NEVF169 08 25.3.2021

dosud: $v_2 = 0$; $v_1 = g$

INTERAKCE TERMÁLNÍCH ČÁSTIC

maxwellovské rozdělení s driftem

e - i srážky

pohyb iontů zanedbatelný

driftová rychlost elektronů $\vec{v}_d$

$$f_e(\vec{v}) = n_e \left(\frac{m_e}{2\pi k_B T_e}\right)^{3/2} \exp\left(-\frac{m(\vec{v}-\vec{v}_d)^2}{2 k_B T_e}\right)$$

$$\frac{d\vec{p}}{dt} = -\int f_e(\vec{v})\, \underbrace{\nu_p(\vec{v})\, m_e \vec{v}}\, d\vec{v} \qquad \vec{p} = m_e \vec{v}_e n_e$$

připomenutí

$$\nu_p = n_i \frac{q_e^2 q_i^2}{(4\pi\varepsilon_0)^2} \frac{4\pi(m_e+m_i)}{m_i m_e^2 v^3} \ln\Lambda_c$$

$$\nu_p \sim \frac{1}{v^3}$$

zjednodušení: 1) $\ln\Lambda_c = \mathrm{const}(\vec{v}) = \ln \frac{\lambda_D}{b_{90}(v_{TH})}$

$$v_{TH} = \sqrt{k_B T_e / m_e}$$

2) nechť $v_d \ll v_{TH}$

definujeme

$$\vec{u} = \frac{\vec{v}}{v_{TH}} \ ; \quad \vec{u}_d = \frac{\vec{v}_d}{v_{TH}} \ ; \quad u_d \ll 1$$

$$f_e = n_e \frac{1}{(2\pi)^{3/2} v_{TH}^3} \exp\left(-\frac{1}{2}(\vec{u}-\vec{u}_d)^2\right) =$$

$$= n_e \frac{1}{(2\pi)^{3/2} v_{TH}^3} \exp\left(-\frac{1}{2}(u^2 - 2\vec{u}\cdot\vec{u}_d + u_d^2)\right)$$

$u_d^2 \sim 0$; rozvoj 1. řádu v $\vec{u}_d$

$$\cong \underbrace{n_e \frac{1}{(2\pi)^{3/2} v_{TH}^3} \exp\left(-\frac{1}{2}u^2\right)}_{f_0} \exp(\vec{u}\cdot\vec{u}_d) =$$

$$\cong f_0(1 + \vec{u}\cdot\vec{u}_d) \qquad | \text{ nechť } \vec{u}_d \parallel \hat{x}$$

$$= f_0(1 + u_x u_d)$$

$$\frac{dp_x}{dt} = -\int f_e \nu_p m_e v_x \, d\vec{v} =$$

$$= -\nu_p(v_{TH}) m_e \int f_0 (1 + u_x u_d) \frac{v_{TH}^3}{v^3} v_x \, d\vec{v} \qquad \frac{v_{TH}^3}{v^3} = 1/u^3$$

$$\sim \int \underbrace{f(u)\cdot v_x}_{\text{lichá}} d\vec{v} = 0$$

$$= -\nu_p(v_{TH}) m_e \int f_0 u_x \frac{v_d}{v_{TH}} \cdot \frac{1}{u^3} v_x \, d\vec{v} = \qquad \frac{v_x}{v_{TH}} \sim u_x$$

$$= -\nu_p(v_{TH}) m_e v_d \underbrace{\int f_0 \frac{u_x^2}{u^3} d\vec{v}}_{?}$$

$$\int \frac{u_x^2}{u^3} f_0 \, d\vec{v} = \left| \text{ze symetrie} \right| = \frac{1}{3} \int \frac{u_x^2 + u_y^2 + u_z^2}{u^3} f_0 \, d\vec{v}$$

$$= \frac{1}{3} \int \frac{1}{u} f_0 \, d\vec{v} = \frac{1}{3} \int \frac{v_{TH}}{v} f_0 \, d\vec{v} =$$

$$= \frac{1}{3} v_{TH} \int_0^\infty \frac{1}{v} f_0 \, 4\pi v^2 \, dv =$$

$$= \frac{4\pi}{3} \cancel{v_{TH}} \int_0^\infty \frac{1}{\cancel{v}} \frac{n_e}{(2\pi)^{3/2} v_{TH}^{\cancel{3}2}} \exp\left(-\frac{v^2}{2v_{TH}^2}\right) v^{\cancel{2}} dv$$

$$= \frac{4\pi}{3} \frac{n_e}{(2\pi)^{3/2} v_{TH}^2} \int_0^\infty \exp\left(-\frac{v^2}{2v_{TH}^2}\right) v \, dv$$

$$\left| X = \frac{v^2}{2v_{TH}^2} \ ; \ dX = \frac{\cancel{2} v}{\cancel{2} v_{TH}^2} dv \to v\,dv = v_{TH}^2 dX \right.$$

$$= \frac{4\pi}{3} \frac{n_e}{(2\pi)^{3/2} \cancel{v_{TH}^2}} \int_0^\infty \exp(-X) \cancel{v_{TH}^2} \, dX =$$

$$= \frac{2}{3} \frac{n_e}{\sqrt{2\pi}} \underbrace{\left[-\exp(-X)\right]_0^\infty}_{1}$$

$$\int \frac{u_x^2}{u^3} f_0 \, d\vec{v} = \frac{2}{3} \frac{n_e}{\sqrt{2\pi}}$$

$$\overline{\nu_{ei}} = -\frac{1}{p}\frac{dp}{dt} = -\frac{1}{\cancel{p}} \nu_p(v_{TH}) \cancel{m_e v_d} \frac{2}{3} \frac{\cancel{n_e}}{\sqrt{2\pi}} \qquad p = m_e v_d \cdot n_e$$

$$= \overline{\nu_p}(v_{TH}) \cdot \frac{2}{3} \frac{1}{\sqrt{2\pi}}$$

$$= \frac{2}{3\sqrt{2\pi}} n_i \frac{q_e^2 q_i^2}{(4\pi\varepsilon_0)^2} \cdot \frac{4\pi(m_e+m_i)}{m_i m_e^2 v_{TH}^3} \ln\Lambda_c \qquad \frac{m_e+m_i}{m_i} \sim 1 \ ; \ v_{TH}^3 \sim (k_B T_e/m_e)^{3/2}$$

$$\underline{= \frac{2}{3\sqrt{2\pi}} n_i \left(\frac{Z q_0^2}{4\pi\varepsilon_0}\right)^2 \frac{4\pi}{m_e^{1/2} (k_B T_e)^{3/2}} \ln\Lambda_c}$$

i - e srážky

ze symetrie

$$p_e \overline{\nu_{ei}} = p_i \overline{\nu_{ie}}$$

$$\overline{\nu_{ie}} = \frac{p_e}{p_i} \overline{\nu_{ei}} = \frac{n_e m_e \cancel{v_d}}{n_i m_i \cancel{v_d}} \overline{\nu_{ei}}$$