NEVF169 2.3.2021

ZÁKLADNÍ VL. PLAZMATU

- (částečně) IONIZOVANÝ PLYN

n_i ... koncentrace iontů m^{-3} cm^{-3}

n_e ... elektronů

n_g neutrálů

$n_i, n_e \ll n_g$ slabě ioniz.

$n_i, n_e > n_g$ silně ioniz.

- ionizační potenciál (IP) $\sim eV$

$$\langle E \rangle = \frac{3}{2} k_B T \qquad \langle E \rangle \gtrsim 1 eV = 1 \frac{q_e}{C} J = 1{,}6 \cdot 10^{-19} J$$

$$\frac{3}{2} k_B T \gtrsim 1 eV = 1 \frac{q}{C} J$$

$$T \gtrsim \frac{q}{k_B} \frac{2}{3} \frac{J}{C} = \frac{2}{3} \frac{16 \cdot 10^{-19} C}{1{,}38 \cdot 10^{-23} J/K} \frac{J}{C} = 7700 K$$

$T \gtrsim 10^3$ .... Sahova rovnice .. později

Pozn.: teplotu udávat v eV

$$T_{eV}\, q \frac{J}{C} \equiv k_B T \to T = T_{eV} \frac{q}{k_B} \frac{J}{C} \simeq T_{eV} \cdot 11600 K$$

Pozn: $T_i \neq T_e \neq T_g$; $T_{KIN}\ (T_t)$
T_{rot}
T_{vib}

KVAZINEUTRALITA

(až na výjimky) $n_i \simeq n_e$

fluktuace $\varphi \sim KT/e$

– KOLEKTIVNÍ CHOVÁNÍ

– dalekodosahová elstat. interakce × plyn – srážky

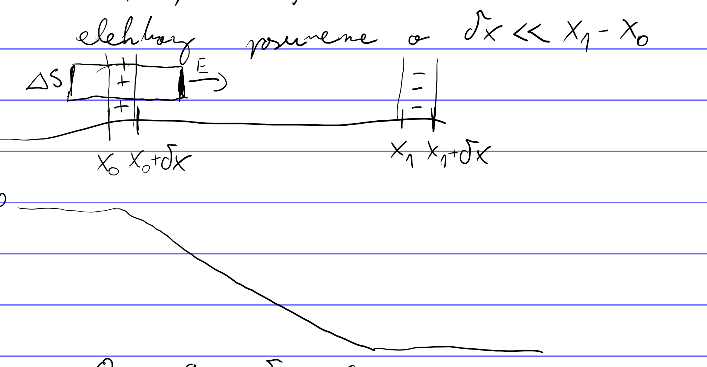
PLAZMOVÁ FREKVENCE

– doba odezvy

Příklad: $n_e = n_i = n$

$x = (x_0, x_1)$ – nábojová vrstva

elektrony posunuté o $\delta x \ll x_1 - x_0$



$$E \Delta S = Q/\varepsilon_0 = q_0 n\, \delta x\, \Delta S / \varepsilon_0$$

$$E = q_0 n\, \delta x / \varepsilon_0$$ pohyb. rce

$$m \frac{d^2 \delta x}{dt^2} = -q_0 E$$

$$\frac{d^2 \delta x}{dt^2} = -\underbrace{\frac{q_0^2 n}{\varepsilon_0 m}}_{\omega_p^2} \delta x$$

$$\delta x = \delta x_0 \cdot \cos(\omega_p t)$$

$$\boxed{\omega_p = \sqrt{\frac{q_0^2 n}{m \varepsilon_0}}}$$

$$t \gg 1/\omega_p$$

$\omega < \omega_p$ elmag. vlny jsou stíněny

DEBYEOVO STÍNĚNÍ

Příklad: plazma v TDE $\varphi_p = 0$

M-B rozdělení

$$n_\alpha = n_0 \exp\left(-\frac{q_\alpha \varphi}{K_B T}\right)$$

– vložíme náboj $\delta\rho_{ext}(\vec{r})$

→ porucha n_e a n_i: $\delta n_e, \delta n_i$

$$\delta\rho = \delta\rho_{ext} + q_0(\delta n_i - \delta n_e)$$

– malá porucha $n_\alpha = n_0 \exp\left(-\frac{q_\alpha \delta\varphi}{K_B T}\right) =$

$$= n_0\left(1 - \frac{q_\alpha \delta\varphi}{K_B T} + \cancel{\ldots}\right)$$

$$\delta\rho = \delta\rho_{ext} + q_0 n_0\left(-\frac{q_i \delta\varphi}{K_B T} + \frac{q_e \delta\varphi}{K_B T}\right) =$$

$$= d\rho_{ext} - q_0^2 n_0\, 2 \frac{\delta\varphi}{K_B T}$$

$$\Delta\delta\varphi = -\frac{\delta\rho}{\varepsilon_0} = -\frac{\delta\rho_{ext} - \frac{2 q_0^2 n_0 \delta\varphi}{K_B T}}{\varepsilon_0}$$

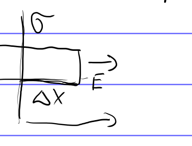
$$\Big(\Delta - 2\underbrace{\frac{q_0^2 n_0}{K_B T \varepsilon_0}}_{1/\lambda_D^2}\Big)\delta\varphi = -\frac{\delta\rho_{ext}}{\varepsilon_0}$$ stíněný Coulombův pot.

$$\lambda_D = \sqrt{\frac{\varepsilon_0 K_B T}{q_0^2 n_0}}$$

1D příklad: $\delta\rho_{ext} = 0 =$

$$\frac{d^2 \delta\varphi}{dx^2} = \frac{2}{\lambda_D^2}\delta\varphi \rightarrow \delta\varphi = \delta\varphi_0 \exp\left(\pm\frac{\sqrt{2}\, x}{\lambda_D}\right)$$

$$\delta\rho_{ext} = \sigma \cdot \underbrace{\delta^{1D}}_{\text{delta fce}}(x)$$



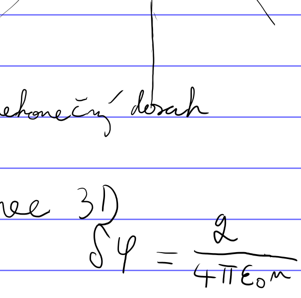
$$2 \cancel{\Delta S} E = \sigma \cancel{\Delta S}$$

$$E\big|_{0^+} = \sigma/2 = -\frac{d\delta\varphi}{dx}\Big|_{0^+} = -\delta\varphi_0\left(-\frac{\sqrt{2}}{\lambda_D}\right)\underbrace{\exp\left(-\cancel{\frac{\sqrt{2}\, x}{\lambda_D}}\right)}_{1}\Big|_{0^+}$$

$$\delta\varphi_0 = \sigma \lambda_D 2^{-3/2}$$

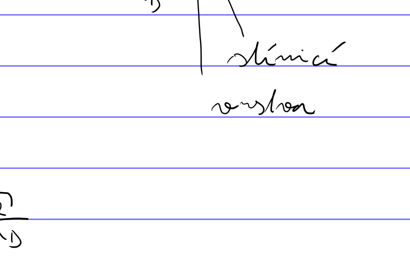
$$\delta\varphi = \sigma \lambda_D 2^{-3/2} \exp\left(-\frac{\sqrt{2}|x|}{\lambda_D}\right)$$

ve vakuu



nekonečný dosah

v plazmatu



stínící vrstva

ve 3D

$$\delta\varphi = \frac{q}{4\pi\varepsilon_0 r} \cdot e^{-r\frac{\sqrt{2}}{\lambda_D}}$$

$$\boxed{L \gg \lambda_D}$$

charakt. rozměr systému

Pozn. rychlost termální

$$v_{tH} = \sqrt{\frac{2 K_B T}{m}}$$

$$l \simeq v_{tH}/\omega_p = \sqrt{\frac{2 K_B T}{\cancel{m}}} \cdot \sqrt{\frac{\cancel{m}\, \varepsilon_0}{q_0^2 n}} = \sqrt{2} \cdot \sqrt{\frac{K_B T \varepsilon_0}{q_0^2 n}} = \sqrt{2}\lambda_D$$