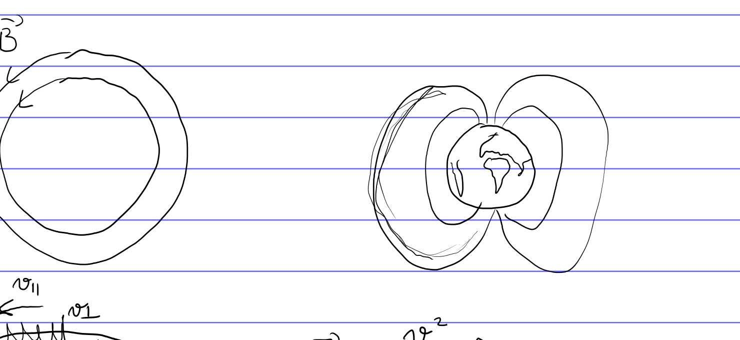
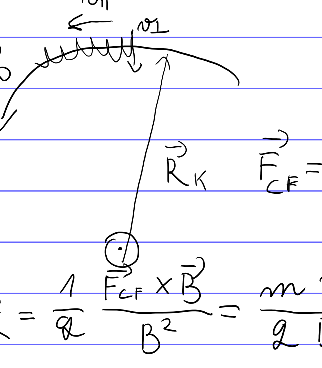
NEVF169 04 11.3.2021





$$\vec{a}_{CF} = \frac{v^2}{r}\hat{r}$$

$$\vec{F}_{CF} = m\,\vec{a}_{CF} = \frac{m v_\parallel^2}{R_K}\cdot\frac{\vec{R}_K}{R_K}$$

$$\vec{v}_R = \frac{1}{q}\frac{\vec{F}_{CF}\times\vec{B}}{B^2} = \frac{m v_\parallel^2}{q B^2}\cdot\frac{\vec{R}_K\times\vec{B}}{R_K^2}$$

DRIFT ZAKŘIVENÍ

$$\nabla\times\vec{B} = 0 \qquad (\vec{j} = 0)$$

$$(\nabla\times\vec{B})_\vartheta = (\nabla\times\vec{B})_r = 0 \quad \text{(symetrie)}$$

$$(\nabla\times B)_z = \frac{1}{r}\frac{\partial}{\partial r}\underbrace{(r B_\vartheta)}_{\sim\ \text{const}} = 0$$

$$B_\vartheta \sim \frac{1}{r} \qquad B = \frac{B_0}{R_K}$$

$$\frac{\nabla|\vec{B}|}{|\vec{B}|} = -\frac{\cancel{B_0}}{R_K^2}\frac{\vec{R}_K}{\cancel{R_K}}\cdot\frac{\cancel{R_K}}{\cancel{B_0}} = -\frac{\vec{R}_K}{R_K^2}$$

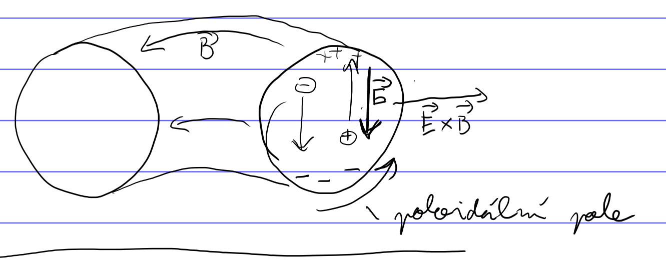
∇B - drift :

$$v_{\nabla B} = \pm\frac{1}{2}v_\perp r_L\frac{\vec{B}\times\nabla B}{B^2} = \mp\frac{1}{2}\frac{v_\perp r_L}{B^2}\vec{B}\times\left(B\frac{\vec{R}_K}{R_K^2}\right)$$

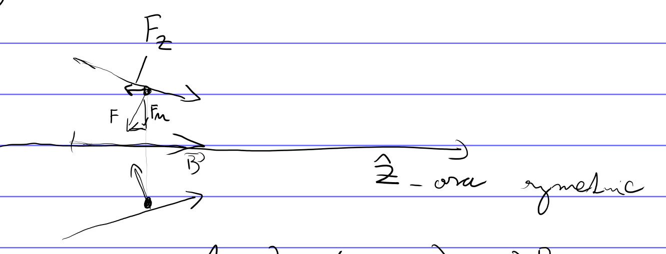
$$\left| r_L = \frac{v_\perp}{\omega_c} = \frac{v_\perp m}{|q| B} = \pm\frac{v_\perp m}{q\, B}\right|$$

$$v_{\nabla B} = -\frac{1}{2}\frac{v_\perp}{B^2}\frac{v_\perp m}{q\,\cancel{B}}\cancel{B}\frac{\vec{B}\times\vec{R}_K}{R_K^2} = \frac{1}{2}\frac{m v_\perp^2}{q}\frac{\vec{R}_K\times\vec{B}}{B^2 R_K^2}$$

$$v_R + v_{\nabla B} = \frac{m}{q}\frac{\vec{R}_K\times\vec{B}}{R_K^2 B^2}\left(v_\parallel^2 + \frac{1}{2}v_\perp^2\right)$$



$\nabla B \parallel \vec{B}$

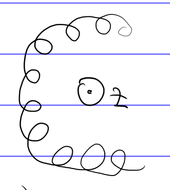


$$\nabla\cdot\vec{B} = 0 \longrightarrow \frac{1}{r}\frac{\partial}{\partial r}(r B_r) + \frac{\partial B_z}{\partial z} = 0$$

$$\frac{\partial}{\partial r} r B_r = -r\frac{\partial B_z}{\partial z} \qquad \Big|\ B_r\big|_{r=0} = 0$$

$$r B_r = -\int_0^r r\underbrace{\frac{\partial B_z}{\partial z}}_{\sim\ \text{const}}\,dr = -\frac{1}{2}r^2\left(\frac{\partial B_z}{\partial z}\right)_{z=0}$$

$$B_r = -\frac{1}{2}r\left(\frac{\partial B_z}{\partial z}\right)_{z=0}$$



$$F_z = q(\vec{v}\times B)_z = q(\cancel{v_r B_\vartheta} - v_\vartheta B_r)$$

$$= \frac{1}{2}q v_\vartheta r\frac{\partial B_z}{\partial z} \qquad ;\ r = r_L,\quad v_\vartheta = \mp v_\perp$$

$$\overline{F_z} = \mp q v_\perp r_L\frac{\partial B_z}{\partial z} = \mp q\frac{v_\perp^2}{\omega_c}\frac{\partial B_z}{\partial z} =$$

$$= -\frac{1}{2}\frac{m v_\perp^2}{B}\frac{\partial B_z}{\partial z}$$

μ, magnetický moment

$$F_z = -\mu\frac{\partial B_z}{\partial z} \longrightarrow \boxed{F_\parallel = -\mu\nabla_\parallel B} = -\mu\frac{\partial B}{\partial s}$$

podél B

$$\mu = \frac{E_\perp}{B}$$

$$\left(\mu = I A = \underbrace{|q|\frac{\omega_c}{2\cancel{\pi}}}_{I}\cancel{\pi} r_L^2 = |q|\frac{\cancel{\omega_c}}{2}\frac{v_\perp^2}{\omega_c^{\cancel{2}}} = \frac{\frac{1}{2}m v_\perp^2}{B}\right)$$

μ - invariant
 - důkaz

$$m\frac{dv_\parallel}{dt} = -\mu\frac{\partial B}{\partial s}$$

$$v_\parallel = \frac{ds}{dt}$$

$$m v_\parallel\frac{dv_\parallel}{dt} = -\mu\frac{\partial B}{\partial s}\,\frac{ds}{dt}$$

$$\frac{d}{dt}\left(\frac{1}{2}m v_\parallel^2\right) = -\mu\frac{dB}{dt} \checkmark \text{ podle trajektorie}$$

$$0 = \frac{d}{dt}\left(\frac{1}{2}m v_\parallel^2 + \frac{1}{2}m v_\perp^2\right) =$$

$$= \frac{d}{dt}\left(\frac{1}{2}m v_\parallel^2 + \mu B\right) = 0$$

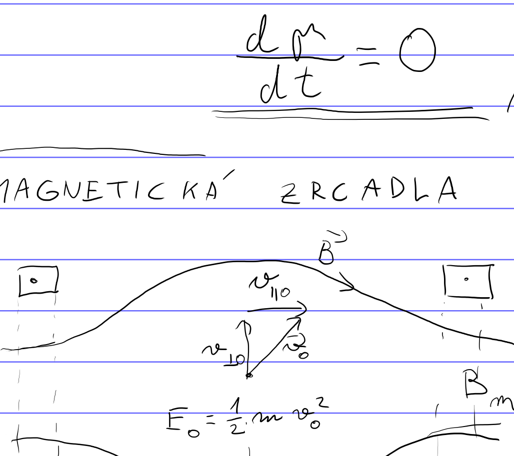
$$-\mu\frac{dB}{dt} + \frac{d}{dt}(\mu B) = 0$$

$$-\cancel{\mu\frac{dB}{dt}} + B\frac{d\mu}{dt} + \cancel{\mu\frac{dB}{dt}} = 0$$

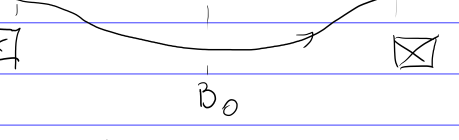
$$\frac{d\mu}{dt} = 0$$

/ platí i v pomalu (adiabaticky) proměnné B

MAGNETICKÁ ZRCADLA



$$\mu = \frac{E_\perp}{B} = \text{const}$$

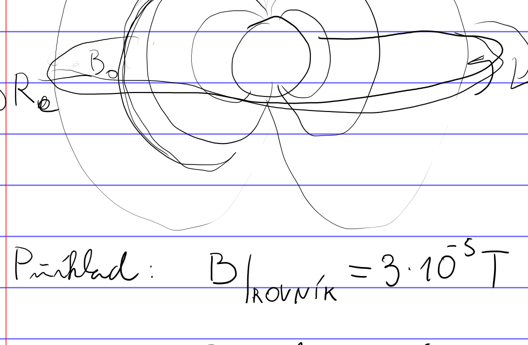


$$E_\perp \sim B$$

$$E_\perp < E_0$$

pro jaké B' nastane $E'_\perp = E_0$

$$\frac{v_{\perp 0}^2}{B_0} = \frac{v_\perp'^2}{B'} \longrightarrow \frac{B_0}{B'} = \frac{v_{\perp 0}^2}{v_\perp'^2} \underset{\text{BOD OBRATU}}{=} \frac{v_{\perp 0}^2}{v_0^2} = \sin^2\vartheta$$



Příklad: $B|_{ROVNÍK} = 3\cdot 10^{-5}\,T$

$$B \sim 1/r^3 \quad \text{(dipól)}$$

vzdálenost $r = 5 R_e$, zemský poloměr na rovníku
elektrony E_e - 100 keV
ionty E_i - 1 eV
$n_i = n_e = 10^7\ m^{-3}$

- rychlost ∇B-driftu
směr ∇B driftu pro ionty a elektrony
doba oběhu Země
proudová hustota (A/m^2)