

Physics 235

→ Notes 3: Transport Channels, Particle
Transport, Ambipolarity

Channels } heat particles
 momentum $\rightarrow e_0 c$
 - Particles } why speak of heat transport?
 test particle diffusivity calculated
 why not particle transport?

Note: The 'point' of stochastic fields is
 $\chi_{\perp} \sim v_{the} \Theta_M$
 \hookrightarrow electron speed.

Useful to:

- \rightarrow consider kinetic eqn.
- \rightarrow distinguish between:
 - a) self-consistent case
 \tilde{B} produced by \tilde{J}_{\perp} in plasma
 (i.e. EM instabilities - Ampere's Law)
 - b) \tilde{B} produced by external means (coil) - i.e. RMP, though plasma response (i.e. screening) significant

Nav

$$\frac{\partial f}{\partial t} + v_{||} \nabla_{||} f + v_{||} \frac{d\tilde{B}}{B_0} \cdot \nabla_{\perp} f + \dots = 0$$

then integrating;

$$\frac{\partial \langle \rho_e \rangle}{\partial t} + \nabla_{\perp} \cdot \left\langle \frac{d \rho_e}{B_0} \frac{\tilde{J}_{\perp e}}{(-\text{noel})} \right\rangle + \dots = 0$$

but

$$\begin{aligned} \nabla_{\perp}^2 A_{\perp} &= -\frac{4\pi}{c} \tilde{J}_{\perp} \\ &= -\frac{4\pi}{c} (\tilde{J}_{\perp e} + \tilde{J}_{\perp i}) \end{aligned}$$

$$\tilde{J}_{\perp e} = \frac{-c}{4\pi} \nabla_{\perp}^2 A - \tilde{J}_{\perp i}$$

$$= \frac{-c}{4\pi} \nabla_{\perp}^2 A_{\perp} - \text{noel } \tilde{V}_{\perp i}$$

↓
den flow
=

so/

$$\frac{\partial \langle \rho_e \rangle}{\partial t} + \nabla_{\perp} \cdot \left\langle \frac{d \rho_e}{B_0} \left(\frac{-c}{4\pi} \nabla_{\perp}^2 \hat{A}_{\perp} - \text{noel } \hat{V}_{\perp i} \right) \right\rangle + \dots = 0$$

$$d \rho_e = \nabla_{\perp} \cdot \hat{A}_{\perp}$$

⇒

$$\frac{\partial \langle Ne \rangle}{\partial t} + \frac{\partial}{\partial r} \left\langle \nabla_0 A_{11} \left(-\frac{e}{4\pi} \nabla_1^2 \hat{A}_{11} - n_{odd} v_{11} \right) \right\rangle = 0$$

⊗

$$\frac{\partial \langle Ne \rangle}{\partial t} = \frac{e}{4\pi} \frac{\partial}{\partial r} \left\langle \overset{\textcircled{1}}{(\nabla_0 \hat{A}_{11}) (\nabla_1^2 \hat{A}_{11})} \right\rangle + n_{odd} \left\langle \overset{\textcircled{2}}{\partial_r B_n v_{11}} \right\rangle$$

①: Taylor identity calculation

$$\left\langle (\nabla_0 \hat{A}_{11}) (\partial_r^2 \hat{A}_{11} + \nabla_0^2 \hat{A}_{11}) \right\rangle \quad \begin{matrix} \text{(akin} \\ \langle v_r v_{\theta}^2 \rangle) \end{matrix}$$

~~odd~~

$$= \left\langle (\nabla_0 \hat{A}_{11}) (\partial_r^2 \hat{A}_{11}) \right\rangle$$

$$= \left\langle \partial_r (\nabla_0 \hat{A}_{11}) (\partial_r \hat{A}_{11}) \right\rangle - \left\langle \nabla_0 (\partial_r \hat{A}_{11}) (\partial_r \hat{A}_{11}) \right\rangle$$

~~odd~~

$$= \partial_r \left\langle (\nabla_0 \hat{A}_{11}) (\partial_r \hat{A}_{11}) \right\rangle$$

$$= -\partial_r \left\langle (d' B_n) (d' B_n) \right\rangle$$

[Magnetic stress.]

$$\frac{d\langle n_e \rangle}{dt} = -\frac{c}{4\pi} \frac{dn}{dt} \langle (\delta B_n)(\delta B_\parallel) \rangle$$

↳ magnetic stress

$$+ n_0 k_B \langle \delta B_n \hat{v}_{\parallel i} \rangle$$

↳ "magnetic flutter" of parallel ion flow. ==

Points:

— no explicit dependence on small electron inertia; i.e. $1/m_e$

— relation of magnetic stress to electron particle transport due to stochastic fields

i.e. suggests effect on zonal flows as zonal flows are fundamentally charge transport effect.

— fluctuating parallel ion flows + magnetic tilt \Rightarrow change electron density. (see Chernukov).

N.B. For external field, key is to calculate

$$\begin{aligned}
 & - \delta B_r \text{ in } A / \text{cm} \\
 & - \tilde{V}_{||0} \text{ in } \text{Alarma.}
 \end{aligned}
 \right.
 \delta B_r \text{ in } \sim \frac{\delta B_{\text{ext}}}{G}$$

→ Re: zonal flows:

Points: Magnetic wandering impacts zonal flows via charge

Recall: - Fluctuations → DW model
i.e. H-M jets

- zonal mode: charge separation, radially - ambipolarity breaking

$\nabla \cdot \underline{J} = 0$

usual e.s; $\nabla_r \underline{J}_r \text{ pol} = 0$

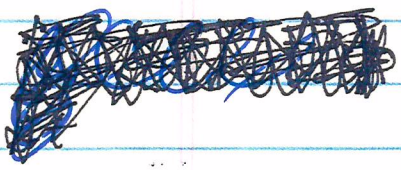
⇒

$$\frac{\partial}{\partial t} \nabla_{\perp}^2 \phi + \underline{V} \cdot \underline{\nabla} \nabla_{\perp}^2 \phi = 0$$

linear pol. drift

NL pol. drift

∂_t , für $\langle \rangle \rightarrow$ zonal symmetry



$$\left[\int_{\text{over } \Omega} - \int_{\text{electron } \Omega} \right]$$

$$\frac{\partial}{\partial t} \langle \nabla_r^2 \phi \rangle + \partial_r \langle \tilde{v}_r \nabla_r^2 \tilde{\phi} \rangle + \dots = 0$$

↓
polarization charge $\langle \rho_{pol} \rangle$

↓
- Flux of polarization charge
(i.e. net difference ions electrons)

- relate to Reynolds stress by Taylor identity

- compute via modulation

∂_t , can view:

$$\frac{\partial}{\partial t} \langle \rho_{pol} \rangle + \partial_r \langle \tilde{v}_r \rho_{pol} \rangle = 0$$

↓

$$\Gamma_{\text{charge}} = \left(\langle \tilde{v}_r \tilde{n}_{i0} \rangle + \langle \tilde{v}_r \tilde{\rho}_{pol} \rangle \right) |_{el}$$

$$- \left(\langle \tilde{v}_r \tilde{n}_{e0} \rangle \right) |_{(el)}$$

$$\hat{n}_c = \hat{n}_e \Rightarrow \nabla \cdot \mathbf{J}_{charge} = 0 \quad \checkmark$$

\downarrow
 $n_{i,ac} + n_{i,ad}$

But magnetic perturbation ~~induces~~ induce new meso charge transport

$$\nabla \cdot \mathbf{J} = 0$$

$$\nabla_{\perp} \cdot \mathbf{J}_{\perp} + \nabla_{||} \mathbf{J}_{||} = 0$$

$$\nabla_{||} = \nabla_{||}^{(0)} + \frac{d\mathbf{B}}{B_0} \cdot \nabla_{\perp}$$

$\frac{\partial \langle \nabla^2 \phi \rangle}{\partial t} + \langle \nabla \cdot \nabla \nabla^2 \phi \rangle = \langle \mathbf{B} \cdot \nabla \mathbf{J}_{||} \rangle$

(n.b. current: electrons = ions)

\downarrow
 ion pol. charge transport \Rightarrow advection

\uparrow
 current flow along tilted lines

Observed from 2D MHD

50

$$\Delta_{+} \langle \sigma^2 \rangle = -dr \left\{ \langle \tilde{v}_r \tilde{v}_\perp \rangle - \langle \tilde{R}_r \tilde{v}_\perp \rangle \right\}$$

so ~~current~~ current flow along tilted lines acts to affect charge balance.

⇒ enters effect in Z.F.

Notes:

- sign not clear a priori

- for ω Alfvénic fluctuations \Rightarrow damps
i.e. acts cool eq.

← obviously related to electron particle transport.

Others

→ electron momentum transport

→ "electron viscosity" / "hyper-resistivity"

i.e.

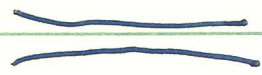
$$E_{||} = n T_{||} - \nabla_{\perp} \cdot \mu \cdot \nabla_{\perp} T_{||}$$

$$\downarrow \left(\frac{\rho}{\sigma} \right)$$

$$\frac{c^2}{4\pi\sigma} \nu_{\perp} \Delta_{\perp}$$

→ Reconnection rate

i.e. Sweet - Parker:



$$V \sim \cancel{\nu_{\perp}} \quad \nu_A \frac{A}{L}$$

$$\sim 1/S^{1/2} \nu_A$$

$$= \nu_A / \sqrt{R_m}$$

Electron viscosity:

$$V \sim \nu_A / (R_m \mu)^{1/4}$$

→ Physics of Hyper-resistivity is essential to ELM crash.

→ One take: Drake '95

ITG: PSFI :: ITG: DJ-drives

$\mu = \mu(VJ) \rightarrow$ nonlinearity ↓

⇒ good topic for further research.