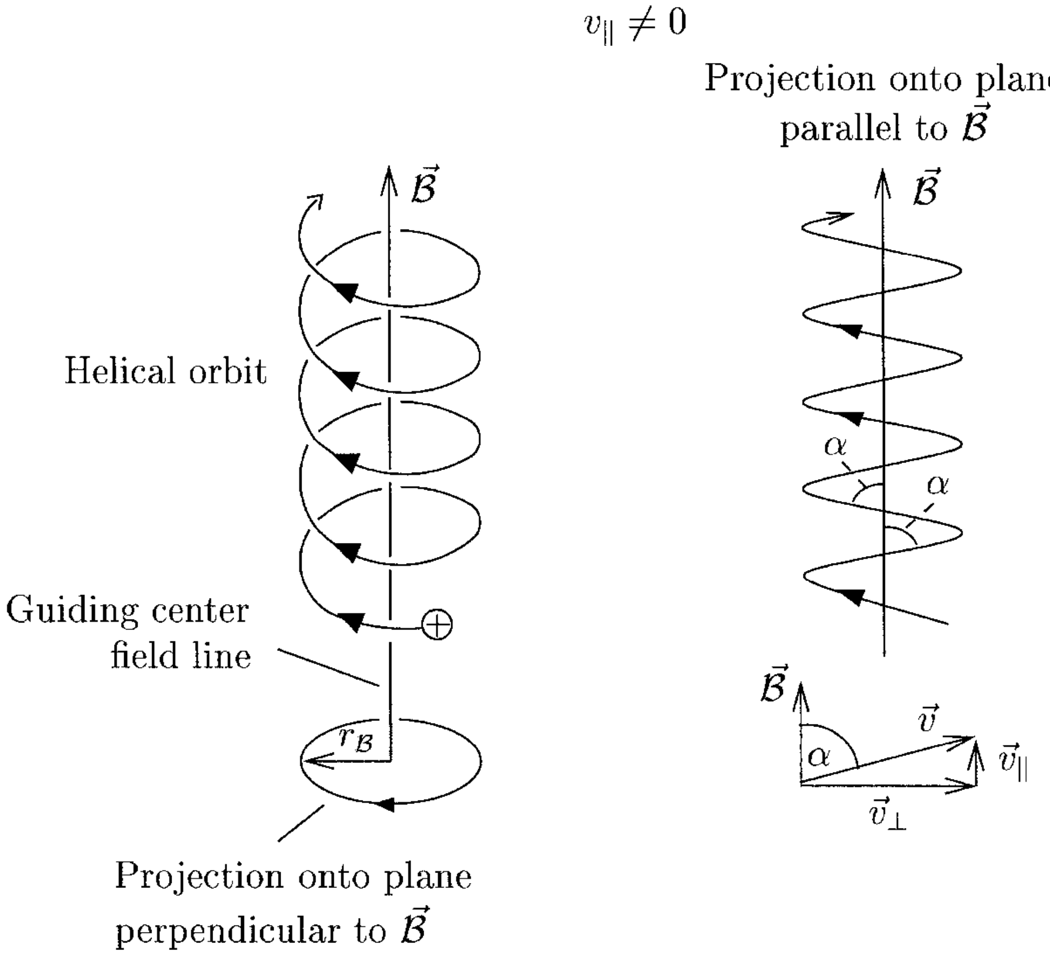
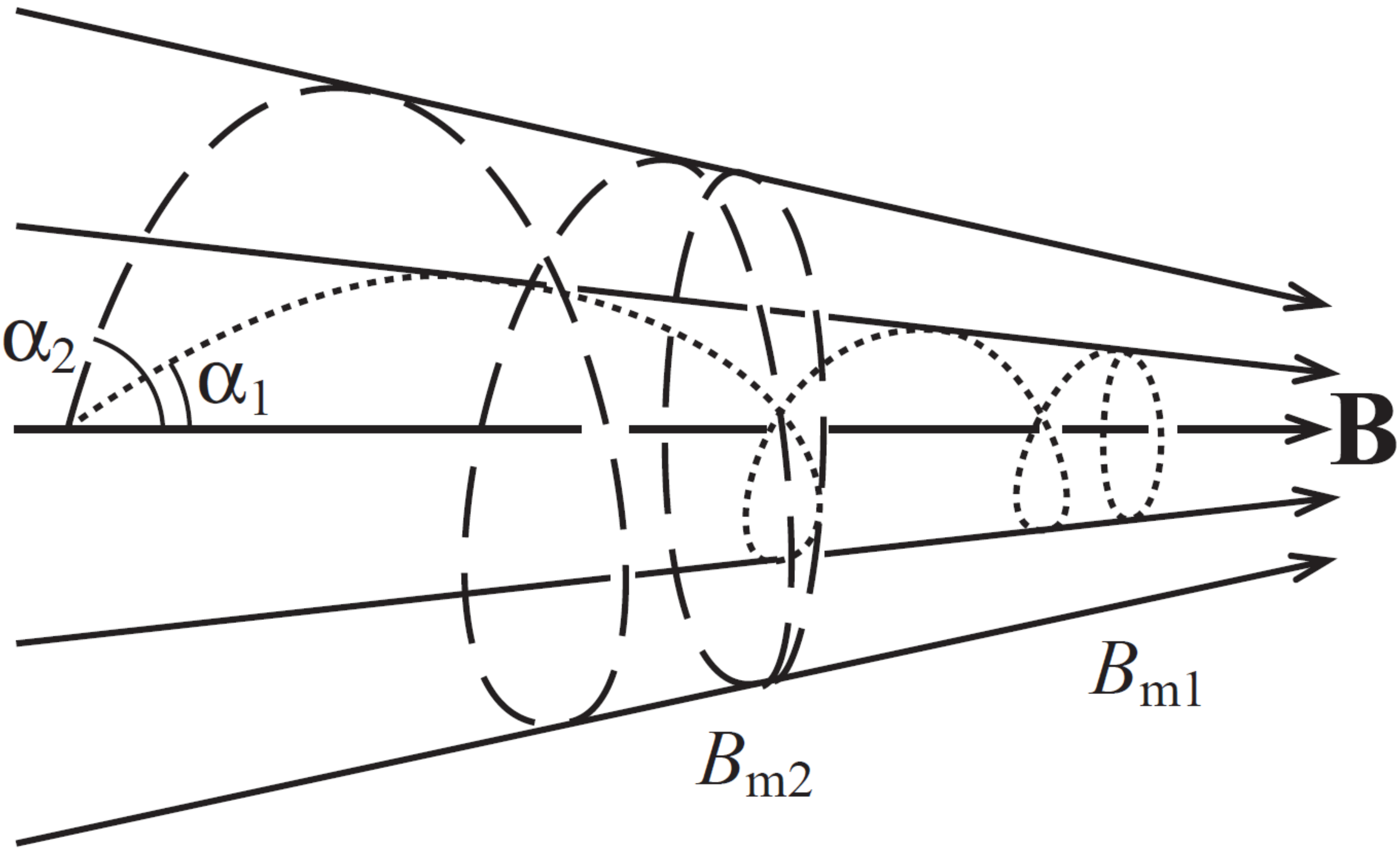
Gyration


$v_{\parallel} \neq 0$
Projection onto plane parallel to $\vec{\mathcal{B}}$
$\vec{\mathcal{B}}$
Helical orbit
Guiding center field line
$r_{\mathcal{B}}$
Projection onto plane perpendicular to $\vec{\mathcal{B}}$
α
$\vec{v}$
$\vec{v}_{\parallel}$
$\vec{v}_{\perp}$

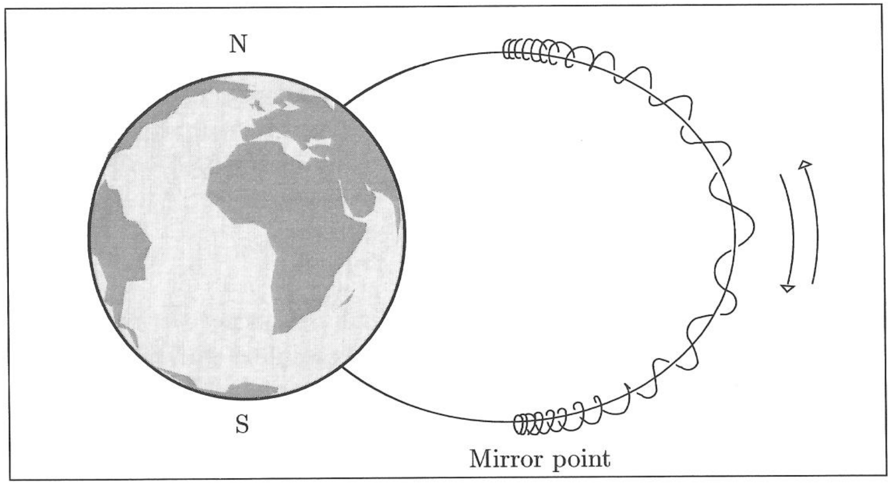
Magnetic mirror/loss cone

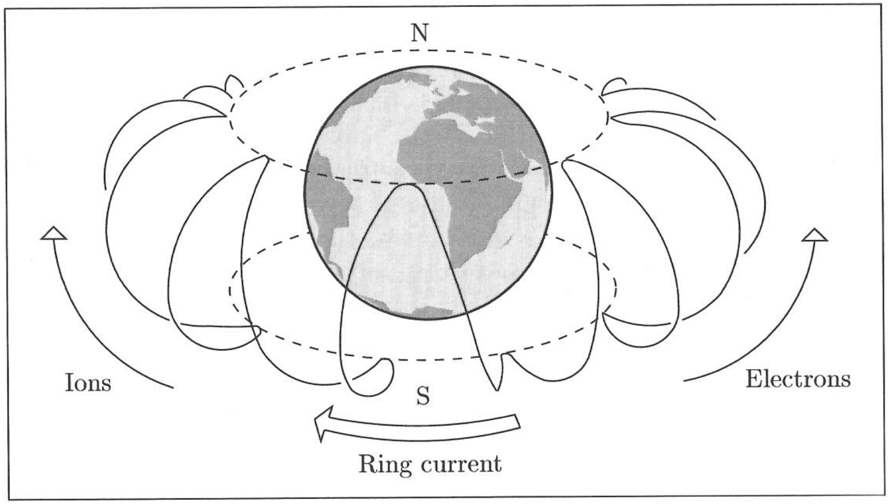


Single particle drifts

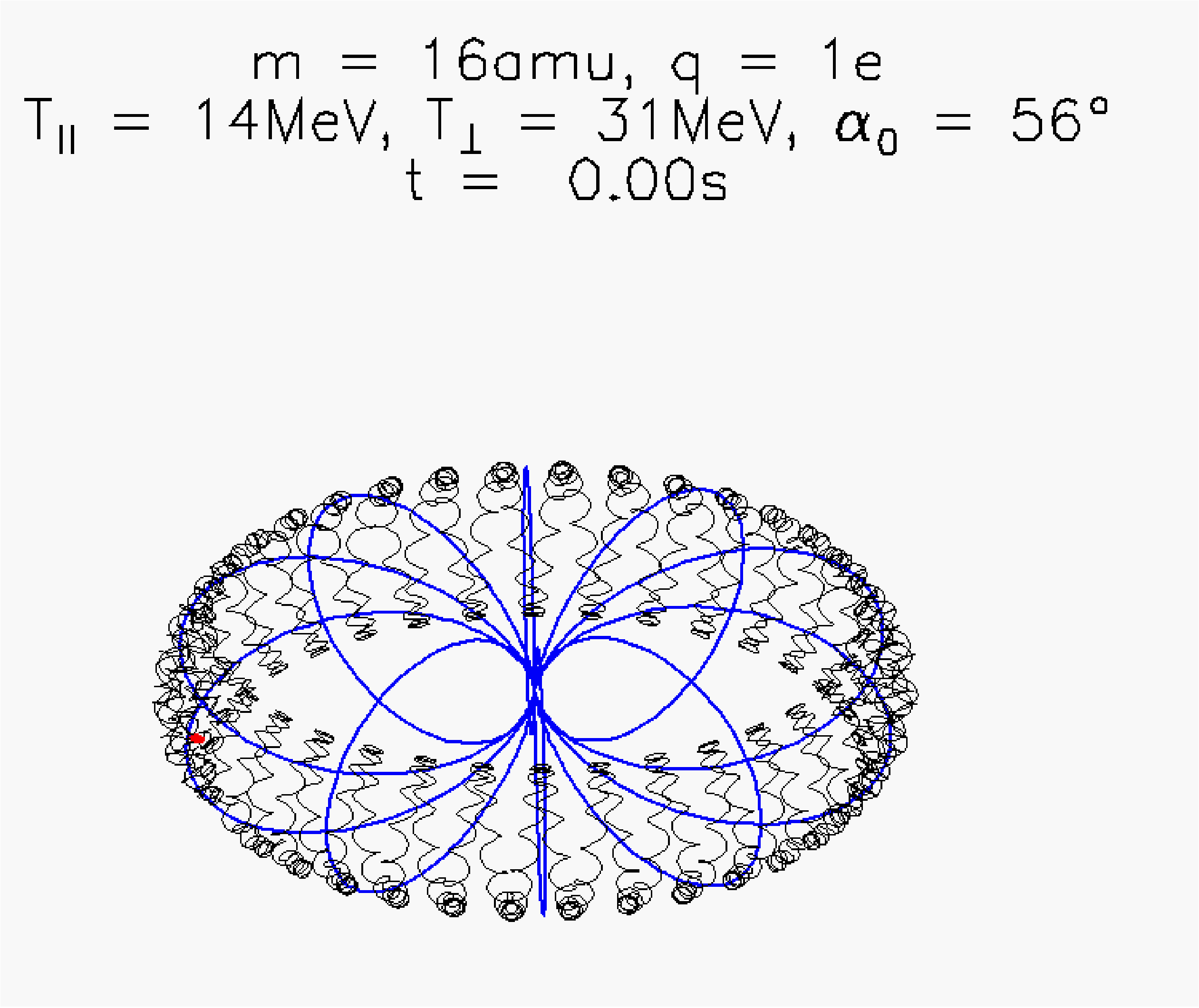
E×B Drift:	$\mathbf{v}_E = \frac{\mathbf{E}\times\mathbf{B}}{B^2}$	
Polarization Drift:	$\mathbf{v}_P = \frac{1}{\omega_g B}\frac{d\mathbf{E}_\perp}{dt}$	$\mathbf{j}_P = \frac{n_e(m_i + m_e)}{B^2}\frac{d\mathbf{E}_\perp}{dt}$
Gradient Drift:	$\mathbf{v}_\nabla = \frac{m v_\perp^2}{2qB^3}(\mathbf{B}\times\nabla B)$	$\mathbf{j}_\nabla = \frac{n_e(\mu_i + \mu_e)}{B^2}(\mathbf{B}\times\nabla B)$
Curvature Drift:	$\mathbf{v}_R = \frac{m v_\parallel^2}{q R_c^2 B^2}(\mathbf{R}_c\times\mathbf{B})$	$\mathbf{j}_R = \frac{2n_e(W_{i\parallel} + W_{e\parallel})}{R_c^2 B^2}(\mathbf{R}_c\times\mathbf{B})$

Bounce and drift motion

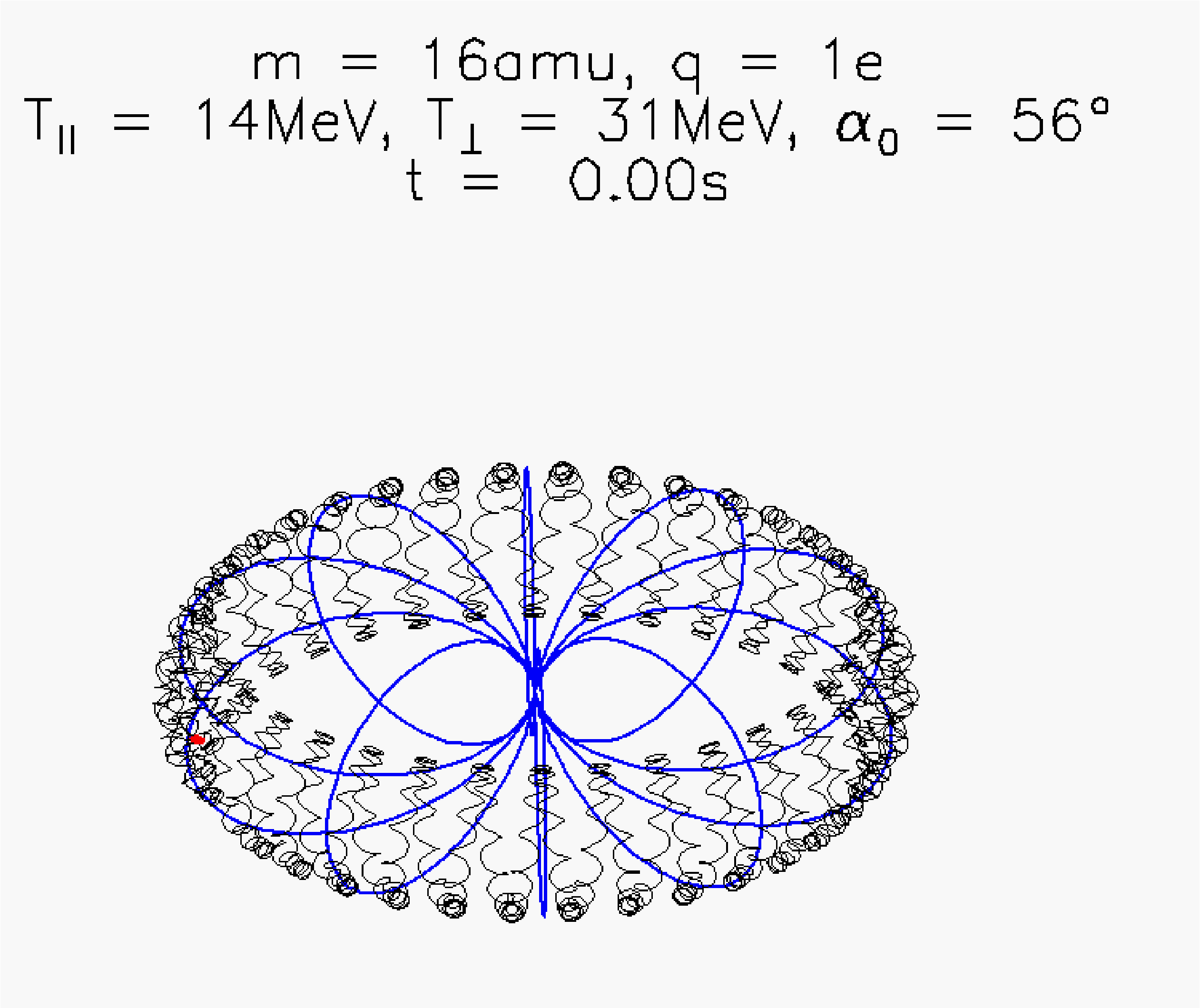




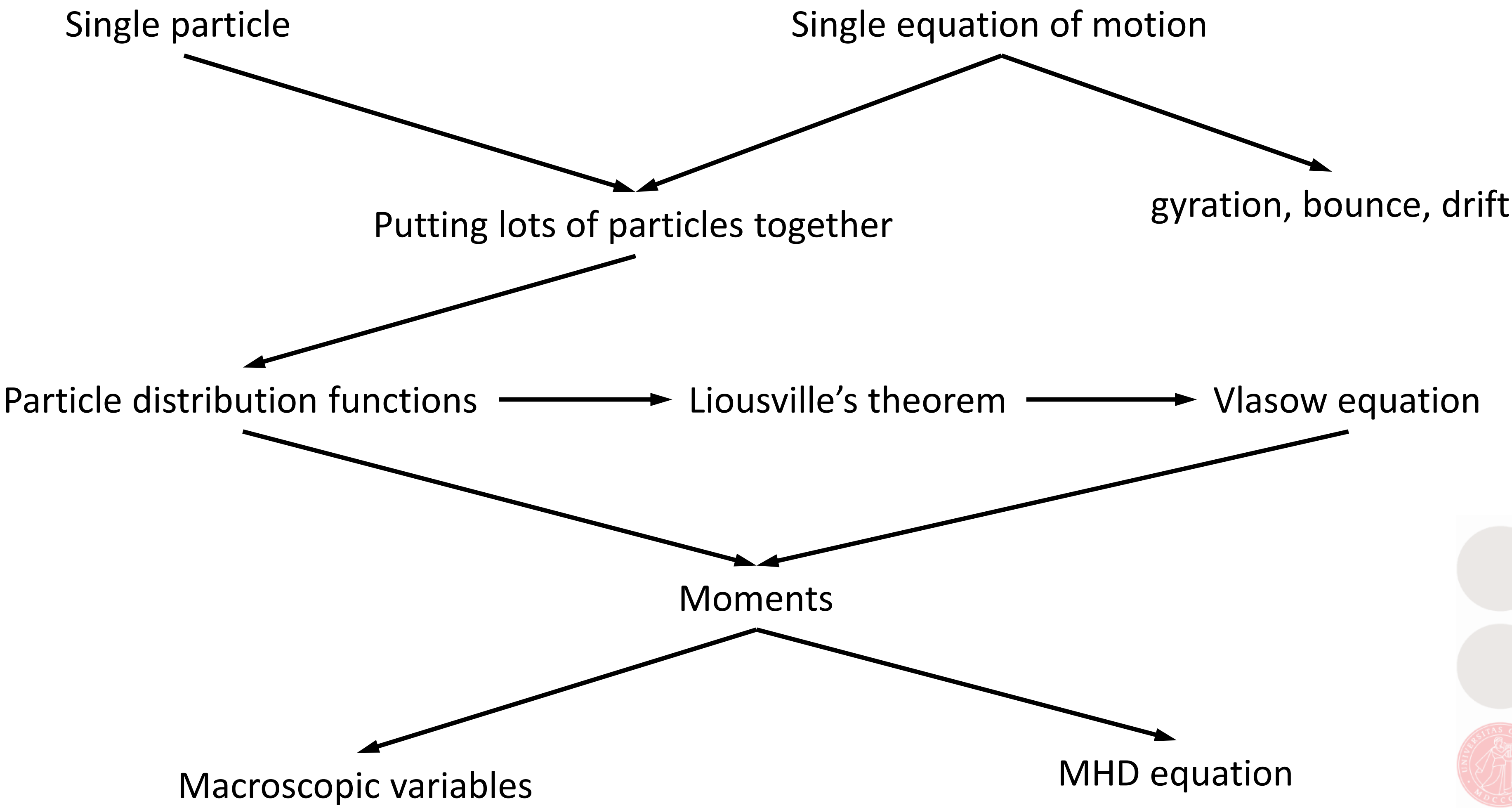
Single particle motion in dipole field



Single particle motion in dipole field



SPM to MHD


Single particle
Single equation of motion
Putting lots of particles together
gyration, bounce, drift
Particle distribution functions
Liousville’s theorem
Vlasow equation
Moments
Macroscopic variables
MHD equation

MHD equations

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = 0$$

$$\frac{\partial (nm\mathbf{v})}{\partial t} + \nabla \cdot (nm\mathbf{v}\mathbf{v}) = -\nabla \cdot \mathsf{P} + \rho\mathbf{E} + \mathbf{j} \times \mathbf{B}$$

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = \eta\mathbf{j} + \frac{1}{ne}\mathbf{j} \times \mathbf{B} - \frac{1}{ne}\nabla \cdot \mathsf{P}_e + \frac{m_e}{ne^2}\frac{\partial \mathbf{j}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0\mathbf{j} + \mu_0\epsilon_0\frac{\partial \mathbf{E}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{u}) = 0$$

$$\rho \frac{\mathrm{D}\vec{u}}{\mathrm{D}t} = -\nabla p + \rho \vec{g} + \vec{j} \times \vec{\mathcal{B}}$$

$$p = \alpha \rho^{\gamma^*}$$

$$\nabla \times \vec{\mathcal{B}} = \mu_0 \vec{j}$$

$$\frac{\partial \vec{\mathcal{B}}}{\partial t} = \nabla \times (\vec{u} \times \vec{\mathcal{B}})$$

Diffusion vs. frozen-in

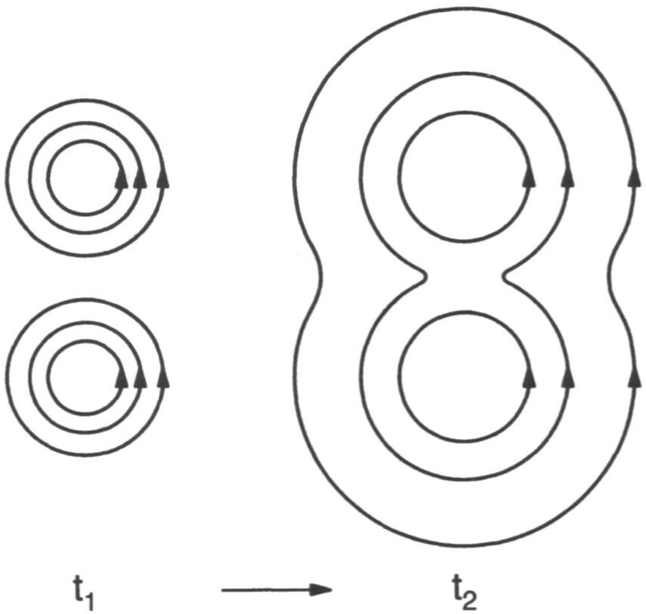


Fig. 5.1. Diffusion of magnetic field lines.

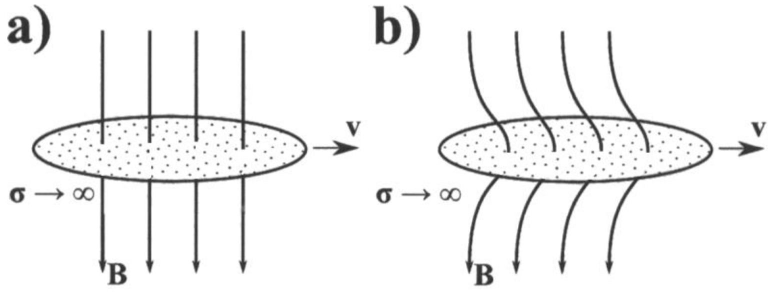


Figure 1.2: Illustration of the "frozen-in" theorem. **a)** A magnetic field penetrates a highly conducting plasma. **b)** As the plasma moves, the magnetic field is "frozen-in" and follows the motion of the plasma.

Magnetic reconnection

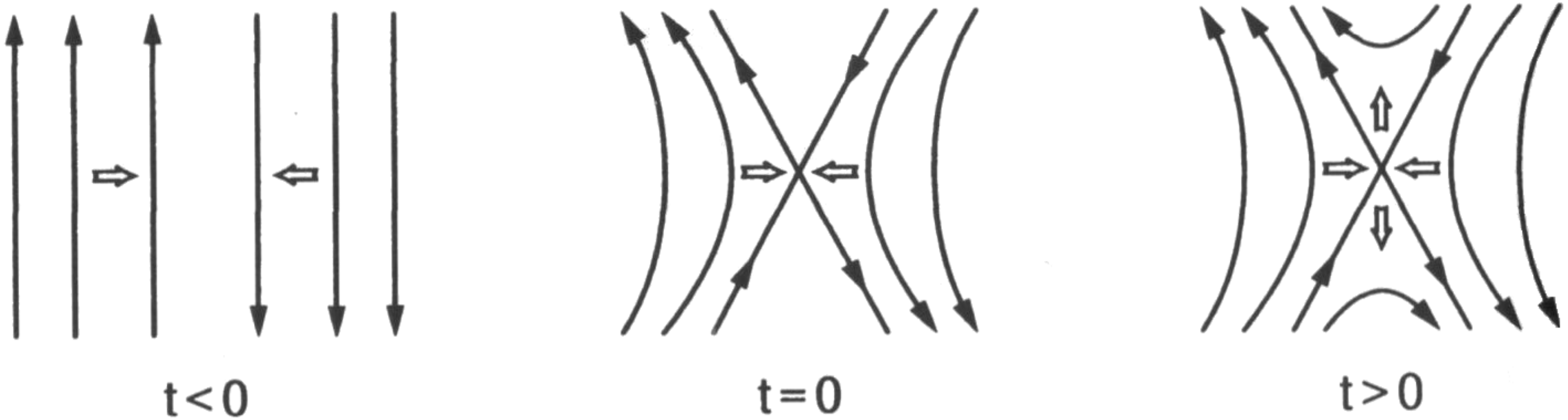


Fig. 5.3. Evolution of field line merging.