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The influence of strong magnetic field on the plasma transport*

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In many celestial and terrestrial environments, the particles' gyro-radii are smaller than the Debye length. For example, in tokamak, the ratio of the thermal gyro-radius to the Debye length for electron could be much smaller than one for the plasma. The magnetic field affects the collision dynamics and associated transport phenomena such as velocity slowing down, temperature relaxation, diffusion, thermal transport etc. It was found that the cross field heat transport can occur even without mass transport when the magnetic field is very strong. [1]

The Fokker-Planck equation in the presence of a uniform magnetic field is derived through the transform method as follows:

$$\frac{\partial f_\alpha(\mathbf{v}_\alpha,\tau)}{\partial \tau} + \Omega_\alpha \mathbf{v}_\alpha \times \hat{\mathbf{e}}_z \cdot \frac{\partial f_\alpha(\mathbf{v}_\alpha,\tau)}{\partial \mathbf{v}_\alpha} = -\frac{\partial}{\partial \mathbf{v}_\alpha}\cdot\left[\langle \Delta \mathbf{V}_\alpha\rangle f_\alpha(\mathbf{v}_\alpha,\tau)\right] + \frac{1}{2}\frac{\partial^2}{\partial \mathbf{v}_\alpha \partial \mathbf{v}_\alpha} : \left[\langle \Delta \mathbf{V}_\alpha \Delta \mathbf{V}_\alpha\rangle f_\alpha(\mathbf{v}_\alpha,\tau)\right],$$

where the Fokker-Planck coefficients $\langle \Delta \mathbf{V}_\alpha\rangle$ and $\langle \Delta \mathbf{V}_\alpha \Delta \mathbf{V}_\alpha\rangle$ are calculated based within the binary collision model and the full magnetized Landau equation is obtained:

$$\frac{\partial f_\alpha(\mathbf{v}_\alpha,\tau)}{\partial \tau} + \Omega_\alpha \mathbf{v}_\alpha \times \hat{\mathbf{e}}_z \cdot \frac{\partial f_\alpha(\mathbf{v}_\alpha,\tau)}{\partial \mathbf{v}_\alpha} = \frac{\partial}{\partial \mathbf{v}_\alpha}\cdot \sum_\beta (2\pi)^3 \frac{q_\alpha^2 q_\beta^2}{m_\alpha}\int_0^\infty \mathrm{d}t \int \mathrm{d}^3\mathbf{k}\int \mathrm{d}^3\mathbf{v}_\beta\, \widetilde{\Phi}_D^2(k) \times \exp\{\mathrm{i}\mathbf{k}\cdot[\mathsf{H}_\alpha(t)-\mathsf{H}_\alpha(0)]\cdot\mathbf{v}_\alpha - \mathrm{i}\mathbf{k}\cdot[\mathsf{H}_\beta(t)-\mathsf{H}_\beta(0)]\cdot\mathbf{v}_\beta\} \times \mathsf{T}_\alpha^{-1}(t)\cdot\mathbf{kk}\cdot\left(\frac{1}{m_\alpha}\frac{\partial}{\partial \mathbf{v}_\alpha} - \frac{1}{m_\beta}\frac{\partial}{\partial \mathbf{v}_\beta}\right)[f_\alpha(\mathbf{v}_\alpha,\tau)\, f_\beta(\mathbf{v}_\beta,\tau)].$$

The above kinetic equation is shown to be identical to the result obtained from the BBGKY approach when the collective effects are neglected and satisfy the conservation of particles, momentum, and energy. [2]

The strong magnetic field may greatly affect the transport essential processes in the plasma. It is shown that the electron-electron and ion-ion temperature relaxation rates first increase and then decrease as the magnetic field grows, and the doubly logarithmic term contained in the electron-ion temperature relaxation rate. [3] It is found that when the electron thermal gyro-radius is smaller than the Debye length, Debye length is replaced by the electron thermal gyro-radius in the Coulomb logarithm in the electron anisotropic temperature relaxation rate due to electron-electron collisions and electron-ion collisions. The electron-ion temperature relaxation rate contains a doubly logarithmic term arising from the exchange between the electron parallel and the ion perpendicular kinetic energies: [4]

$$\ln\Lambda_B \approx \ln\Lambda + \frac{1}{2}\ln\left(\frac{m_i T_e}{m_e T_i}\right)\ln\left(\frac{\lambda_{De}}{R_{the}}\right), \quad for \quad R_{the} < \lambda_{De} < R_{thi}.$$

For $n_e = 10^{19} m^{-3}$, $B = 3.5\mathrm{T}$, $m_i/m_e = 3672$, $T_e = 2T_i$, and $\ln\Lambda = 15$, we have

$$\ln\Lambda_B/\ln\Lambda = 1.37.$$

The other transport processes such as the velocity slowing down, diffusion, thermal conductivity and so on are being studied.

References

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