

# EXERCISES WEEK 38

## Thursday 22 August, 2005

### 1) Exercise 2.2 a-d from K&R

2)

The momentum equations for ions and electrons are given by

$$m_i \frac{d\vec{v}_i}{dt} = e(\vec{E} + \vec{v}_i \times \vec{B}) \quad \text{Eq. 1.1}$$

$$m_e \frac{d\vec{v}_e}{dt} = -e(\vec{E} + \vec{v}_e \times \vec{B}) \quad \text{Eq. 1.2}$$

- a) Assume a static uniform electric field along the y-axis and a static uniform magnetic field along the z-axis. Sketch the particle trajectories separately for electrons and ions.
- b) Show that the zeroth order drift of the guiding center is given by

$$\vec{v}_{gc} = \vec{u}_E = \frac{\vec{E}_\perp \times \vec{B}}{B^2}, \quad \text{Eq. 1.3}$$

independent of both the mass and charge.

{ *Hint:*  $\vec{a} \times (\vec{b} \times \vec{c}) = \vec{b}(\vec{a} \cdot \vec{c}) - \vec{c}(\vec{a} \cdot \vec{b})$  }

- c) Assume a magnetic field along the z-direction increasing in strength with increasing y, and no electric field. Draw a sketch showing the particle trajectories separately for ions and electrons.

Assume that the magnetic field strength increase linearly with increasing  $y$ .

d) Show that the magnetic field can be expressed as

$$\mathbf{B}_z = B_{0z} + \left( \frac{\partial B_z}{\partial y} \right) r_c \cos \phi \quad \text{Eq. 1.4}$$

where  $r_c = \frac{mv_{\perp}}{eB_z}$  is the gyro radius, and  $\phi$  is the angle that the position vector  $\vec{r} = (x, y)$  makes with  $y$  in a guiding center reference frame.

e) Show that the average forces over one gyro-period are given by

$$\langle F_x \rangle = \frac{-qv_{\perp}}{2\pi} \int_0^{2\pi} \left( B_{0z} \sin \phi + r_c \left( \frac{\partial B_z}{\partial y} \right) \sin \phi \cos \phi \right) d\phi \quad \text{Eq. 1.5}$$

and

$$\langle F_y \rangle = \frac{-qv_{\perp}}{2\pi} \int_0^{2\pi} \left( B_{0z} \cos \phi + r_c \left( \frac{\partial B_z}{\partial y} \right) \cos^2 \phi \right) d\phi \quad \text{Eq. 1.6}$$

in  $x$  and  $y$  directions, respectively.

f) Integrate Eqs. 1.5 and 1.6 and derive the following expression for the gradient drift of the guiding center:

$$\vec{v}_{gc} = -\frac{1}{2} \frac{mv_{\perp}^2}{qB_z^2} \left( \frac{\partial B_z}{\partial y} \right) \hat{x} \quad \text{Eq. 1.7}$$

$$\{ \text{Hint: } \int \cos^2 x \, dx = \frac{1}{2} \sin x \cos x + \frac{1}{2} x + C \quad ; \quad \int \sin x \cos x \, dx = \frac{1}{2} \sin^2 x + C \}$$

The general expression for the gradient drift is:

$$\vec{u}_{VB} = \frac{1}{2} mv_{\perp}^2 \frac{\vec{B} \times \nabla \vec{B}}{qB^3} \quad \text{Eq. 1.8}$$

### 3) Exercise 2.4 from K&R