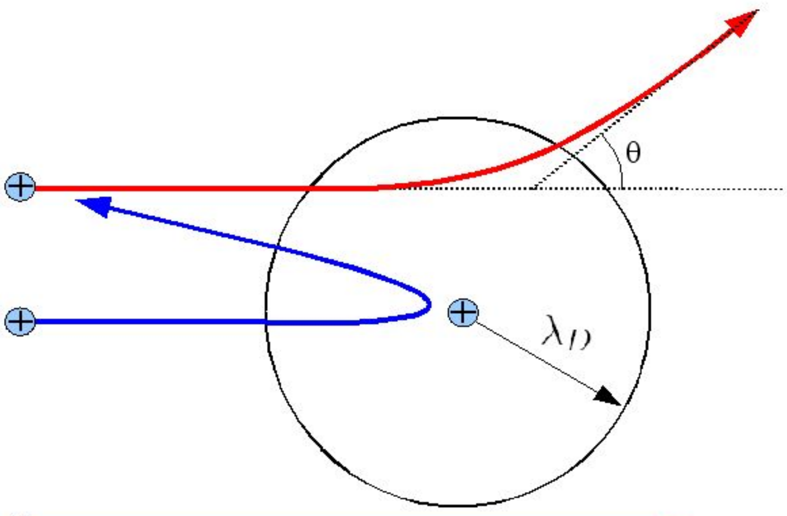
Physics of fusion power

Lecture 14: Collisions / Transport

Collisions

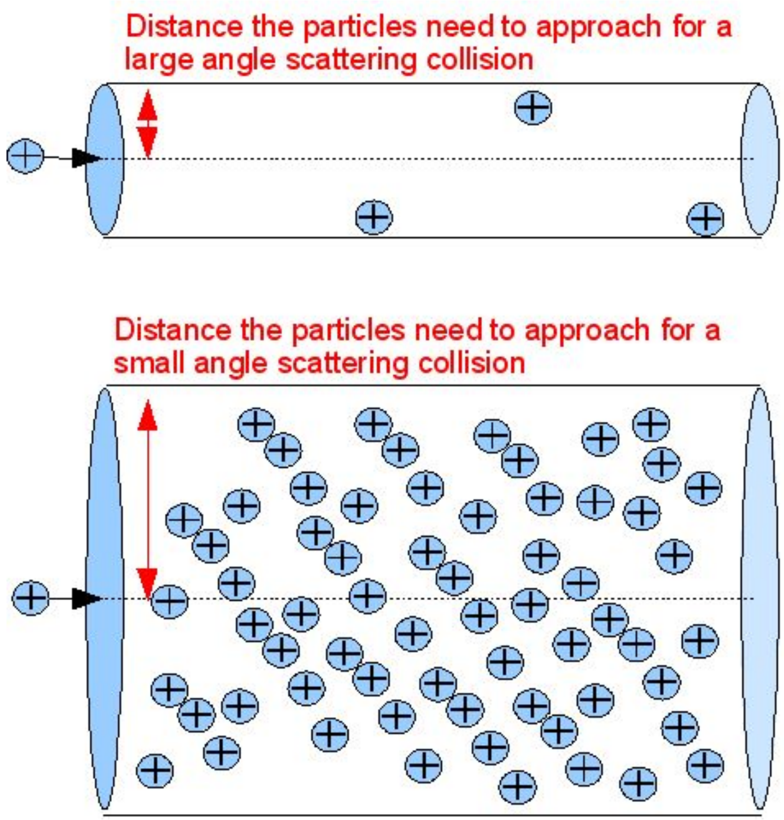
- Coulomb interaction between electrons and ions leads to the scattering of particles -> Collisions
- Interaction occurs only within the Debye sphere
- The angle of deflection depends on how close the particles are approaching each other.



Collisions between the ions

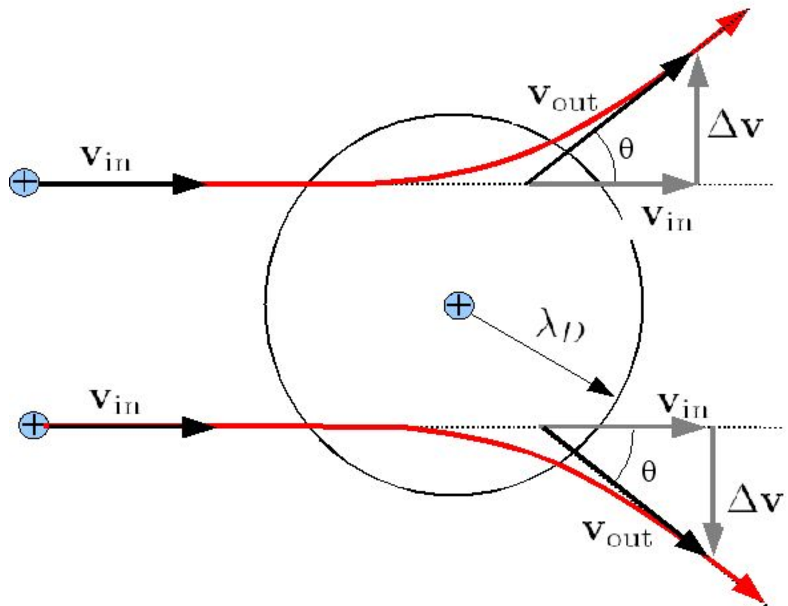
Small / Large angle scattering

- Deflection depends on how close the particles approach each other
- For a given time a particle moving through the plasma will collide with all particles in a cylinder
- For large angle scattering collisions the distance must be small and so is the radius of the cylinder
- For small angle scattering collisions the radius is much larger
- It turns out that small angle scattering collisions dominate



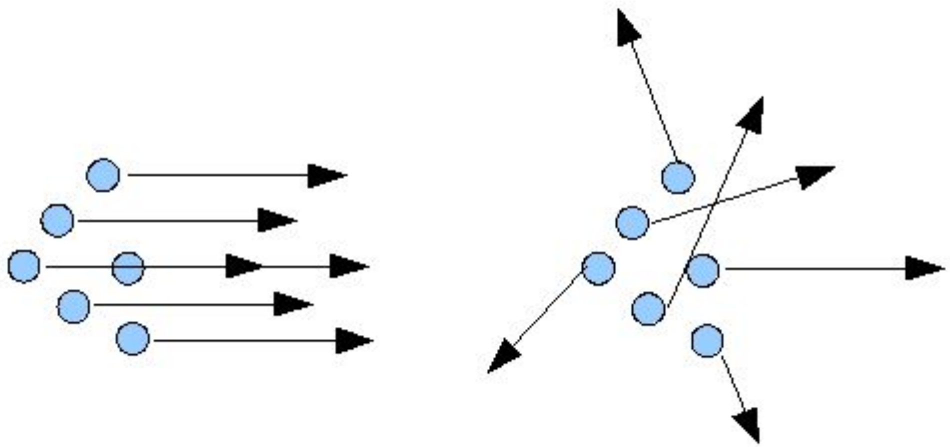
Many body problem

- The plasma has some 10^{22} particles. No description is possible that allows for the determination of position and velocity of all these particles
- Only averaged quantities can be described.
- The evolution of the averaged velocity is however influenced by a microscopic process : the collisions
- Each collision can have a different outcome depending on the unknown initial conditions



Depending on the (unknown) initial conditions the outcome of a collision can be very different

Diffusion of the velocity direction



Initially particles move in one direction

After some time the collisions lead to a random direction

Diffusion of the velocity

- Diffusion coefficient

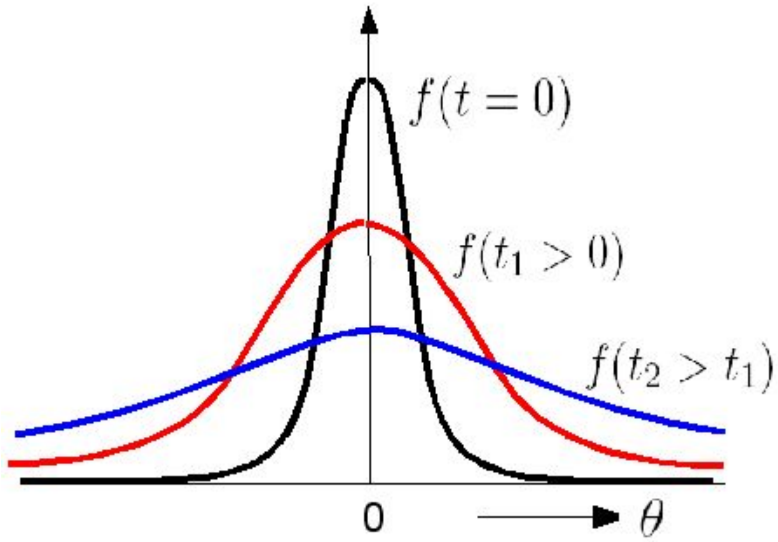
$$D = \frac{\langle \Delta\theta \Delta\theta \rangle}{2\tau}$$

- Define a function that determines the number of particles moving in a direction given by the angle θ

$$\mathrm{d}N = f(\theta)\mathrm{d}\theta$$

- Collisions lead to a diffusion in the angle described by

$$\frac{\partial f}{\partial t} = D \frac{\partial^2 f}{\partial \theta^2}$$



Initial distribution of particles moving mostly in the same direction (same angle) are scattered by collisions which randomize the angle of propagation

Transport in a homogeneous magnetic field

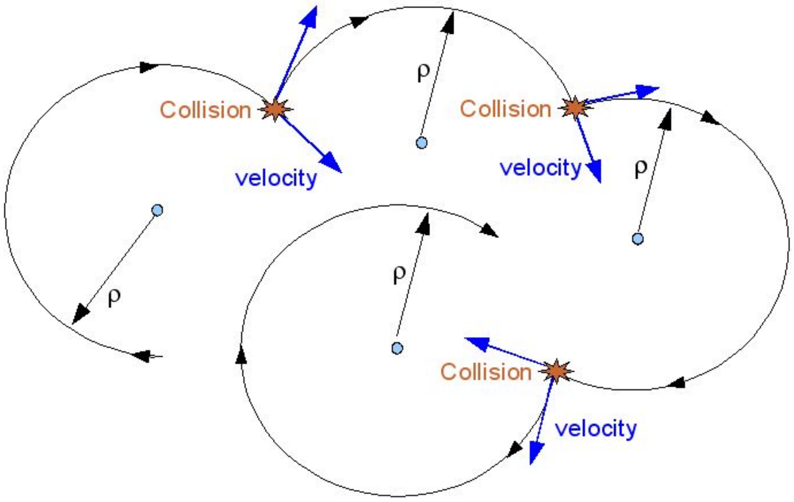
- Particles undergo scattering. The diffusion coefficient

$$D = \frac{(\Delta x)^2}{2\tau}$$

- Typical step size is the Larmor radius, typical time the collision frequency

$$\Delta x = \rho \qquad \frac{1}{\tau} = \nu$$

$$D = \frac{1}{2}\rho^2 \nu$$



Collisional scattering leads to a random walk of the particle in space

Transport in a homogeneous magnetic field

- Typical values for a reactor

$$D = \frac{1}{2}\rho^2\nu \qquad \rho = 4\,\mathrm{mm} \qquad \nu = 1000\,\mathrm{s}^{-1}$$

$$D \approx 8 \cdot 10^{-3}\ \mathrm{m}^2/\mathrm{s}$$

- The particles satisfy a diffusion equation

$$\frac{\partial n}{\partial t} = D\frac{\partial^2 n}{\partial x^2} \xrightarrow{\text{Rough estimate for r = a gives confinement time T}} \frac{n}{T} = D\frac{n}{a^2}$$

$$a = \sqrt{DT} \xrightarrow{\text{For T = 3 s}} a = 15\ \mathrm{cm}$$