NEVF169 03 9.3.2021

TEORETICKÝ POPIS PLAZMATU

- ČÁSTICOVÝ
  - trajektorie částic
- problém mnoha těles
- srážky + makroskopické pole
  (ne) selfkonzistentní

- KINETICKÝ POPIS
  - rozdělovací funkce $f(\vec{r}, \vec{v}, t)$
  - Boltzmannova rovnice

- TEKUTINOVÝ MODEL
  - více tekutin
  - vodivá tekutina MHD

POHYB NAB. ČÁSTIC VE VN. POLI

- neselfkonzistentní

Lorentzova síla

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

- $\vec{E} = const$, $|\vec{B}| = 0$ – rovnoměrně zrychlený pohyb

- $|\vec{E}| = 0$; $\vec{B} = const$

$$m\frac{d\vec{v}}{dt} = q\,\vec{v}\times\vec{B} \quad ; \text{ nechť } \vec{B} \equiv B\hat{z}$$

↓ složky

$$m\dot{v}_x = q v_y B \quad ; m\dot{v}_y = -q v_x B ; \quad m\dot{v}_z = 0$$

$/\frac{d}{dt}$ $\quad \ddot{v}_x = \frac{qB}{m}\dot{v}_y = -\left(\frac{qB}{m}\right)^2 v_x$

$/\frac{d}{dt}$ $\quad \ddot{v}_y = \frac{-qB}{m}\dot{v}_x = -\left(\frac{qB}{m}\right)^2 v_y$

$$\omega_c = \frac{|q|B}{m} \text{ cyklotronová frekvence}$$

(Larmorova, gyro-)

$$v_x = v_\perp \cos(\pm\omega_c t + \delta) = v_\perp \cos(\omega_c t)$$

sign q $\quad \delta = 0$

$$v_y = \frac{\dot{v}_x}{\pm\omega_c} = \frac{1}{\pm\cancel{\omega_c}} v_\perp(-\sin(\omega_c t))\cancel{\omega_c} =$$

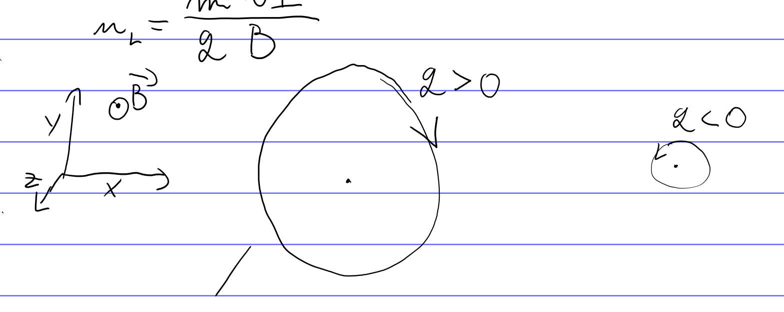
$$= \mp v_\perp \sin(\omega_c t)$$

$$X = \int_0^t v_\perp \cos(\omega_c t)\,dt + X_0' = \frac{v_\perp}{\omega_c}\sin(\omega_c t) + X_0$$

$$Y = \int_0^t v_y\,dt + Y_0' = \pm\frac{v_\perp}{\omega_c}\cos(\omega_c t) + Y_0$$

$\frac{v_\perp}{\omega_c} = r_L$ Larmorův poloměr

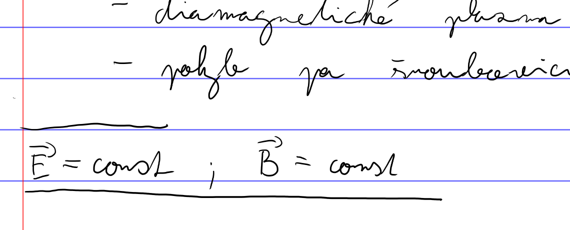
$$r_L = \frac{m v_\perp}{qB}$$



generuje mag pole antiparalelní $\vec{B}$

- diamagnetické plazma
- pohyb po šroubovici $\vec{v} = \vec{v}_\parallel + \vec{v}_\perp$

$\vec{E} = const$; $\vec{B} = const$



driftový + cyklotronový pohyb

$\vec{B} = B\hat{z}$; $E_y \equiv 0$

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

$$\dot{v}_z = \frac{q}{m}E_z$$

$$\dot{v}_x = \frac{q}{m}E_x \pm \omega_c v_y \qquad \Big/ \frac{d}{dt}$$

$$\dot{v}_y = \mp\omega_c v_x$$

$$\ddot{v}_x = -\omega_c^2 v_x$$

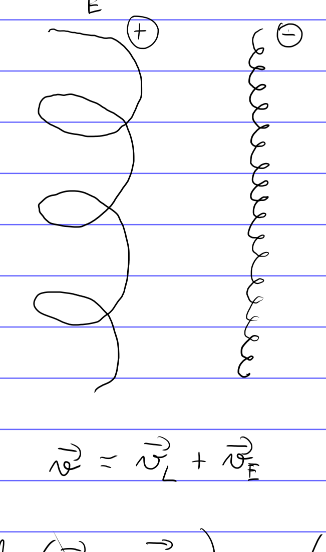
$$\ddot{v}_y = \mp\omega_c\dot{v}_x = \mp\omega_c\left(\frac{q}{m}E_x \pm \omega_c v_y\right) =$$

$$= -\omega_c^2\left(v_y + \frac{E_x}{B}\right)$$

$$\frac{d^2}{dt^2}\underbrace{\left(v_y + \frac{E_x}{B}\right)}_{v_y'} = -\omega_c^2\left(v_y + \frac{E_x}{B}\right)$$

$$v_x = v_\perp\cos(\omega_c t)$$

$$v_y' = \mp v_\perp\sin(\omega_c t) \rightarrow v_y = v_y' - \frac{E_x}{B} = \mp v_\perp \sin \omega_c t \underbrace{- \frac{E_x}{B}}_{\text{drift}}$$



$$\vec{v} = \vec{v}_L + \vec{v}_E$$

$$\underbrace{m\frac{d}{dt}(\vec{v}_L}_{1} + \underbrace{\vec{v}_E}_{\substack{const(t)\\ = 0}}) = q(\vec{E} + (\underbrace{\vec{v}_L}_{1} + \vec{v}_E)\times\vec{B})$$

$$\vec{E} + \vec{v}_E\times\vec{B} = 0 \qquad /\times\vec{B}$$

$$\vec{E}\times\vec{B} + (\vec{v}_E\times\vec{B})\times\vec{B} = 0 \quad /(a\times b)\times c = (c\cdot a)b - (c\cdot b)a$$

$$\vec{E}\times\vec{B} + \underbrace{(\vec{v}_E\cdot\vec{B})}_{\substack{\text{dokážeme } \vec{v}_E \perp B\\ 0}}\vec{B} - B^2\vec{v}_E = 0$$

$$\boxed{\vec{v}_E = \frac{\vec{E}\times\vec{B}}{B^2}}$$

drift ve zkřížených polích
E-cross-B drift

nezávisí na q ani m

platí i pro obecnou sílu

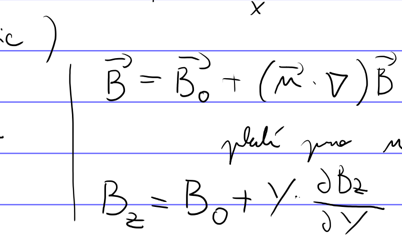
$qE \rightarrow F$ (gravitační, odstředivá)

$$\vec{v}_F = \frac{1}{q}\frac{\vec{F}\times\vec{B}}{B^2}$$

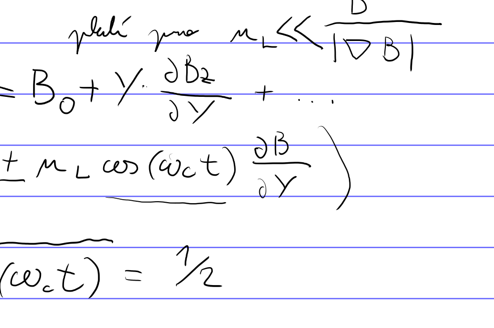
$$\vec{v}_g = \frac{m}{q}\frac{\vec{g}\times\vec{B}}{B^2}$$

nehomogenní $\vec{B}$

$\nabla B \perp \vec{B}$



$\nabla B \parallel \hat{Y}$ $\qquad \vec{F} = q\vec{v}\times\vec{B}$



$\overline{F_x} = 0$ (symetrie)

$$F_y = -q v_x B_z \qquad \left| \begin{array}{l} \vec{B} = \vec{B}_0 + (\vec{r}\cdot\nabla)\vec{B} + \ldots \\ \text{platí pro } r_L \ll \frac{B}{|\nabla B|} \\ B_z = B_0 + Y\cdot\frac{\partial B_z}{\partial Y} + \ldots \end{array}\right.$$

$$F_y = -q v_\perp \cos(\omega_c t)\left(B_0 \pm r_L \underline{\cos(\omega_c t)}\frac{\partial B}{\partial Y}\right)$$

$$\overline{\cos(\omega_c t)} = 0 \qquad \overline{\cos^2(\omega_c t)} = 1/2$$

$$\overline{F_y} = \mp q v_\perp r_L \frac{1}{2}\frac{\partial B}{\partial Y}$$

$$v_{\nabla B} = \frac{1}{q}\frac{\vec{F}\times\vec{B}}{B^2} = \frac{1}{q}\frac{F_y}{|B|}\hat{X} = \mp\frac{v_\perp r_L}{B}\cdot\frac{1}{2}\frac{\partial B}{\partial Y}\hat{X}$$

$$\boxed{\vec{v}_{\nabla B} = \pm\frac{1}{2}v_\perp r_L\frac{\vec{B}\times\nabla B}{B^2}} \quad \text{grad-B drift}$$