}\cdot\frac{\partial f}{\partial \boldsymbol{p}} = \frac{e}{c}\boldsymbol{v}\times\boldsymbol{B}\cdot\frac{\partial f}{\partial \boldsymbol{p}} + C(f), \tag{1}$$

where $\boldsymbol{B}$ is the magnetic field, $\boldsymbol{E}$ is the electric field, $\boldsymbol{p}$ is the electron momentum, $-e$ is the electron charge, c is the light speed in a vacuum, and $C(f)$ is the electron–ion collision term. Furthermore, we assume that

$$f(\boldsymbol{r},\boldsymbol{v},t) = f_0(\boldsymbol{r},\boldsymbol{v}) + \delta f(\boldsymbol{r},\boldsymbol{v},t),$$

where $f_0(\boldsymbol{r},\boldsymbol{v})$ is the stationary equilibrium distribution and $\delta f(\boldsymbol{r},\boldsymbol{v},t)$ is the small perturbation, i.e.,

$$\delta f(\boldsymbol{r},\boldsymbol{v},t) \ll f_0(\boldsymbol{r},\boldsymbol{v}).$$

Then the collision integral can be written as[28]

$$C(f) = -\nu_{ei}\delta f. \tag{2}$$

The electron–ion collision frequency $\nu_{ei}(v)$ is usually given by

$$\nu_{ei}(v) = \frac{4\pi z e^4 N_e L^{(ei)}}{m^2 v^3}, \tag{3}$$

where m is electron mass, v is magnitude of electron velocity, $L^{(ei)}$ is scattering factor, ze is charge of the ion and N_e is electron number density. In Eq. (1), we can take $\boldsymbol{E} = \boldsymbol{0}$ since $\boldsymbol{E}$ only appears in the required current $\boldsymbol{j}$ as a sum formula $\boldsymbol{E} + \nabla p/eN_e$,[28] or it can be seen from the view point of the electric field in the moving reference frame (with speed $\boldsymbol{u}$) as[29]

$$\boldsymbol{E}' = \boldsymbol{E} + \frac{1}{c}\boldsymbol{u}\times\boldsymbol{B} = 0.$$

Besides, since the longitudinal transport coefficients are independent of the magnetic field, all involved quantities for the plasma can be regarded as only depending on the coordinates in the plane perpendicular to $\boldsymbol{B}$. With all these considerations, one gets the following starting equation

$$(\boldsymbol{v}\cdot\nabla_\perp) f_0 = \frac{e}{c}\boldsymbol{v}\times\boldsymbol{B}\cdot\frac{\partial \delta f}{\partial \boldsymbol{p}} + C(f), \tag{4}$$

where $\nabla_\perp$ is along the direction perpendicular to $\boldsymbol{B}$. A remarkable and useful solution of Eq. (4) is

$$\delta f = -\frac{\omega_{Be}}{\omega_{Be}^2+\nu_{ei}^2}[\boldsymbol{v}\cdot(\boldsymbol{b}\times\nabla_\perp f_0)] - \frac{\nu_{ei}}{\omega_{Be}^2+\nu_{ei}^2}(\boldsymbol{v}\cdot\nabla_\perp f_0), \tag{5}$$

where $\boldsymbol{b} = \boldsymbol{B}/B$ is the unit vector of magnetic field $\boldsymbol{B}$.

In order to calculate the electronic transport coefficients such as the electric conductivity and thermal conductivity, the current density and the generalized Ohm law as well the heat flux and the generalized heat flow law are need. They are respectively given as (refer to Ref. [28])

$$\boldsymbol{j} = -e\int \boldsymbol{v}\delta f \mathrm{d}^3\boldsymbol{p}, \tag{6}$$

$$\boldsymbol{E} + \frac{1}{c}\boldsymbol{v}\times\boldsymbol{B} + \frac{1}{eN_e}\nabla P = \frac{\boldsymbol{j}_\parallel}{\sigma_\parallel} + \frac{\boldsymbol{j}_\perp}{\sigma_\perp} + \Re(\boldsymbol{B}\times\boldsymbol{j}) + \alpha_\parallel(\nabla T)_\parallel + \alpha_\perp(\nabla T)_\perp + \aleph(\boldsymbol{B}\times\nabla T), \tag{7}$$

and

$$\boldsymbol{q} = \frac{e}{2}\int v^2\boldsymbol{v}\delta f \mathrm{d}^3\boldsymbol{p}, \tag{8}$$

$$\boldsymbol{q} + \frac{w_e}{e}\boldsymbol{j} = \alpha_\parallel T\boldsymbol{j}_\parallel + \alpha_\perp T\boldsymbol{j}_\perp + \aleph T(\boldsymbol{B}\times\boldsymbol{j}) - \kappa_\parallel(\nabla T)_\parallel - \kappa_\perp(\nabla T)_\perp + \ell(\boldsymbol{B}\times\nabla T), \tag{9}$$

where $\boldsymbol{j}$ is current density, $\boldsymbol{q}$ is heat flux, T is temperature, P is pressure, σ is electric conductivity, α is the thermoelectric coefficient, κ is thermal conductivity, and the coefficients $\Re$, $\aleph$, and ℓ respectively represent the Hall, Nernst, and Leduc–Righi effects.

Before giving the detailed physical analysis and numerical results, we first see the concrete expressions for the current density and the heat flux, respectively. Substituting Eq. (5) into Eq. (6), one can obtain

$$\boldsymbol{j} = \frac{1}{3}e\boldsymbol{b}\times\nabla_\perp N_e\left\langle v^2\cdot\frac{\omega_{Be}}{\omega_{Be}^2+\nu_{ei}^2}\right\rangle + \frac{1}{3}e\nabla_\perp N_e\left\langle v^2\cdot\frac{\nu_{ei}}{\omega_{Be}^2+\nu_{ei}^2}\right\rangle, \tag{10}$$

where we have introduced an average value defined by

$$\langle F(v)\rangle = \int F(v) f_0 \mathrm{d}\boldsymbol{v}.$$

Similarly, substituting Eq. (5) into Eq. (8), the heat flux is

$$\boldsymbol{q} = -\frac{1}{6} m\boldsymbol{b}\times\nabla_\perp N_\mathrm{e}\left\langle v^4\cdot\frac{\omega_\mathrm{Be}}{\omega_\mathrm{Be}^2+\nu_\mathrm{ei}^2}\right\rangle - \frac{1}{6} m\nabla_\perp N_\mathrm{e}\left\langle v^4\cdot\frac{\nu_\mathrm{ei}}{\omega_\mathrm{Be}^2+\nu_\mathrm{ei}^2}\right\rangle. \tag{11}$$

For simplicity the following normalized variables are introduced as follows:

$$V = v/u_\mathrm{T}, \quad \Omega = \omega_\mathrm{Be}/\nu_\mathrm{T}, \quad \nu_\mathrm{T} = \nu_\mathrm{ei}(u_\mathrm{T}), \tag{12}$$

where $u_\mathrm{T} = \sqrt{T/m}$ is the magnitude of electron thermal velocity.

3. Physical analysis and numerical results

In Section 2, we have given the theoretical frame and analytical formula. Let us now turn to calculate the transverse transport coefficients for the different distribution functions.

3.1. Results for the Maxwellian distribution function

In the case of a Maxwellian distribution function, f_0 can be written as

$$f_0 = N_\mathrm{e}\left(\frac{m}{2\pi T}\right)^{3/2}\exp\left(-\frac{mv^2}{2T}\right). \tag{13}$$

By substituting Eqs. (10) and (13) into Eq. (7), one can obtain the electric conductivity

$$\sigma_\perp = \frac{2(\Omega^2\alpha_{10}^2+\alpha_7^2)}{9\pi\alpha_7}, \tag{14}$$

where

$$\alpha(\Omega)_n = \int \frac{V^n}{V^6\Omega^2+1}\exp\left(-\frac{V^2}{2}\right)\mathrm{d}V$$

is defined, and $\sigma_\perp$ is normalized by $\sigma_{\perp 0} = 3\sqrt{\pi}e^2N_\mathrm{e}/\sqrt{2}m\nu_\mathrm{T}$ in the weak collision.[28,29] Similarly, by substituting Eqs. (10) and (13) into Eq. (9), one can obtain the thermal conductivity

$$\kappa_\perp = \frac{3\alpha_{12}\alpha_7}{13\alpha_{10}} - \frac{2\alpha_9}{13}, \tag{15}$$

where $\kappa_\perp$ is normalized by $13N_\mathrm{e}T/6\sqrt{\pi}m\nu_\mathrm{T}$.

The $\sigma_\perp$ and $\kappa_\perp$ against Ω are plotted in Fig. 1. First from Fig. 1(a) when $\Omega\to 0$, one can see that the collision leads to the enhanced electronic mobility and heat conduction due to the large transverse divergency by the electron–ion collision scattering. With the increase of Ω, $\sigma_\perp$ decreases and recovers to the value $\sigma_{\perp 0}$ when $\Omega\to\infty$ due to the strong magnetic field decreasing the impact of the collision. This is not surprising because the magnetic field reduces the mobility of electrons as the Larmor radius becomes smaller than the collision mean free paths,[32,34] which results in that the mobility of an electron is limited. Similarly, since the magnetic field can suppress heat flow by decreasing the heat-carrying electronic mobility, the $\kappa_\perp$ decreases also with the increase of Ω and recovers to the value $\kappa_{\perp 0}$ of ultra-strong magnetic field when $\Omega\to\infty$, as seen in Fig. 1(b). As the reduction of $\sigma_\perp$ and $\kappa_\perp$, electronic transverse mobility and heat flow are greatly suppressed.

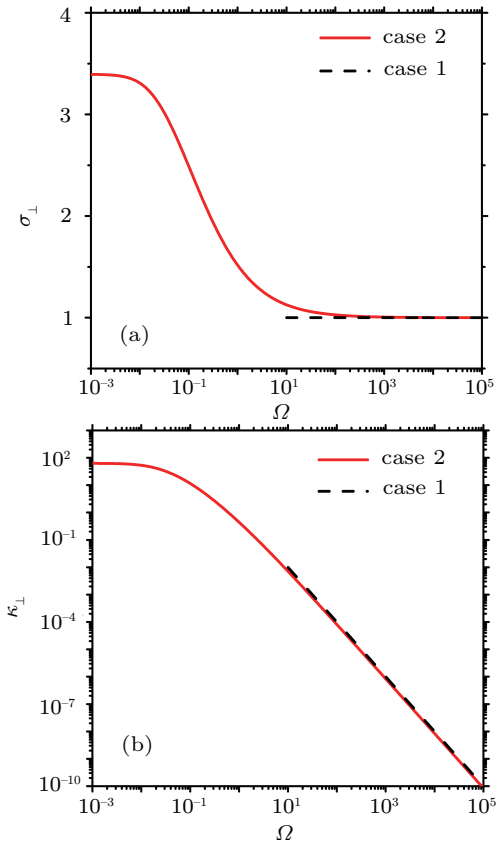


Fig. 1. (color online) Transverse electric conductivity $\sigma_\perp$ (a) and thermal conductivity $\kappa_\perp$ (b) against Ω for the case of Maxwellian distribution. The black dashed line (case 1) and red solid line (case 2) represent the condition of weak collision ($\omega_\mathrm{Be}\gg\nu_T$, see Refs. [28] and [29]) and the full condition without any limitation to the magnetic field and collision.

It is interesting to see the decreasing degree when the magnetic field increases, for example, in the typical case of ICF ($\omega_\mathrm{Be}\sim\nu_\mathrm{ei}$), compared to that without magnetic field, the $\sigma_\perp$ reduces about by 55.27%, however, $\kappa_\perp$ reduces dramatically at about by 99.21%. This means that the spontaneous magnetic field can reduce the influence of collision on the electronic transport, in particular the heat flux. This would lead to the electrons being highly collimated by the magnetic field in the transverse direction.

3.2. Results for the quasi-monoenergetic distribution function

It is worth pointing out that in many cases, for example in some regions of ICF or/and laser interacting with a solid target, the distribution of electrons may be non-Maxwellian,

therefore, the electronic transverse transport may exhibit different behavior. Now we consider a typical case of the quasi-monoenergetic distribution. For convenience as well as comparison with the previous Maxwellian case, the electrons distribution function is written as

$$f_0 = N_e \frac{1}{\varepsilon^3} \frac{1}{(2\pi)^{3/2}} \exp\left[-\frac{(\boldsymbol{v}-\boldsymbol{v}_T)^2}{2\varepsilon^2}\right], \tag{16}$$

where ε is the full width at half maximum (FWHM) or the quasi-monoenergetic degree, and $\boldsymbol{v}_T$ is the virtual "electron thermal speed" which is associated to the electrons peak energy E_m through $v_T = \sqrt{2E_m/m}$ and the corresponding virtual "temperature" $T_m = 2E_m$. Here we assume that the directional speed $\boldsymbol{v}_T$ is approximately longitudinal, i.e. $\boldsymbol{v}_T \approx (0,0,v_T)$, so that the electric field is still ignored. If the collision is not significant, i.e., when $\Omega \to \infty$, one has

$$\sigma_{\perp 0} = \frac{\sqrt{2}\phi_2^2}{3\sqrt{\pi}\bar{\varepsilon}^3\phi_{-1}} \frac{e^2 N_e}{m v_T}, \tag{17}$$

where

$$\phi_n = \int V^n (V-1)^2 \exp\left[-\frac{1}{2}\left(\frac{V-1}{\bar{\varepsilon}}\right)^2\right] \mathrm{d}V$$

and $\bar{\varepsilon} = \varepsilon/v_T$ are defined and introduced, respectively. However, when the electron–ion collision is included, the transverse electric conductivity would become

$$\sigma_\perp = \frac{\sqrt{2}(\Omega^2\varphi_8^2 + \varphi_5^2)}{3\sqrt{\pi}\bar{\varepsilon}^3\varphi_5} \frac{e^2 N_e}{m v_T}, \tag{18}$$

where

$$\varphi(\Omega)_n = \int \frac{V^n}{\Omega^2 V^6 + 1} (V-1)^2 \exp\left[-\frac{1}{2}\left(\frac{V-1}{\bar{\varepsilon}}\right)^2\right] \mathrm{d}V$$

is defined. It is ready to check that in the limit of $\Omega \to \infty$, equation (18) recovers to Eq. (17). Thus, it is convenient to get the following normalized $\sigma_\perp$ by $\sigma_{\perp 0}$ as

$$\sigma_\perp = \frac{\phi_{-1}(\Omega^2\varphi_8^2 + \varphi_5^2)}{\varphi_5\phi_2^2}. \tag{19}$$

Similarly, for the thermal conductivity we can get respectively

$$\kappa_{\perp 0} = \left(\frac{\sqrt{2}\phi_4\phi_{-1}}{4\sqrt{\pi}\bar{\varepsilon}^3\phi_2} - \frac{\sqrt{2}\phi_1}{6\sqrt{\pi}\bar{\varepsilon}^3}\right) \frac{1}{\Omega^2}, \tag{20}$$

and

$$\kappa_\perp = \frac{\sqrt{2}\varphi_{10}\varphi_5}{4\sqrt{\pi}\bar{\varepsilon}^3\varphi_8} - \frac{\sqrt{2}\varphi_7}{6\sqrt{\pi}\bar{\varepsilon}^3}, \tag{21}$$

where both $\kappa_{\perp 0}$ and $\kappa_\perp$ are normalized by $N_e T_m / m v_T$.

The $\sigma_\perp$ and $\kappa_\perp$ dependent of Ω are shown in Fig. 2 for a quasi-monoenergetic distribution with different energy spread width ε. From Fig. 2 one can see that there exist the similar effect of magnetic field on lowering the transverse transport coefficients for a certain $\bar{\varepsilon}$ as in the case of Maxwellian distribution. Moreover, it is also found that there exist some delicate discrepancies for different distributions. First the transverse transport coefficients decrease rapidly as $\bar{\varepsilon}$ decreases, which means that an electron's motion and heat flow can be suppressed greatly. Second, for the given $\bar{\varepsilon}$, as the magnetic field increases, the reduction effect of the magnetic field on the electric transport in the regime of a strong magnetic field (see the lower right curves of Fig. 2(a)), as well heat transport in the regime of a weak magnetic field (see the upper left curves of Fig. 2(b)), would become weaker and weaker. These results may be attributed to the fact that the distribution is far away from the Maxwellian distribution. It is not surprising to understand the lowering transport dependence of decreasing width. Because the narrower width would lead to the decrease of high-energy electrons, for example, in Ref. [33] it is demonstrated that the heat-flow is dominated by a small number of high energy electrons within $3v_T$–$4v_T$, which would limit the heat flow greatly. Therefore, it concludes that the smaller the ε is, the less amount the transverse transport exhibits.

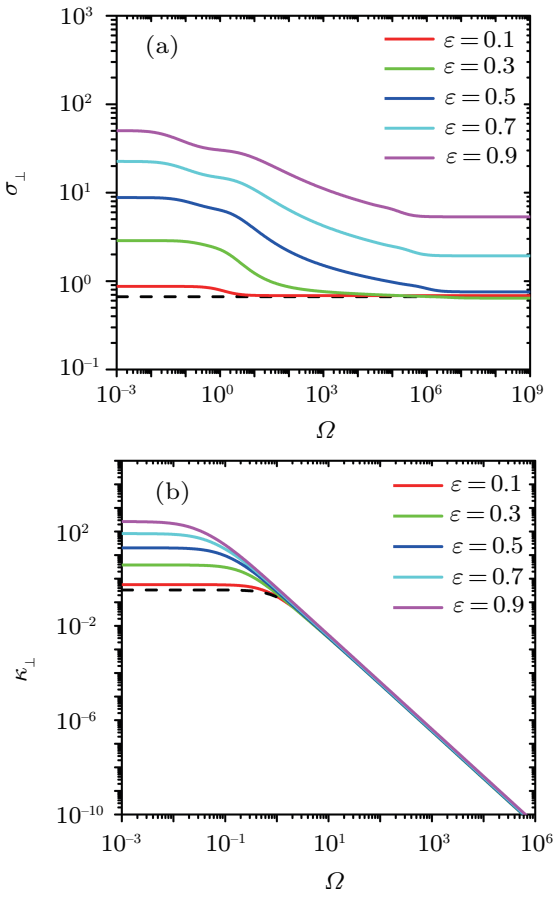


Fig. 2. (color online) Transverse electric conductivity $\sigma_\perp$ (a) and thermal conductivity $\kappa_\perp$ (b) against Ω with different width ε. The dashed line represents the condition of $\bar{\varepsilon} \to 0$.

On the other hand, it is also noted that when $\bar{\varepsilon}$ varies from 0.5–0.9, the conductivity can still be affected by Ω at 10^4–10^6. This can be explained by the relation between Larmor radius

r_b and magnetic field B:

$$r_{\rm b} = \frac{m_{\rm e}c^2}{eB}\left(\frac{E^2}{m_{\rm e}^2c^4} - 1\right)^{1/2},$$

where E is the electron energy. We can see that $r_{\rm b}$ is proportional to E while inversely proportional to B. For $\bar{\varepsilon}$ varies from 0.5–0.9, which means that there are more electrons in the higher energy region, so that a stronger magnetic field is required to collimate the transverse transport of electrons.

It is worth noting that for our special interested cases of ICF when $\omega_{\rm Be} \sim \nu_{\rm ei}$, $\sigma_\perp$ and $\kappa_\perp$ are also reduced as the $\bar{\varepsilon}$ decreases while this influence becomes weaker and weaker. A more interesting aspect is that the transport is hardly affected by the magnetic field when $\bar{\varepsilon} \to 0$ for $\sigma_\perp$ (as seen in the dashed lines in Fig. 2(a)) as well for $\kappa_\perp$ when $\Omega < 1$ (as seen in the dashed lines in Fig. 2(a)). This will be studied further in the following subsection and discussed in the final section.

3.3. Results for the Delta distribution function

In the limit of $\varepsilon \to 0$, quasi-monoenergetic distribution will recover to the Delta one with almost perfect monoenergetic electron density. Thus it is necessary to discuss this special condition in this subsection. First the distribution function is now written as

$$f_0 = N_{\rm e}\delta(\boldsymbol{v} - \boldsymbol{v}_{\rm T}). \tag{22}$$

As mentioned above, in the limit of $\Omega \to \infty$, $\sigma_\perp$ and $\kappa_\perp$ are given as

$$\sigma_{\perp 0} = \frac{1}{3}, \quad \kappa_{\perp 0} = \frac{1}{6\Omega^2}. \tag{23}$$

When electron–ion collision is included, one obtains

$$\sigma_\perp = \frac{1}{3}, \quad \kappa_\perp = \frac{1}{6(\Omega^2+1)}, \tag{24}$$

where all of the coefficients are normalized by $e^2N_{\rm e}/m\nu_{\rm T}$ and $N_{\rm e}T_m/m\nu_{\rm T}$, respectively.

In the comparison with each other in two cases (the weak collision, i.e., $\omega_{\rm Be} \gg \nu_{\rm ei}$), $\sigma_\perp$ does not change over all the parameter change region of Ω, and $\kappa_\perp$ also hardly changes at the region of $\Omega < 1$ (as seen in the left red line of Fig. 3(b)). The reason for the conductivity insensitivity to the magnetic field is due to the combinational effects of the Hall term and the thermal pressure term. And it is also seen as the result of $\boldsymbol{v}_{\rm T} \parallel \boldsymbol{B}$. Certainly if the higher order is included or there exists the perpendicular directional velocity, the conductivity would not keep constant to the magnetic field. In particular, for example in our interested case of ICF where $\omega_{\rm Be} \sim \nu_{\rm ei}$, the $\kappa_\perp$ is reduced about one half. On the other hand the region hardly affected on the transverse transport $\kappa_\perp$ is now only limited to the parameter changed region of $\Omega < 1$. When $\Omega > 1$, the $\kappa_\perp$ is dramatically reduced similar to the case of weak collision ($\omega_{\rm Be} \gg \nu_{\rm ei}$),[28] due to the $\kappa_\perp$ being always proportional to $1/\Omega^2$ or $1/(\Omega+1)^2$.

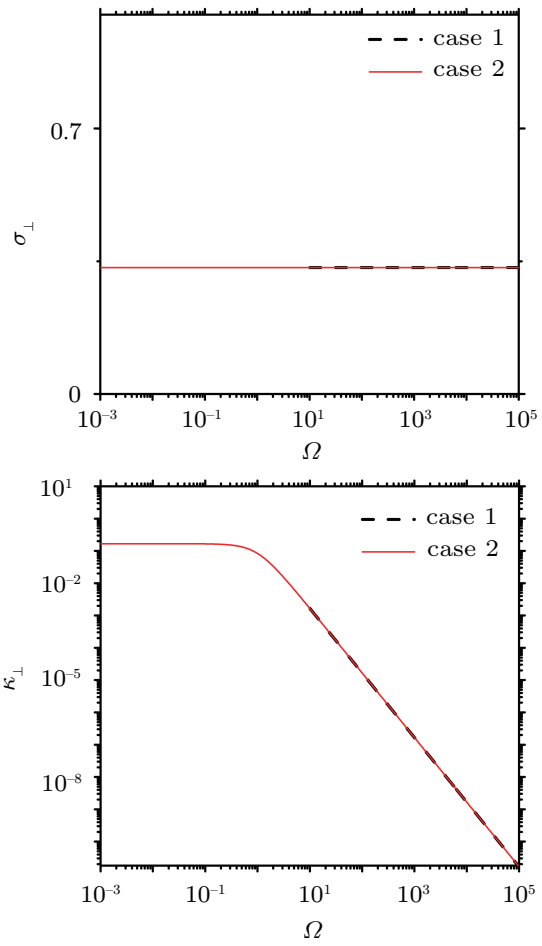


Fig. 3. (color online) Same as in Fig. 1 except for the case of Delta distribution.

4. Summary and discussion

In summary, we have investigated the electronic transverse transport with the collision effect in the presence of a magnetic field for different electrons density distributions. According to our analyses, the transverse transport is not only affected by magnetic field and collision, but also modified by distribution functions.

First, for the Maxwellian one, when $\Omega < 1$, the transverse transport is dominated by a collision effect. But with the competition of magnetic field and collision, $\sigma_\perp$ and $\kappa_\perp$ are obviously reduced due to the Larmor radius becoming smaller than the collision mean free paths and magnetic field effect will be dominant at $\Omega > 1$. Therefore, the magnetic field leads to great suppression of the electronic mobility and heat flux.

Second when the distribution function is far away from the Maxwellian, the transport is different from the classical transport theory. In this case, the transverse transport coefficients are significantly modified by a magnetic field as well as the distribution. On the one hand, similar to the Maxwellian one, all of the transverse transport coefficients decrease with the increase of Ω. On the other hand, the electronic mobility and heat flow are suppressed greatly as $\bar{\varepsilon}$ decreases. As a

result, the smaller the ε is, the less amount the transverse transport exhibits. On the other hand, however, with the decrease of $\bar{\varepsilon}$, the magnetic field and collision balances with each other in the region of $\Omega < 1$ so that $\sigma_\perp$ and $\kappa_\perp$ change weaker and weaker. Until to the region of $\Omega > 1$, in which $\kappa_\perp$ is rapidly reduced due to the fact that the magnetic field effect is dominated over the collision effect, which destroys the weak balance.

Finally, in the limit of $\varepsilon \to 0$, the distribution will tend to be the Delta function with almost perfect monoenergetic density distribution. Under this circumstance, the thermal pressure of affecting $\sigma_\perp$ and the Hall effect of affecting $\sigma_\perp$ are canceled with each other, which causes a perfect balance so that the $\sigma_\perp$ keeps a constant for the whole region of Ω. But this behavior is approximately valid to $\kappa_\perp$ only when $\Omega < 1$ and again the magnetic field effect is dominated over the collision effect when $\Omega > 1$ in which the $\kappa_\perp$ decrease rapidly.

In a word, the results studied in this paper indicate that the magnetic field and proper quasi-monoenergetic distribution can effectively reduce the transverse transport and suppress the transverse divergence of electrons. It would be helpful to understand the transport problem of Lorenz plasma as well the fast electrons transport in ICF background. Besides, we consider the first-order approximation in the process of calculation. High-order small quantities may also slightly affect the results, which we will investigate in the future.

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