

gradB :

$$\vec{v} = -c\{B_z + \frac{mc}{q}(\frac{cE_A \sin\{2\pi(\frac{t}{T} - \frac{LR_0\theta}{\lambda}) + \frac{\pi}{2}\}}{B_z^2}\xi_r)\}^{-1}(E_A \sin\{2\pi(\frac{t}{T} - \frac{LR_0\theta}{\lambda}) + \frac{\pi}{2}\} - \frac{\mu}{q}\xi_r + \frac{mc^2}{q} \frac{(E_A \sin\{2\pi(\frac{t}{T} - \frac{LR_0\theta}{\lambda}) + \frac{\pi}{2}\})^2 \xi_r}{B_z^3})\vec{e}_\theta$$

$$\text{so, } v_{grad} = \frac{c}{B_z} \frac{\mu}{q} \xi_r$$

assumption $B_z = \frac{B_E}{L^3}$ (in magnetic equator) , $B_E = 3.11 \times 10^{-5} \text{T} = 3.11 \times 10^{-1} \text{G}$
if $L = 6$, $B_z = 1.4 \times 10^{-7} \text{T} = 1.4 \times 10^{-3} \text{G}$

assumption : $v_\perp = 0.01c = 3.0 \times 10^8 \text{cm/s}$

$$\mu = \frac{mv_\perp^2}{2B_z} = \frac{(9.1 \times 10^{-28} \text{g}) \times (3.0 \times 10^8 \text{cm/s})^2}{2.0 \times 1.4 \times 10^{-3} \text{G}}$$

$$\xi_r = \frac{\partial B_z}{\partial r} = \frac{\partial B_z}{\partial L} \frac{\partial L}{\partial r} = -3 \frac{B_E}{L^4} \frac{1}{R_0} = \frac{-3 \times 3.1 \times 10^{-1} \text{G}}{6^4 \times 6 \times 10^8 \text{cm}}$$

$$v_{grad} = \frac{c}{B_z} \frac{\mu}{q} \xi_r = \frac{3.0 \times 10^{10} \text{cm/s}}{1.4 \times 10^{-3} \text{G}} \times \frac{1}{4.8 \times 10^{-10} \text{statC}} \times \frac{(9.1 \times 10^{-28} \text{g}) \times (3.0 \times 10^8 \text{cm/s})^2}{2.0 \times 1.4 \times 10^{-3} \text{G}} \times \frac{-3 \times 3.1 \times 10^{-1} \text{G}}{6^4 \times 6 \times 10^8 \text{cm}}$$

$$v_{grad} = -\frac{3.0 \times 9.1 \times 3.0 \times 3.0 \times 3 \times 3.1}{1.4 \times 4.8 \times 2.0 \times 1.4 \times 6^4 \times 6} 10^5 \text{cm/s} \approx 1500 \text{cm/s}$$

from basic space plasma physics

$$v_\nabla = \frac{mv_\perp^2}{2qB^3} (\vec{B} \times \nabla B)$$

$$v_\nabla = \frac{9.1 \times 10^{-31} \text{kg} \times (3.0 \times 10^6 \text{m/s})^2}{2 \times (1.6 \times 10^{-19} \text{C}) \times (1.4 \times 10^{-7} \text{T})^3} (1.4 \times 10^{-7} \text{T}) \times (-3 \frac{B_E}{L^4} \frac{1}{R_0})$$

$$v_\nabla = \frac{9.1 \times 10^{-31} \text{kg} \times (3.0 \times 10^6 \text{m/s})^2}{2 \times (1.6 \times 10^{-19} \text{C}) \times (1.4 \times 10^{-7} \text{T})^3} (1.4 \times 10^{-7} \text{T}) \times (-3 \frac{3.11 \times 10^{-5} \text{T}}{6^4} \frac{1}{6.0 \times 10^6 \text{m}})$$

$$v_\nabla = -\frac{9.1 \times 9.0 \times 1.4 \times 3 \times 3.11}{2 \times 1.6 \times 1.4^3 \times 6^4 \times 6} \frac{10^{-31}}{10^{-34}} \text{m/s}$$

$$v_\nabla = -\frac{9.1 \times 9.0 \times 1.4 \times 3 \times 3.11}{2 \times 1.6 \times 1.4^3 \times 6^4 \times 6} 10^3 \text{m/s} = 0.015 \times 10^3 \text{m/s} = 15 \text{m/s}$$