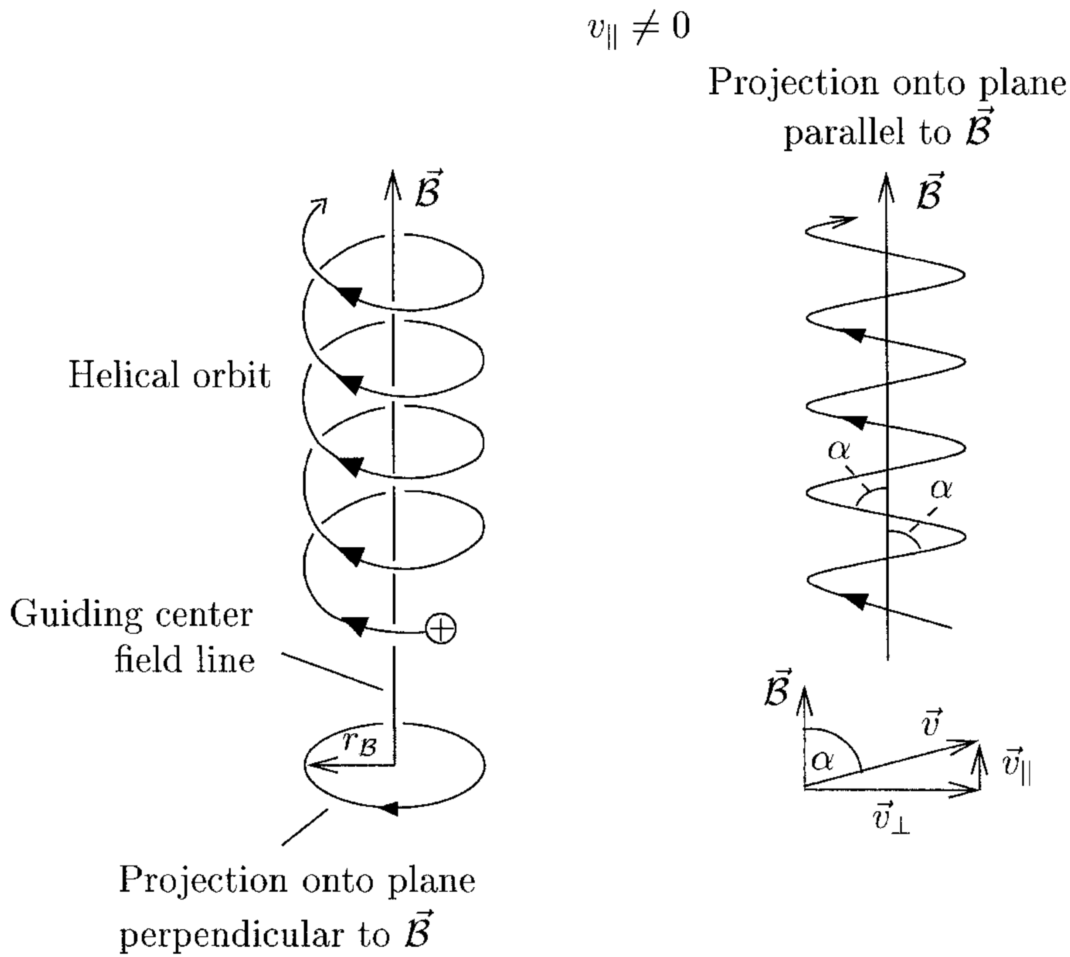
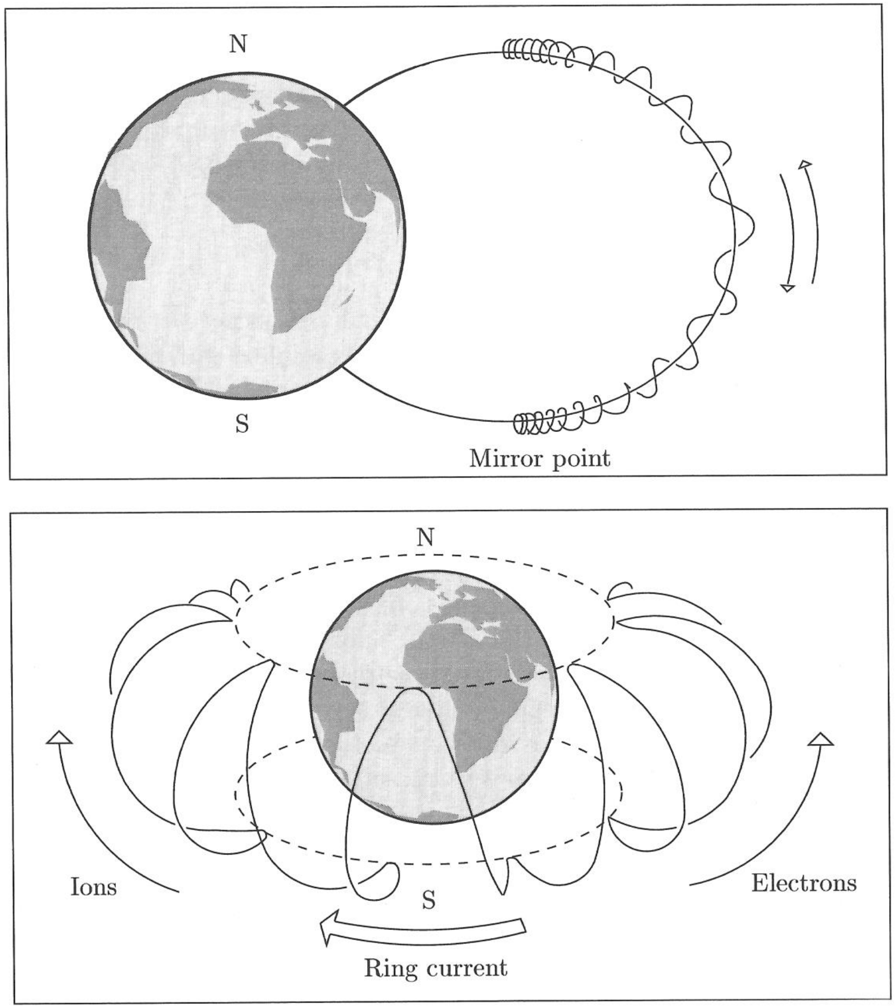
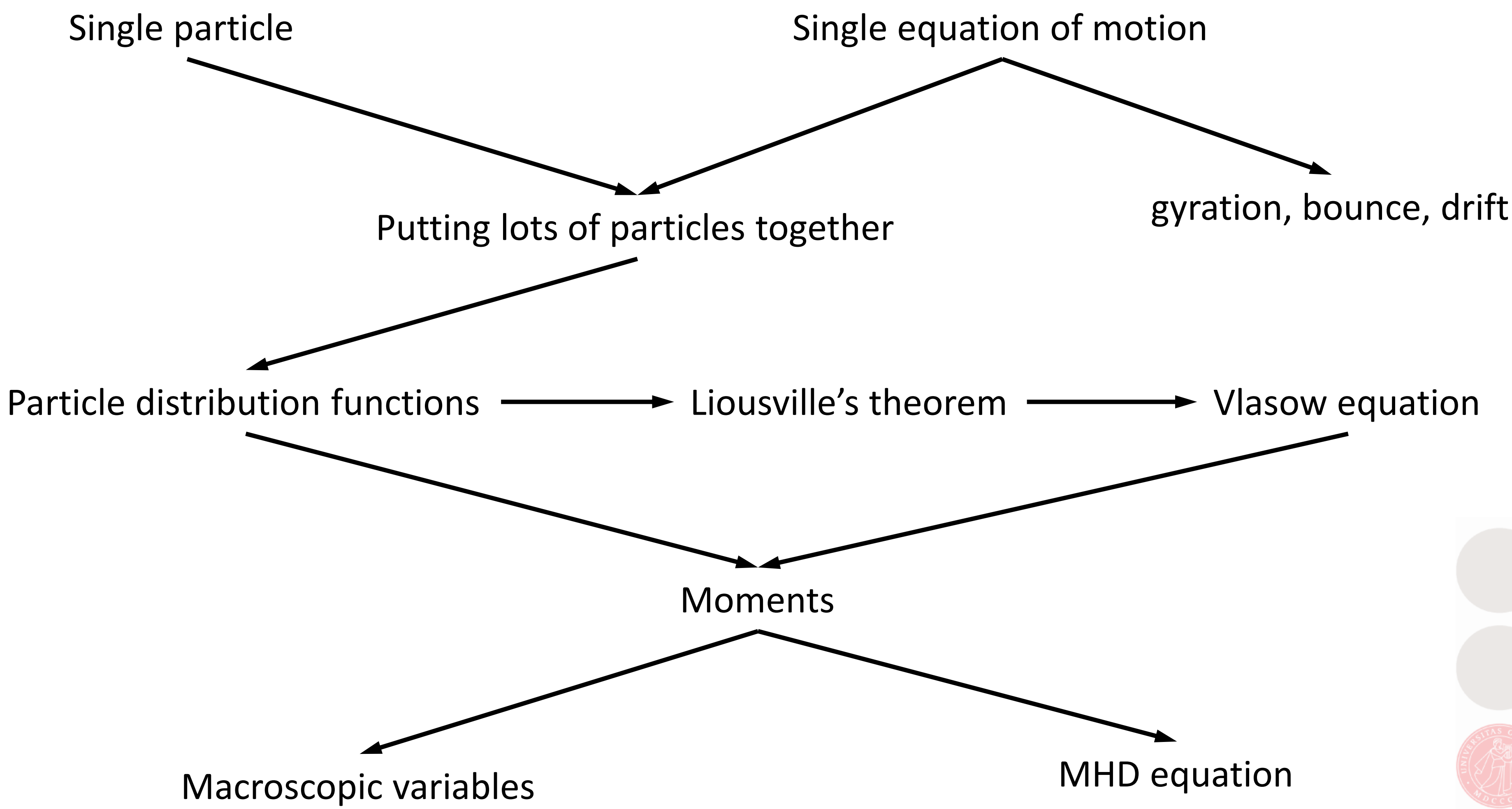
Gyration


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

Bounce and drift motion



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

The road to MHD

	State	Fields	Dynamics
Single particle motion	$q, m, \vec{r}, \vec{v}$	they just are	$m\frac{d\vec{v}}{dt} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$
kinetic theory	$q_s, m_s, f_s(\vec{v}, \vec{r}, t)$	$\rho = \sum_s q_s \int f_s(\vec{v}, \vec{r}, t) d^3v$ $\vec{j} = \sum_s q_s \int \vec{v} f_s(\vec{v}, \vec{r}, t) d^3v$ $\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \nabla \cdot \vec{B} = 0$ $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \nabla \times \vec{B} = \mu_0 \vec{j} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$	$\frac{df_s}{dt} = 0$
Magnetohydro-dynamics (MHD)	$m, n, \vec{v}, p$	$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \nabla \times \vec{B} = \mu_0 \vec{j}$ $\vec{j} = \sigma\left(\vec{E} + \vec{v} \times \vec{B}\right) \qquad p\rho^{-\gamma} = const.$	$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$ $\rho \frac{d\vec{v}}{dt} = -\nabla p + \vec{j} \times \vec{B}$

MHD equations

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

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

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

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

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

Diffusion vs. frozen-in

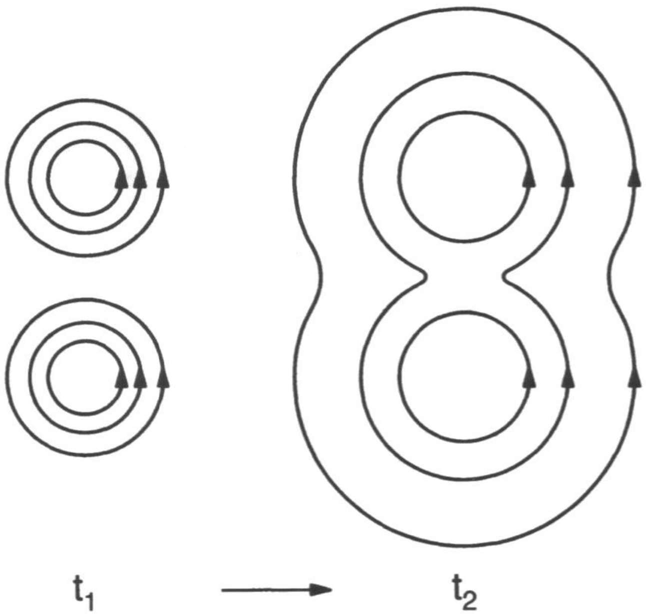


Fig. 5.1. Diffusion of magnetic field lines.

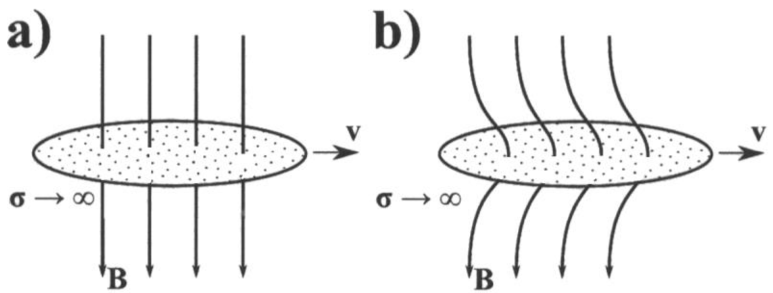


Figure 1.2: Illustration of the "frozen-in" theorem. **a)** A magnetic field penetrates a highly conducting plasma. **b)** As the plasma moves, the magnetic field is "frozen-in" and follows the motion of the plasma.

Magnetic reconnection

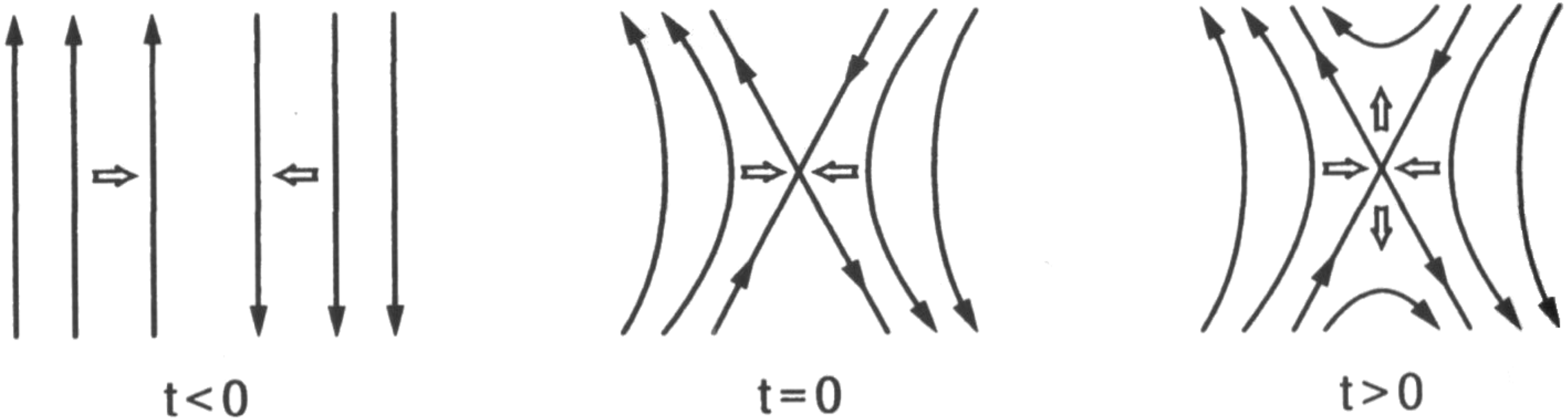


Fig. 5.3. Evolution of field line merging.