Difúze a Drift v magnetickém poli

PFP II 28 05 7A 2025

Difúze, Ambipolární difúze,

Drift

Difúze a drift v přítomnosti magnetického pole

$$\overline{\vec{v}} = -D\frac{\nabla_r n}{n}$$

$$\overline{\vec{v}} = \pm \mu \vec{E}$$

Úvod do fyziky plazmatu

ČSAV, Academia Praha 1984

Francis F. Chen

Pohyb nabitých částic v nehomogenních E,B poli

mystérium

Doporučená literatura:

Úvod do fyziky plazmatu
ČSAV, Academia Praha 1984
Francis F. Chen

Fundamental of Plasma Physics
Springer 2004, Third Edition
J.A. Bittencourt

Solution in Cartesian Coordinates

$$\boxed{\vec{B} = const.,\ \vec{E} = 0}$$

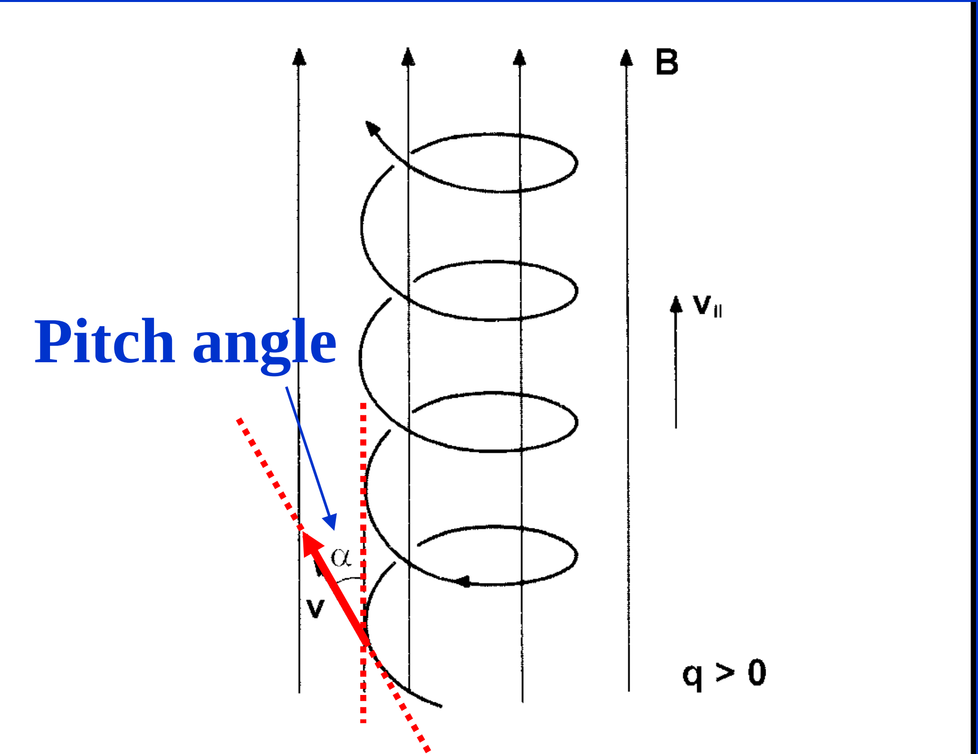


Fig. 3 *Helicoidal trajectory of a positively charged particle in a uniform magnetostatic field.*

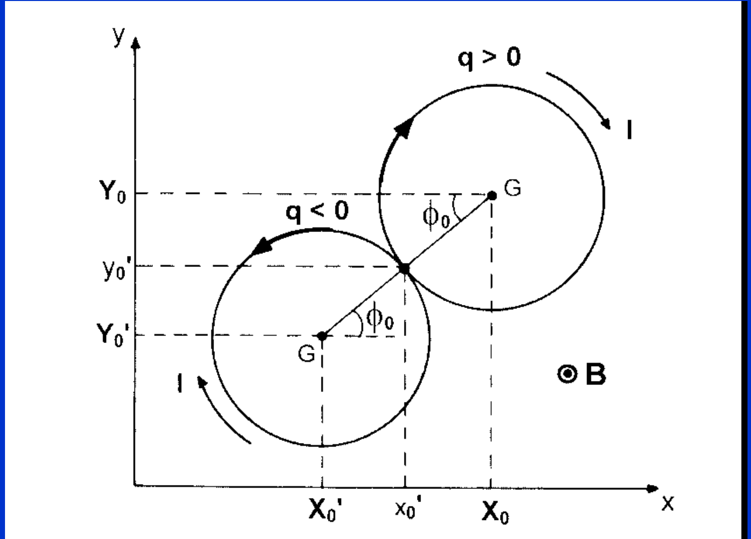


Fig. 4 *Circular trajectory of a charged particle in a uniform and constant* **B** *field (directed out of the paper), and the direction of the associated electric current.*

Radius of gyration

$$r_c = \frac{v_\perp}{\varpi_c} = \frac{m v_\perp}{qB}$$

$$-\frac{q}{m}\vec{B} = \vec{\varpi}_c$$

q_e=1.6x10^{-19}C

B=1T

$$\varpi_c(electron) = \frac{q}{m_e}B$$

m_e=9.109x10^{-31}kg

~100K **1eV** **1MeV**

$$\varpi_c(electron) = 1.76x10^{11}B \sim 176GHz$$

$$\varpi_c(proton) = \frac{q}{m_P}B$$

m_P=1.673x10^{-27}kg

$$\varpi_c(proton) = 9.58x10^{7}B \sim 96MHz$$

$$\varpi_c(Ar^+) = \frac{q}{m_{Ar}}B$$

m_{Ar}=40xm_P

$$\varpi_c(Ar^+) = \frac{1}{40}9.58x10^{7}B \sim \frac{1}{40}96MHz \sim 2.4MHz$$

Parameters of the circular motion

$$\omega_c \equiv \frac{|q|B}{m}$$

$$\vec{B} = const.,\ \vec{E} = 0$$

$$\varpi_c = \frac{eB}{m} = \frac{1.6x10^{-19}}{9.1x10^{-31}} B = 1.8x10^{11} B$$

$at \quad B = 1T \quad \varpi_c = 1.8x10^{11} \sim 180\ GHz$

$at \quad B = 0.1T \quad \varpi_c = 1.8x10^{10} \sim 18\ GHz$

$$r_c = \frac{v_\perp}{\varpi_c} = \frac{mv_\perp}{qB}$$

With assumption of Max. distribution

$$r_L \sim \frac{m\sqrt{kT/m}}{qB}$$

For thermal electron plasma

electrons

$at \quad T = 300K \quad \& \quad B = 1T \quad r_l = 1\mu m$

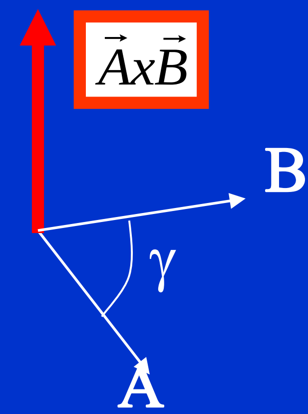
$at \quad T = 3K \quad \& \quad B = 1T \quad r_l = 0.1\mu m$

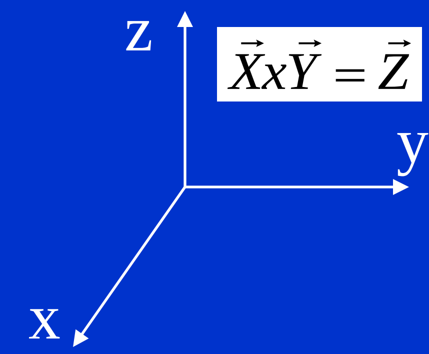
$at \quad T = 300K \quad \& \quad B = 0.1T \quad r_l = 10\mu m$

Je to skutečně pohyb po kružnici ???

Charged particle motion in constant and uniform electromagnetic fields

$$\frac{d\vec{p}}{dt} = \vec{F} = q(\vec{E} + \vec{v}x\vec{B})$$





$$\vec{A} \bullet \vec{B} = A_x B_x + A_y B_y + A_z B_z = AB\cos\gamma$$

$$\left|\vec{A}x\vec{B}\right| = AB\sin\gamma$$

$$\vec{A}x\vec{B} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = (A_y B_z - A_z B_y)\vec{i} + (A_z B_x - A_x B_z)\vec{j} + (A_x B_y - A_y B_x)\vec{k}$$

Energy conservation E=0 B≠0

$$m\frac{d\vec{v}}{dt} = q(\cancel{\vec{E}} + \vec{v}x\vec{B})$$

$$m\frac{d\vec{v}}{dt} = q(\vec{v}x\vec{B}) \qquad /\vec{v}$$

$$m\frac{d\vec{v}}{dt}.\vec{v} = q(\vec{v}x\vec{B}).\vec{v} = 0$$

$$m\frac{d\vec{v}}{dt}.\vec{v} = \frac{d(\frac{1}{2}mv^2)}{dt} = 0$$

$$\frac{d(\frac{1}{2}mv^2)}{dt} = 0$$

Static magnetic field does not change the particle kinetic energy.

This result is valid whatever the spatial dependence of the magnetic flux density B

Energy change in electrostatic and magnetostatic field

$$\boxed{\Delta x \vec{E} = 0}$$

$$\boxed{m\frac{d\vec{v}}{dt} = \vec{F} = q(\vec{E} + \vec{v}x\vec{B}) \qquad / \vec{v}}$$

$\boxed{E \neq 0}$ $\boxed{B \neq 0}$

$$m\frac{d\vec{v}}{dt}.\vec{v} = q(\vec{E}.\vec{v}) + \underbrace{\cancel{q(\vec{v}x\vec{B}).\vec{v}}}_{=0} = q(\vec{E}.\vec{v}) = -q(\nabla\varphi).\frac{d\vec{r}}{dt} = -q\frac{d\varphi}{dt}$$

$$m\frac{d\vec{v}}{dt}.\vec{v} = \frac{d(\frac{1}{2}mv^2)}{dt} = -q\frac{d\varphi}{dt} \longrightarrow \boxed{\frac{d}{dt}(\frac{1}{2}mv^2 + q\varphi) = 0}$$

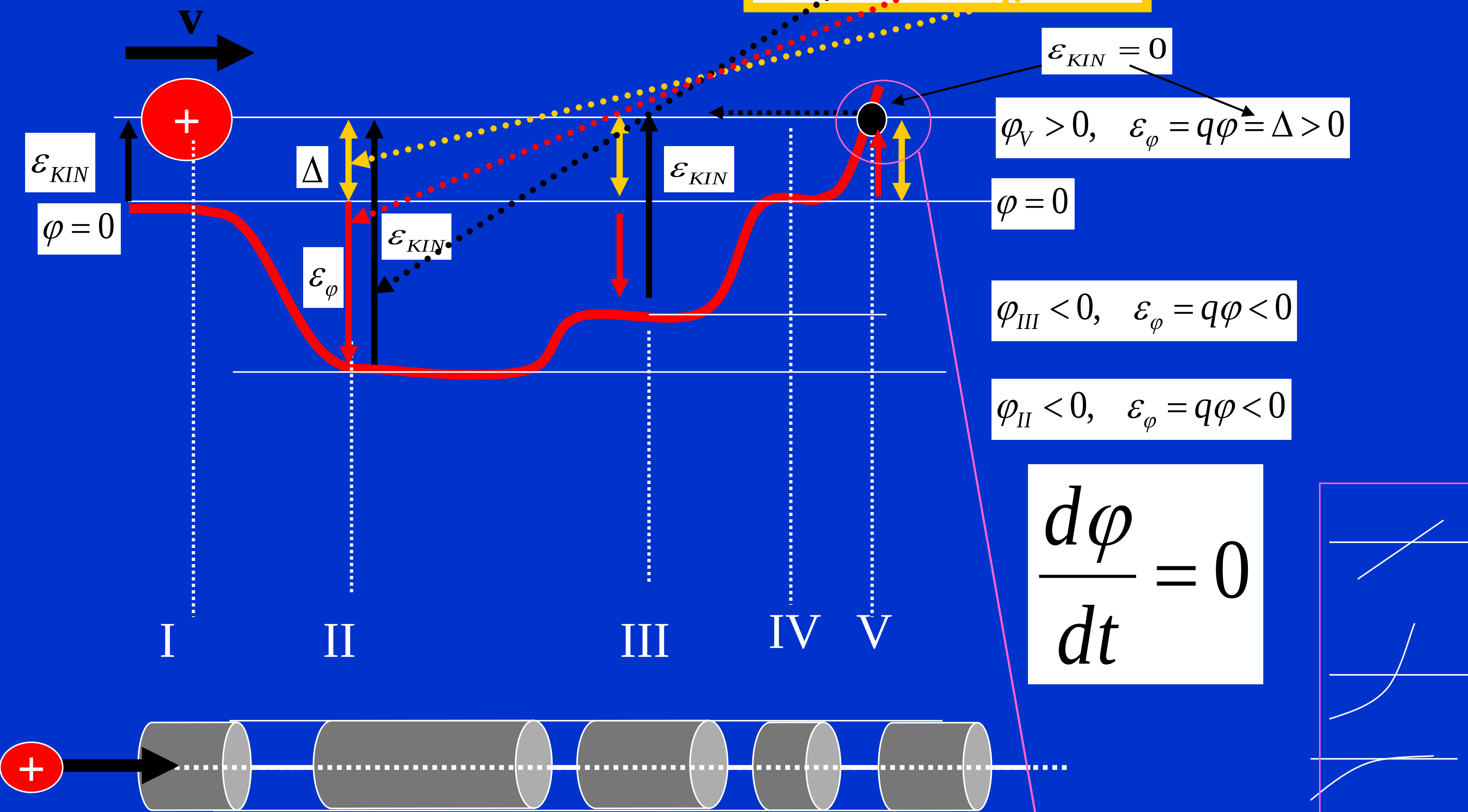
Částice se bude pohybovat v E a B tak, aby splňovala rovnici

Energy change in E-B field

$$m\frac{d\vec{v}}{dt}.\vec{v} = q(\vec{E}.\vec{v}) + \cancel{q(\vec{v}x\vec{B}).\vec{v}} = q(\vec{E}.\vec{v}) = -q(\nabla\varphi).\frac{d\vec{r}}{dt} = -q\frac{d\varphi}{dt}$$

$$\boxed{m\frac{d\vec{v}}{dt} = \vec{F} = q(\vec{E} + \vec{v}x\vec{B}) \qquad /\vec{v}}$$

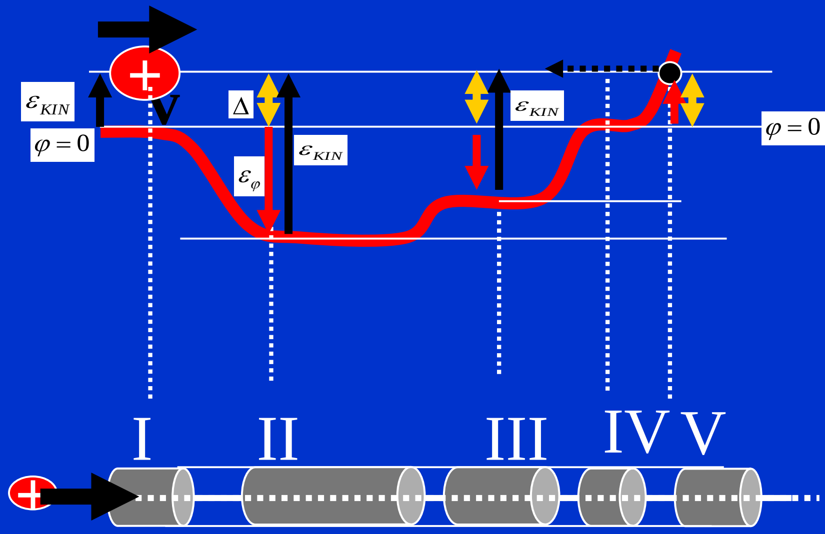
$$\boxed{\frac{d}{dt}\left(\boxed{\tfrac{1}{2}mv^2} + \boxed{q\varphi}\right) = \frac{d}{dt}\boxed{(\Delta)} = 0}$$



Častica sa zastaví, alebo vráti ?????

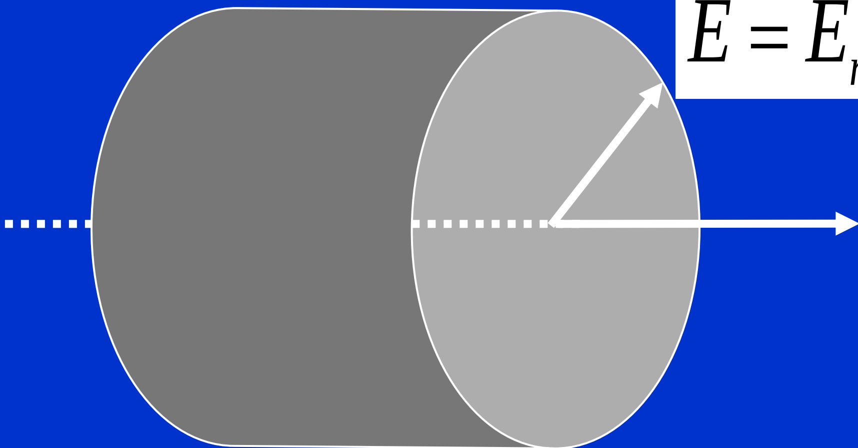
Energy change in E-B field, E perpendicular to v of particles (to Beam)

$$m\frac{d\vec{v}}{dt} = \vec{F} = q(\vec{E} + \vec{v}x\vec{B}) \qquad /.\vec{v}$$



$$\frac{d\varphi}{dt} = 0$$

$$\vec{E} = \vec{E}_r$$



$$\vec{v} = \vec{v}_{\Pi}$$

In axial symmetry, with v=v_{Π}, E_r and its time variation have no influence on v

$$\vec{A} \bullet \vec{B} = AB\cos\gamma$$

$$\vec{E} \bullet \vec{v} = \vec{E}_r \bullet \vec{v}_{\Pi} = 0$$

$$\vec{E} = \vec{E}_r \qquad \vec{v} = \vec{v}_{\Pi}$$

$$m\frac{d\vec{v}}{dt}.\vec{v} = q(\vec{E}.\vec{v}) + \underbrace{q(\vec{v}x\vec{B}).\vec{v}}_{=0} = \underbrace{q(\vec{E}.\vec{v})}_{=0} = -q(\nabla\varphi).\frac{d\vec{r}}{dt} = -q\frac{d\varphi}{dt} \quad \mathbf{=0}$$

$$\frac{d(\frac{1}{2}mv^2)}{dt} = 0$$

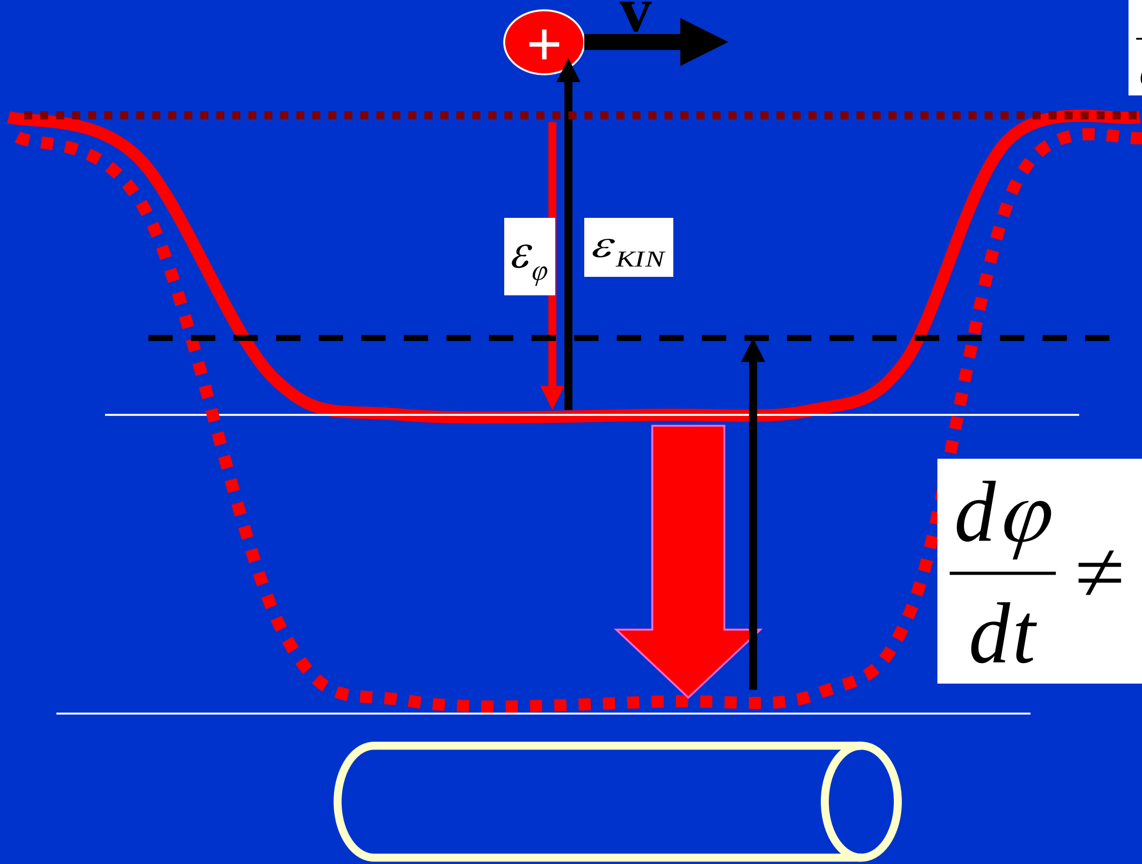
Energy change in static E/B field

$$m\frac{d\vec v}{dt}.\vec v = q(\vec E.\vec v) + \cancel{q(\vec v x\vec B).\vec v} = q(\vec E.\vec v) = -q(\nabla\varphi).\frac{d\vec r}{dt} = -q\frac{d\varphi}{dt}$$

$$\boxed{m\frac{d\vec v}{dt} = \vec F = q(\vec E + \vec v x\vec B) \qquad /\vec v}$$

$$\frac{d}{dt}\left(\tfrac{1}{2}mv^2 + q\varphi + \tfrac{1}{2}mv_0{}^2 + q\varphi_0\right) = 0$$

$$\frac{d}{dt}\left(\tfrac{1}{2}mv^2 + q\varphi\right) = 0$$



$$\frac{d\varphi}{dt} \neq 0$$

$$\boxed{\frac{d\varphi}{dt} \neq 0 \Rightarrow \frac{d(\tfrac{1}{2}mv^2)}{dt} \neq 0}$$

Některé postupy jsou „nestandardní“
ale pokud víme výsledek….
tak je snadno odvodíme……

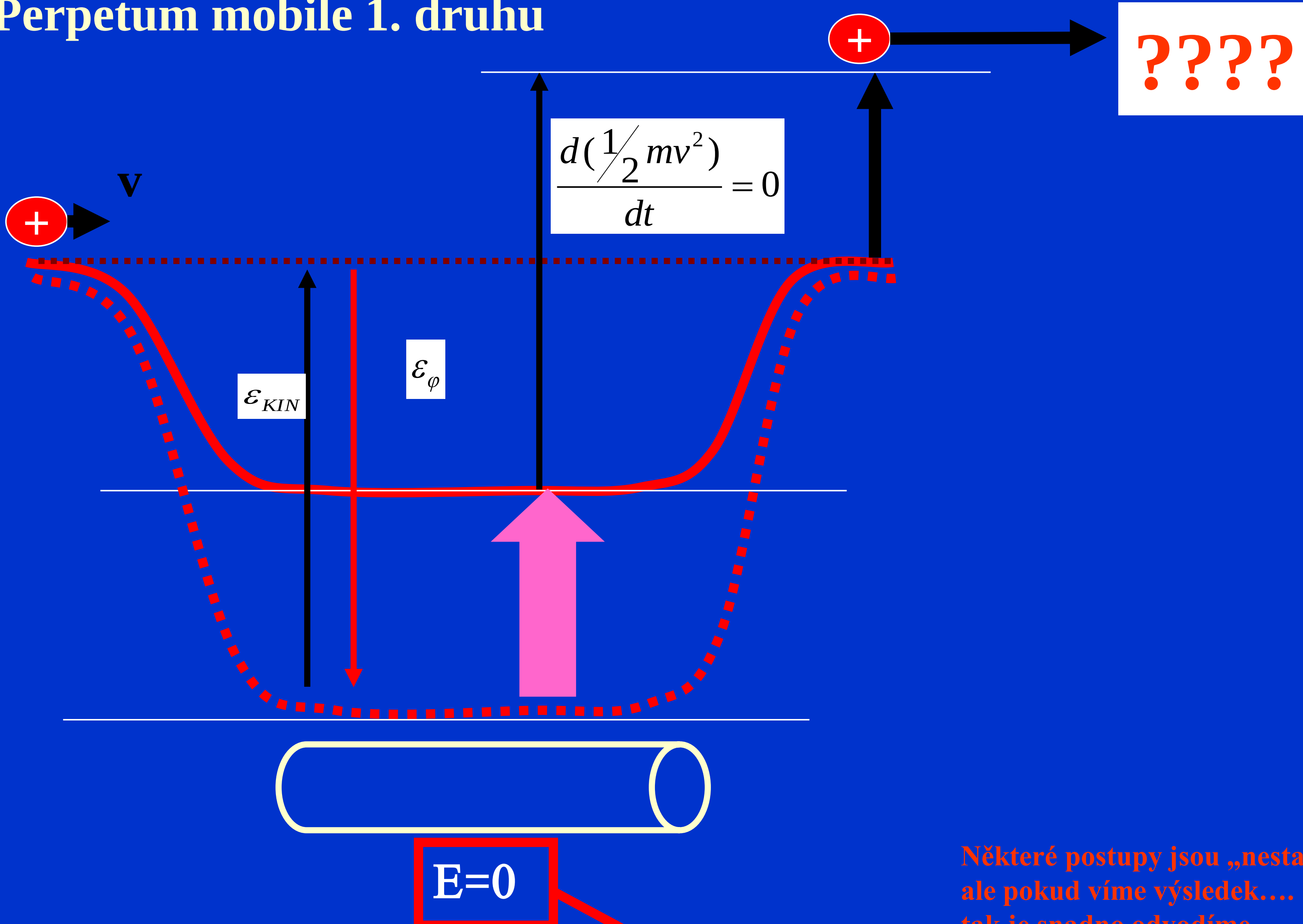
????

E=0

$$m\frac{d\vec v}{dt}.\vec v = q(\vec E.\vec v) + q(\vec v x\vec B).\vec v = q(\vec E.\vec v) = q(0.\vec v) = 0$$

$$\frac{d(\tfrac{1}{2}mv^2)}{dt} = 0$$

Perpetum mobile 1. druhu



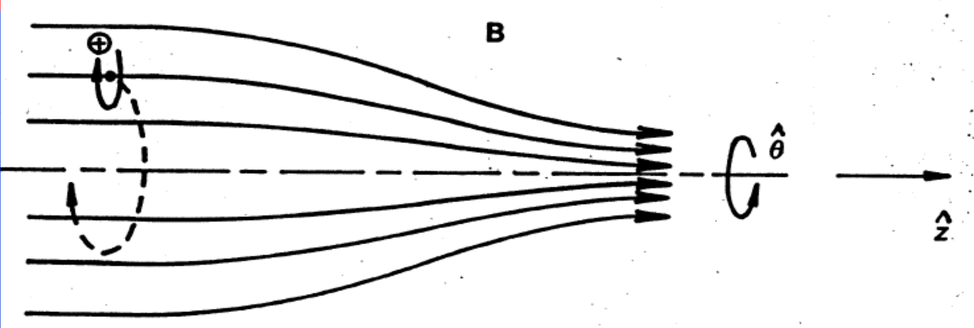
Některé postupy jsou „nestandardní“
ale pokud víme výsledek….
tak je snadno odvodíme……

$$m\frac{d\vec{v}}{dt}.\vec{v} = q(\vec{E}.\vec{v}) + q(\vec{v}x\vec{B}).\vec{v} = q(\vec{E}.\vec{v}) = q(0.\vec{v}) = 0$$

????

$$\frac{d(\frac{1}{2}mv^2)}{dt} = 0$$

Coaxial magnetic mirror



Drift částice v poli magnetického zrcadla.

B_r můžeme obdržet ze vztahu $\nabla . \mathbf{B} = 0$

$$\frac{1}{r}\frac{\partial}{\partial r}(rB_r) + \frac{\partial B_z}{\partial z} = 0 .$$

From Lorentz force

$$F_z = \frac{1}{2} q \boxed{v_\vartheta} r(\partial B_z/\partial z) .$$

Nyní musíme středovat přes jeden oběh. Pro jednoduchost uvažujme částici, jejíž gyrační střed leží na ose. v_ϑ pak zůstává při oběhu konstantní; podle znaménka q je $v_\vartheta = \pm v_\perp$. Protože $r = r_L$, je průměrná síla

$$\bar{F}_z = \mp \frac{1}{2} q v_\perp r_L \frac{\partial B_z}{\partial z} = \mp \frac{1}{2} q \frac{v_\perp^2}{\omega_c} \frac{\partial B_z}{\partial z} = -\frac{1}{2} \frac{m v_\perp^2}{B} \frac{\partial B_z}{\partial z} . \qquad [2\text{-}35]$$

$$\boxed{\mu \equiv m v_\perp^2 / B}$$

$$\bar{F}_z = -\mu(\partial B_z/\partial z) .$$

For diamagnetic particle

$$\mathbf{F}_\parallel = -\mu\, \partial B/\partial \mathbf{s} = -\mu \nabla_\parallel B ,$$

Jak řešit magnetické pole

Jak řešit magnetické pole

- Difúze

$$m\frac{d\mathbf{v}}{dt} = q\mathbf{v}\times\mathbf{B}.$$

Položíme-li $\hat{\mathbf{z}}$ * do směru $\mathbf{B}$ $(\mathbf{B} = B\hat{\mathbf{z}})$, dostáváme

$$m\dot{v}_x = qBv_y, \qquad m\dot{v}_y = -qBv_x, \qquad m\dot{v}_z = 0,$$

$$\ddot{v}_x = \frac{qB}{m}\dot{v}_y = -\left(\frac{qB}{m}\right)^2 v_x, \qquad \ddot{v}_y = -\frac{qB}{m}\dot{v}_x = -\left(\frac{qB}{m}\right)^2 v_y.$$

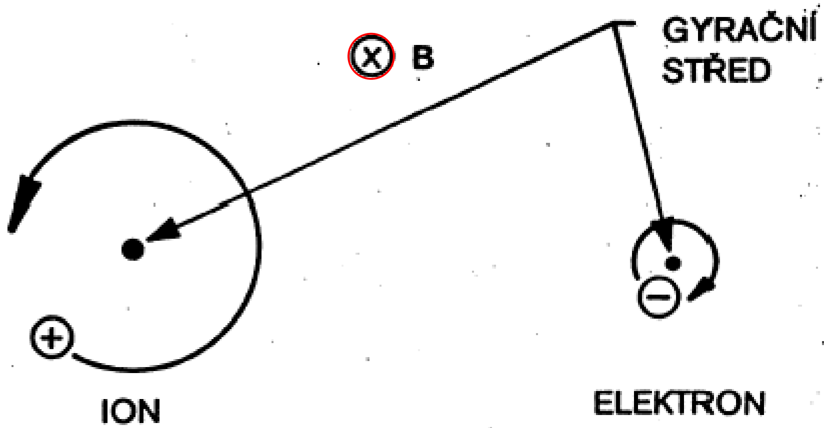
$$\boxed{\omega_c \equiv \frac{|q|\,B}{m}}$$

$$\varpi_c = \frac{eB}{m} = \frac{1.6x10^{-19}}{9.1x10^{-31}}B = 1.8x10^{11}B$$

$$at \quad B = 1T \quad \varpi_c = 1.8x10^{11} \sim 180\ GHz$$

$$at \quad B = 0.1T \quad \varpi_c = 1.8x10^{10} \sim 18\ GHz$$

$$\boxed{r_L \equiv \frac{v_\perp}{\omega_c} = \frac{mv_\perp}{|q|\,B}} \qquad [2\text{-}6]$$



Larmorovy orbity v magnetickém poli.

$$r_L \sim \frac{m\sqrt{kT/m}}{B}$$

$$at \quad T = 300K \ \& \ B = 1T \quad r_l = 1\mu m$$

$$at \quad T = 3K \ \& \ B = 1T \quad r_l = 0.1\mu m$$

$$at \quad T = 300K \ \& \ B = 0.1T \quad r_l = 10\mu m$$

Pro termální plazmu

$$r_L \sim \frac{m\sqrt{kT/m}}{B}$$

Jak řešit magnetické pole

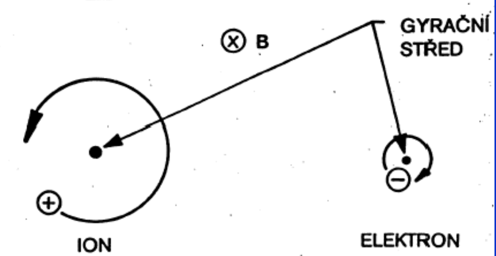
$$m\frac{d\mathbf{v}}{dt} = q\mathbf{v}\times\mathbf{B}.$$

Položíme-li $\hat{\mathbf{z}}$ * do směru $\mathbf{B}$ $(\mathbf{B} = B\hat{\mathbf{z}})$, dostáváme

$$m\dot{v}_x = qBv_y, \qquad m\dot{v}_y = -qBv_x, \qquad m\dot{v}_z = 0,$$

$$\ddot{v}_x = \frac{qB}{m}\dot{v}_y = -\left(\frac{qB}{m}\right)^2 v_x, \qquad \ddot{v}_y = -\frac{qB}{m}\dot{v}_x = -\left(\frac{qB}{m}\right)^2 v_y.$$

$$\boxed{r_L \equiv \frac{v_\perp}{\omega_c} = \frac{mv_\perp}{|q|\,B}} \qquad [2\text{-}6]$$



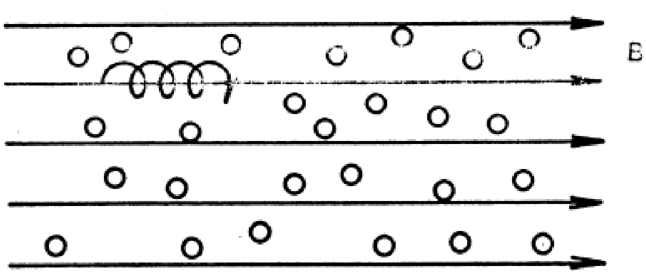
Larmorovy orbity v magnetickém poli.

Žádný ztráty (uniky)???!!!!

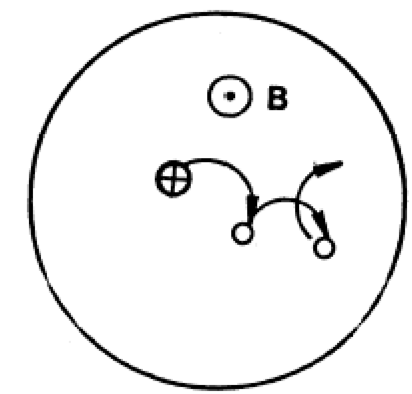
- Difúze

$$\boxed{\omega_c \equiv \frac{|q|\,B}{m}} \qquad r_L \sim \frac{m\sqrt{kT/m}}{B}$$

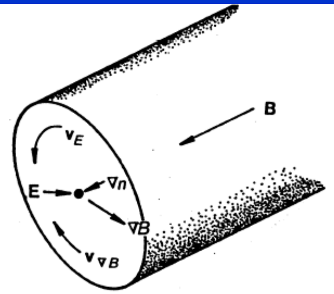
Ve směru z $\quad \Gamma_z = \pm\mu n E_z - D\frac{\partial n}{\partial z}.$



Nabitá částice bude v magnetickém poli rotovat okolo jedné siločáry, dokud se nesrazí.



Difúze rotujících částic při srážkách s neutrálními atomy.



Drifty částic v cylindricky symetrickém sloupci plazmatu nevedou ke ztrátám.

Transportní rovnice pro plazma – vodivost a magnetické pole

a rovnice pro proudovou hustotu $\boldsymbol{j}$ (zobecněný Ohmův zákon) má nyní tvar

(3.216) $$\boxed{\frac{\partial \boldsymbol{j}}{\partial t} - \frac{e^2 n_e}{m_e}(\boldsymbol{E} + \boldsymbol{v}_0 \times \boldsymbol{B}) + \frac{e}{m_e}\boldsymbol{j} \times \boldsymbol{B} - \frac{e}{m_e}\nabla_r p_e - \sum_{(k)} \frac{Z_k^2 e^2 n_k}{m_k}\boldsymbol{F}_k = -\frac{\boldsymbol{j}}{\tau_e}.}$$

(3.205′) $$\varrho_i \frac{\partial \bar{\boldsymbol{v}}_i}{\partial t} + \nabla_r p_i - en(\boldsymbol{E} + \bar{\boldsymbol{v}}_i \times \boldsymbol{B}) - n_i \boldsymbol{F}_i = \frac{n_e m_e}{\tau_e}(\bar{\boldsymbol{v}}_e - \bar{\boldsymbol{v}}_i)$$

(3.206′) $$\varrho_e \frac{\partial \bar{\boldsymbol{v}}_e}{\partial t} + \nabla_r p_e + en(\boldsymbol{E} + \bar{\boldsymbol{v}}_e \times \boldsymbol{B}) - n_e \boldsymbol{F}_e = -\frac{n_e m_e}{\tau_e}(\bar{\boldsymbol{v}}_e - \bar{\boldsymbol{v}}_i)$$

Zde je ovšem nutno poznamenat, že zobecněný Ohmův zákon (3.216) je použitelný pro plně ionizované plazma opět pouze v prvním přiblížení. Obecně totiž může pravá strana této rovnice záviset na magnetickém poli uvnitř plazmatu a gradientu teploty elektronů. Jestliže zanedbáme $\nabla_r T_e$, pak je pravá strana (3.216) stále ještě složena ze dvou členů; jestliže systém není daleko rovnováhy, pak přesnější tvar pravé strany rovnice (3.216) je

(3.217) $$-\frac{1}{\tau_e}\left(\frac{\boldsymbol{j}_\parallel}{1{,}96} + \boldsymbol{j}_\perp\right),$$

kde $\boldsymbol{j}_\parallel$ je složka proudové hustoty ve směru magnetického pole a $\boldsymbol{j}_\perp$ je složka proudové hustoty ve směru kolmém na magnetické pole.

Rozdíl mezi (3.217) a (3.215) resp. pravou stranou (3.216), si ukážeme názorně na příkladu. Předpokládejme stacionární stav, tj. $\partial \boldsymbol{j}/\partial t = 0$ a nechť $\boldsymbol{F}_k = 0$. Z rovnice (3.216) pak dostaneme

(3.218) $$\boldsymbol{E}' = \frac{\boldsymbol{j}}{\sigma} + \frac{1}{n_e e}\boldsymbol{j} \times \boldsymbol{B},$$

kde

(3.219) $$\boldsymbol{E}' = \boldsymbol{E} + (\boldsymbol{v}_0 \times \boldsymbol{B}) + \frac{1}{n_e e}\nabla_r p_e$$

a

(3.220) $$\boxed{\sigma = \frac{e^2 n_e \tau_e}{m_e}}$$ VODIVOST

je vodivost plazmatu. Vyjádříme-li z (3.218) $\boldsymbol{j}$, dostaneme po menších úpravách, že

(3.221) $$\boxed{\boldsymbol{j} = \sigma \boldsymbol{E}'_\parallel + \frac{\sigma}{1 + \omega_{ce}^2 \tau_e^2}\{\boldsymbol{E}'_\perp + \omega_{ce}\tau_e(\boldsymbol{h} \times \boldsymbol{E}')\},}$$

kde

(3.222) $$\boldsymbol{h} = \frac{\boldsymbol{B}}{B} \quad \text{a} \quad \omega_{ce} = \frac{eB}{m_e}$$

je elektronová cyklotronová frekvence.

vodivost

$$\sigma = \frac{e^2 n_e \tau_e}{m_e}$$

Jestliže nyní použijeme na pravé straně (3.216) výrazu (3.217), dostaneme, že

(3.223) $$\boldsymbol{E}' = \frac{\boldsymbol{j}_\parallel}{\sigma_\parallel} + \frac{\boldsymbol{j}_\perp}{\sigma_\perp} + \frac{1}{n_e e}(\boldsymbol{j} \times \boldsymbol{B}),$$

kde

(3.224) $$\boxed{\sigma_\parallel = 1{,}96\sigma \quad \text{a} \quad \sigma_\perp = \sigma;}$$

vyloučením $\boldsymbol{j}$ pak dostaneme

(3.225) $$\boxed{\boldsymbol{j} = \sigma_\parallel \boldsymbol{E}'_\parallel + \frac{\sigma_\perp}{1 + \omega_{ce}^2 \tau_e^2}\{\boldsymbol{E}'_\perp + \omega_{ce}\tau_e(\boldsymbol{h} \times \boldsymbol{E}')\}.}$$

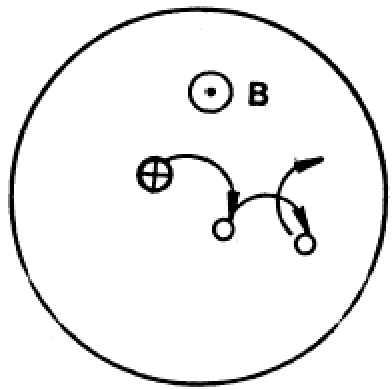
Odtud již vidíme, že i v tak jednoduchém případě, kdy $\nabla_r T_e = 0$ a systém je blízko rovnováhy, je vodivost plazmatu závislá na směru magnetického pole.

V obecném případě má vodivost plazmatu tenzorový charakter.*)

Elektronova cyklotronova frekvence

With collisions it is drift

Srážky a magnetické pole



Difúze rotujících částic při srážkách s neutrálními atomy.

Jestliže nyní použijeme na pravé straně (3.216) výrazu (3.217), dostaneme, že

(3.223) $$\boldsymbol{E}' = \frac{\boldsymbol{j}_{\parallel}}{\sigma_{\parallel}} + \frac{\boldsymbol{j}_{\perp}}{\sigma_{\perp}} + \frac{1}{n_e e}(\boldsymbol{j} \times \boldsymbol{B}),$$

kde

(3.224) $$\sigma_{\parallel} = 1{,}96\sigma \quad \text{a} \quad \sigma_{\perp} = \sigma;$$

vyloučením $\boldsymbol{j}$ pak dostaneme

(3.225) $$\boldsymbol{j} = \sigma_{\parallel}\boldsymbol{E}'_{\parallel} + \frac{\sigma_{\perp}}{1 + \omega_{ce}^2\tau_e^2}\{\boldsymbol{E}'_{\perp} + \omega_{ce}\tau_e(\boldsymbol{h} \times \boldsymbol{E}')\}.$$

Odtud již vidíme, že i v tak jednoduchém případě, kdy $\nabla_r T_e = 0$ a systém je blízko rovnováhy, je vodivost plazmatu závislá na směru magnetického pole.

V obecném případě má vodivost plazmatu tenzorový charakter.*)

Přidáme magnetické pole

Drift

Rovnice B

Nenulové magnetické pole

$$\cancel{\frac{\partial \boldsymbol{f}_1}{\partial t}} + \cancel{\mathbf{v}\nabla f_0} + \frac{\boldsymbol{\Gamma}}{v}\frac{\partial f_0}{\partial v} - (\boldsymbol{\omega}_c \times \boldsymbol{f}_1) = -\nu_1 \boldsymbol{f}_1$$

$$\vec{\Gamma} = \frac{e\vec{E}}{m}$$

$$\omega_c = \frac{|q|\,B}{m}$$

$$\overline{\varphi} = \frac{4\pi}{n}\int_0^\infty v^2 f_0 \varphi\, dv$$

$$\frac{\partial}{\partial t} = 0 \qquad \nabla_r = 0 \qquad \vec{E} \neq 0 \qquad B \neq 0$$

$$\frac{\Gamma}{v}\frac{\partial f_0}{\partial v} - (\varpi_c x \vec{f}_1) = -\nu_1 \vec{f}_1$$

$$\overline{\vec{\varphi}} = \frac{4\pi}{3}\frac{1}{n}\int_0^\infty v^4 \vec{f}_1 \varphi' dv$$

$$\vec{\varphi} = \vec{v}.\varphi(v,\vec{r},t)$$

$$\varphi = 1$$

$$\vec{f}_1 = -\frac{\Gamma}{\nu_1 v}\frac{\partial f_0}{\partial v} + \frac{1}{\nu_1}(\varpi_c x \vec{f}_1)$$

Per-partes

+ conditions of limits of f

$$\overline{\vec{v}} = \frac{4\pi}{3}\frac{1}{n}\int v^4 \vec{f}_1 dv = -\frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{1}{\nu_1}\frac{\vec{\Gamma}}{v}\frac{\partial f_0}{\partial v} dv + \frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{1}{\nu_1}(\varpi_c x \vec{f}_1) dv$$

$$= -\frac{4\pi}{3}\frac{1}{nm\nu_1} e\vec{E}\int v^3 \frac{\partial f_0}{\partial v} dv \quad + \quad \frac{4\pi}{3}\frac{1}{n}\varpi_c x \int v^4 \frac{1}{\nu_1}\vec{f}_1 dv$$

$$= -\frac{4\pi}{3}\frac{3}{nm\nu_1} e\vec{E}\int v^2 f_0 dv \quad + \quad \varpi_c x\left(\frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{1}{\nu_1}\vec{f}_1 dv\right)$$

$$== -\frac{e}{m\nu_1}\vec{E}.1 \quad + \quad \varpi_c x \overline{\left(\frac{\vec{v}}{\nu_1}\right)}$$

$$\overline{\vec{v}} = \mu\vec{E} + \varpi_c x \overline{\left(\frac{\vec{v}}{\nu_1}\right)} = \mu\vec{E} + \frac{e}{m}\vec{B}x\overline{\left(\frac{\vec{v}}{\nu_1}\right)} = \mu\vec{E} + \frac{e}{m\nu_1}\vec{B}x\overline{\vec{v}}$$

$$\overline{\vec{v}} = \mu\vec{E} + \frac{e}{m\nu_1}\vec{B}x\overline{\vec{v}}$$

Odvození rovnice pro drift a difuzi z B. rovnice

$\nabla_r \neq 0$

Drift + Diffusion

Rovnice B

$$\cancel{\frac{\partial \boldsymbol{f}_1}{\partial t}} + \nabla_r f_0 + \frac{\Gamma}{v}\frac{\partial f_0}{\partial v} - (\boldsymbol{\omega}_c \times \boldsymbol{f}_1) = -\nu_1 \boldsymbol{f}_1$$

$$\overline{\vec{\varphi}} = \frac{4\pi}{3}\frac{1}{n}\int_0^\infty v^4 \vec{f}_1 \varphi' dv$$

$$\overline{\varphi} = \frac{4\pi}{n}\int_0^\infty v^2 f_0 \varphi \, dv$$

$$\frac{\partial}{\partial t} = 0$$

$\nabla_r \neq 0$ $\vec{E} \neq 0$ $B \neq 0$

$$\nabla_r f_0 + \frac{\Gamma}{v}\frac{\partial f_0}{\partial v} - (\varpi_c x \vec{f}_1) = -\nu_1 \vec{f}_1$$

$$\vec{f}_1 = -\frac{\Gamma}{\nu_1 v}\frac{\partial f_0}{\partial v} + \frac{1}{\nu_1}(\varpi_c x \vec{f}_1) - \frac{1}{\nu_1}\nabla_r f_0$$

$$\overline{\vec{v}} = \frac{4\pi}{3}\frac{1}{n}\int v^4 \vec{f}_1 dv = -\frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{1}{\nu_1}\frac{\vec{\Gamma}}{v}\frac{\partial f_0}{\partial v} dv + \frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{1}{\nu_1}(\varpi_c x \vec{f}_1) dv - \frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{\nabla f_0}{\nu_1} dv$$

$$= -\frac{4\pi}{3}\frac{1}{nm\nu_1} e\vec{E}\int v^3 \frac{\partial f_0}{\partial v} dv + \frac{4\pi}{3}\frac{1}{n}\varpi_c x \int v^4 \frac{1}{\nu_1}\vec{f}_1 dv - \frac{1}{3}\frac{4\pi}{n}\frac{1}{n}\int \frac{v^2}{\nu_1} v^2 \nabla f_0 dv$$

$$= -\frac{4\pi}{3}\frac{3}{nm\nu_1} e\vec{E}\int v^2 f_0 dv + \varpi_c x\left(\frac{4\pi}{3}\frac{1}{n}\int v^4 \frac{1}{\nu_1}\vec{f}_1 dv\right) - \frac{1}{3}\frac{4\pi}{n}\frac{1}{n}\int \frac{v^2}{\nu_1} v^2 \nabla f_0 dv$$

$$= -\frac{e}{m\nu_1}\vec{E}.1 + \varpi_c x \overline{\left(\frac{\vec{v}}{\nu_1}\right)} - \frac{1}{3}\nabla\left(\left(\overline{\frac{v^2}{\nu_1}}\right).n\right)$$

$$\overline{\vec{v}} = \mu\vec{E} + \varpi_c x \overline{\left(\frac{\vec{v}}{\nu_1}\right)} - \frac{1}{3}\nabla\left(\left(\overline{\frac{v^2}{\nu_1}}\right).n\right) = \mu\vec{E} + \frac{e}{m}\vec{B}x\overline{\left(\frac{\vec{v}}{\nu_1}\right)} - \frac{1}{3}\nabla\left(\left(\overline{\frac{v^2}{\nu_1}}\right).n\right) = \mu\vec{E} + \frac{e}{m\nu_1}\vec{B}x\overline{\vec{v}} - D\frac{\nabla n}{n}$$

Difúze a Drift v magnetickém poli

- B

$$\vec{E} \neq 0 \quad , \quad \vec{B} \neq 0 \quad , \quad \frac{\nabla n}{n} \neq 0$$

$$\overline{\vec{v}} = \mu\vec{E} + \varpi_c x \overline{\left(\frac{\vec{v}}{\nu_1}\right)} - \frac{1}{3}\nabla((\frac{\overline{v^2}}{\nu_1}).n) = \mu\vec{E} + \frac{e}{m}\vec{B}x\overline{\left(\frac{\vec{v}}{\nu_1}\right)} - \frac{1}{3}\nabla((\frac{\overline{v^2}}{\nu_1}).n) = \mu\vec{E} + \frac{e}{m\nu_1}\vec{B}x\overline{\vec{v}} - D\frac{\nabla n}{n}$$

Zjednodušeně

$$\overline{\vec{v}} = \mu\vec{E} + \frac{e}{m\nu_1}\vec{B}x\overline{\vec{v}} - D\frac{\nabla n}{n}$$

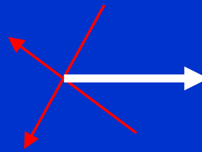
A co dál ????…… budeme řešit pro jednoduché konfigurace

Difúze napříč magnetickým polem

$$\boxed{\vec{\bar{v}} = \mu\vec{E} + \frac{e}{m\nu_1}\vec{B}x\vec{\bar{v}} - D\frac{\nabla n}{n}}$$

- Chen

$$\cancel{mn\frac{d\mathbf{v}_\perp}{dt}} = \pm en(\mathbf{E} + \mathbf{v}_\perp \times \mathbf{B}) - KT\,\nabla n - mn\nu\mathbf{v} = 0\,.$$



$$mn\nu v_x = \pm enE_x - KT\frac{\partial n}{\partial x} \pm env_yB\,,$$

$$mn\nu v_y = \pm enE_y - KT\frac{\partial n}{\boxed{\partial x}} \pm env_xB\,.$$

$$v_x = \pm\mu E_x - \frac{D}{n}\frac{\partial n}{\partial x} \pm \frac{\omega_c}{\nu}v_y$$

$$v_y = \pm\mu E_y - \frac{D}{n}\frac{\partial n}{\boxed{\partial x}} \mp \frac{\omega_c}{\nu}v_x$$

$$\tau = \nu^{-1}$$

$$v_y(1 + \omega_c^2\tau^2) = \pm\mu E_y - \frac{D}{n}\frac{\partial n}{\partial y} - \omega_c^2\tau^2\frac{E_x}{B} \pm \omega_c^2\tau^2\frac{KT}{eB}\frac{1}{n}\frac{\partial n}{\partial x}$$

$$v_x(1 + \omega_c^2\tau^2) = \pm\mu E_x - \frac{D}{n}\frac{\partial n}{\boxed{\partial x}} - \omega_c^2\tau^2\frac{E_y}{B} \mp \omega_c^2\tau^2\frac{KT}{eB}\frac{1}{n}\frac{\partial n}{\partial y}$$

- Chen pp. 153

$$\boxed{v_\perp = \pm\mu_\perp E - D_\perp\frac{\nabla n}{n} +}$$

Pozor bude to inak

$$\mu_\perp = \frac{\mu}{1 + \omega_c^2\tau^2}$$

$$\boxed{D_\perp = \frac{D}{1 + \omega_c^2\tau^2}}$$

…..?????   pro B=0