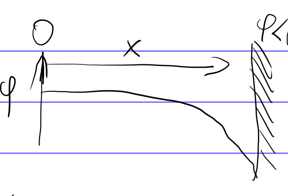
NEVF 169 25.5.2021



STĚNOVÁ VRSTVA

$$\frac{d^2\overset{\sim\varphi}{\chi}}{d\xi^2} = \left(1 + \frac{2\chi}{M^2}\right)^{-1/2} - e^{-\chi} \qquad \Big/ \cdot \frac{d\chi}{d\xi}$$

$$\underbrace{\frac{d^2\chi}{d\xi^2}\frac{d\chi}{d\xi}} = \left(1+\frac{2\chi}{M^2}\right)^{-1/2}\frac{d\chi}{d\xi} - e^{-\chi}\frac{d\chi}{d\xi}$$

$$\frac{1}{2}\frac{d}{d\xi}\left[\left(\frac{d\chi}{d\xi}\right)^2\right] = \frac{d}{d\xi}\left(1+\frac{2\chi}{M^2}\right)^{1/2} M^2 + \frac{d}{d\xi}\left(e^{-\chi}\right) \qquad \Big/ \int_0^{\xi} d\xi'$$

$$\frac{1}{2}\left(\left(\frac{d\chi}{d\xi}\right)^2 - \underbrace{\left(\frac{d\chi}{d\xi}\right)_0^2}_{0}\right) = \underbrace{M^2\left(\left(1+\frac{2\chi}{M^2}\right)^{1/2} - 1\right) + e^{-\chi} - 1} \qquad / \chi(0) = 0$$

~E v plazmatu ≪ E ve stínicí vrstvě

musí být ≥ 0 aby ∃ řešení

pro $\chi \ll 1$ (rozhraní s plazmatem)

$$M^2\left(\cancel{1} + \frac{1}{2}\frac{2\chi}{M^2} - \frac{1}{8}\frac{4\chi^2}{M^4} + \dots - \cancel{1}\right) + \cancel{1} - \chi + \frac{\chi^2}{2} - \dots - \cancel{1}$$

$$\cancel{\chi} - \frac{\chi^2}{2M^2} \qquad \cancel{-\chi}\ \frac{\chi^2}{2} \geq 0$$

$$\frac{\chi^2}{2}\underbrace{\left(-\frac{1}{M^2} + 1\right)}_{\geq 0} \geq 0$$

$$M^2 \geq 1 \Rightarrow u_0 \geq \sqrt{\frac{KT_e}{m_i}}$$

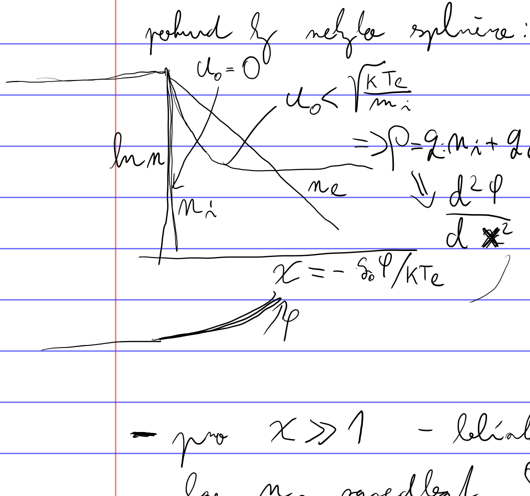
$$\frac{1}{2}m_i u_0^2 \geq \frac{1}{2}KT_e$$

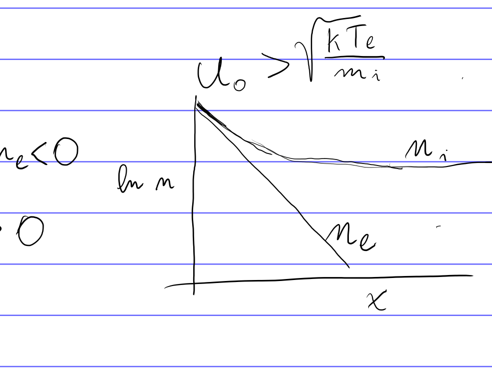
Bohmovo kritérium stěnové vrstvy

(SHEATH)

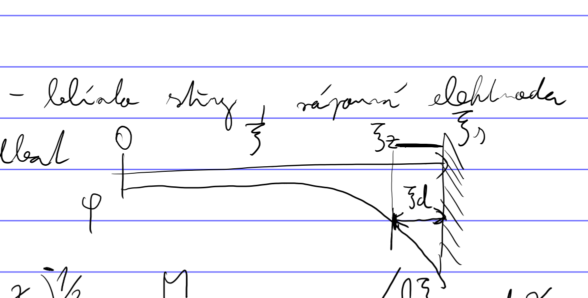
– musí existovat "presheath"

pokud by nebylo splněno:





– pro $\chi \gg 1$ – blízko stěny, zápornou elektrodu lze n_e zanedbat



$$\frac{d^2\chi}{d\xi^2} \simeq \Big(1 + \underbrace{\frac{2\chi}{M^2}}_{\gg 1}\Big)^{-1/2} \simeq \frac{M}{\sqrt{2\chi}} \qquad \Big/ \int_{\xi_z}^{\xi} - \frac{d\chi}{d\xi}\, d\xi$$

$$\frac{1}{2}\left(\left(\frac{d\chi}{d\xi}\right)^2 - \left(\frac{d\chi}{d\xi}\right)_z^2\right) = \sqrt{2}M\left(\sqrt{\chi} - \sqrt{\chi_z}\right)$$

nechť $\chi(\xi_z) = \chi_z \equiv 0$

nechť $\left(\frac{d\chi}{d\xi}\right)_z^2 \ll \left(\frac{d\chi}{d\xi}\right)^2$ (absence elektronů)

$\Downarrow$

$$\frac{d\chi}{d\xi} = 2^{3/4}\cdot\sqrt{M}\,\chi^{1/4}$$

$$\frac{d\chi}{\chi^{1/4}} = 2^{3/4}\sqrt{M}\,d\xi \qquad \int_{\xi_z}^{\xi_z + \xi_d = \xi_s}$$

$$\frac{4}{3}\chi_s^{3/4} = 2^{3/4}\sqrt{M}\,\xi_d$$

$$M = \left(\frac{4}{2^{3/4}}\right)^2 \cdot \frac{1}{9}\frac{\chi_s^{3/2}}{\xi_d^2}$$

$$\downarrow \frac{u_0}{\sqrt{KT_e/m_i}} = \frac{4\sqrt{2}}{9}\left(\frac{q|\varphi_s|}{KT_e}\right)^{3/2}\left(\frac{\lambda_D}{d}\right)^2 \qquad \lambda_D = \sqrt{\frac{\varepsilon_0 KT_e}{q^2 n_0}}$$

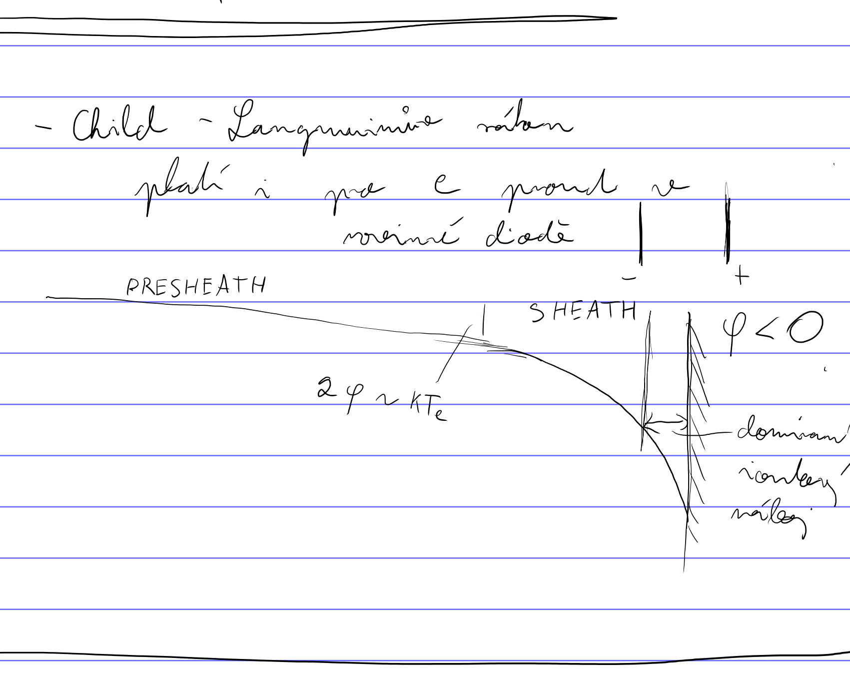
$$u_0 = \sqrt{\frac{\cancel{KT_e}}{\cancel{m_i}}}\cdot\frac{4\sqrt{2}}{9}\left(\frac{\cancel{q}|\varphi_s|}{\cancel{KT_e}}\right)^{3/2}\frac{1}{d^2}\frac{\varepsilon_0 \cancel{KT_e}}{\sqrt{q^2}\, n_0}$$

$$J = ? = q n_0 u_0$$

$$\underline{\underline{J = q n_0 u_0 = \frac{4}{9}\frac{\sqrt{2}\sqrt{q}}{\sqrt{m_i}}\frac{\varepsilon_0|\varphi_s|^{3/2}}{d^2}}} \sim |\varphi_s|^{3/2}$$

– Child-Langmuirův zákon

platí i pro e proud ve vakuové diodě



TEKUTINOVÝ POPIS

– tekutina – prostorové rozdělení parametrů

odvození – momenty BKR

0. moment $\int (BKR)\,d\vec{v}$

$$\frac{\partial n_s}{\partial t} + \nabla\cdot(n_s\vec{u}_s) = 0 + \underbrace{I - R}$$ — Eulerovský

el. / neresonanční srážky

vznik a zánik ve reakcích

chemická kinetika

$$\vec{u}_s = \langle\vec{v}_s\rangle = \int \vec{v}_s f_s\, d\vec{v}_s$$

unášivá rychlost

driftová

$$\underbrace{\frac{\partial n_s}{\partial t} + \vec{u}_s\cdot\nabla n_s} + n_s\nabla\cdot\vec{u}_s = 0$$

$$\frac{Dn_s}{Dt} = -n_s\underbrace{\nabla\cdot\vec{u}_s}$$ – Lagrangeovský

expanze objemového elementu

– máme 1 skal. rovnici pro n_s, ale neznáme $\vec{u}_s$

↓ vypočteme 1. moment pro hybnost

$$\int m\vec{v}\,(BKR)\,d\vec{v}$$

$$m_s n_s\left(\frac{\partial\vec{u}_s}{dt} + (\vec{u}_s\cdot\nabla)\vec{u}_s\right) = n_s q_s\left(\vec{E} + \vec{u}_s\times\vec{B}\right) -$$

$$-\nabla p_s - \nu_{ss'} n_s m_s\left(\vec{u}_s - \vec{u}_{s'}\right)$$

izotropní tlak

obecně: $\vec{w}_s = \vec{v}_s - \vec{u}_s$

(chaotický, termální pohyb, $\langle\vec{w}_s\rangle = 0$)

$\overleftrightarrow{P}_s = \langle m\vec{w}_s\vec{w}_s\rangle$; $\nabla\cdot\overleftrightarrow{P}$

izotropní $p_s = \frac{1}{3}\langle m w_s^2\rangle \Big|^{\text{pro MXW}}_{\text{rozděl.:}}\Big| = n_s KT_s$

– chybí rovnice pro p_s, $\overleftrightarrow{P}_s$

↳ 2. moment: $\int \frac{1}{2}m v^2\,(BKR)\,d\vec{v}$

nebo $\int m\vec{v}\vec{v}\,(BKR)\,d\vec{v}$ (anizotropní plazma)

– bude chybět rovnice pro tepelný tok Q

⇒ soustavu je potřeba ukončit

– např. použití stavové rovnice pro p:

$$\underline{p\, n^{-\gamma} = \text{const}}$$

speciálně

– izotermický: $T = \text{const}$, $\gamma = 1$ ($p = nKT$)

– adiabatický: l stup. volnosti: $\gamma = 1 + 2/l$

– 1 stup. (mag. pole) $\gamma = 3$

– 3 stup. (izotropní) $\gamma = 5/3$

+ MXW rovnice

$$\rho = q_e n_e + q_i n_i$$

$$\vec{j} = q_e n_e\vec{u}_e + q_i n_i\vec{u}_i$$

$$\nabla\cdot B = 0 \qquad \nabla\cdot E = \frac{\rho}{\varepsilon_0}$$

$$\nabla\times B = \mu_0\vec{j} + \frac{1}{c^2}\frac{\partial E}{\partial t} \qquad \nabla\times E = -\frac{\partial B}{\partial t}$$

e-i plazma: 16 neznámých   16 nezávislých