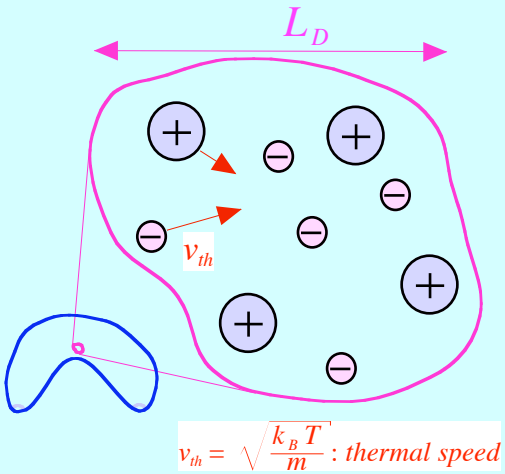
Typical scales used in both approaches...

Kinetic approach... **particle** is a fundamental object (its internal structure is not considered)



Typical scales:

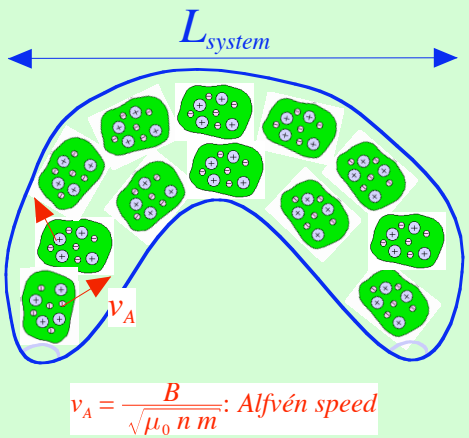
Length... L_D (Debye length)

e.g., 1 cm for a solar coronal plasma

Time... $L_D / v_{th} \sim 1 / \nu_p$ (plasma frequency)

e.g. 5×10^{-9} s for a solar coronal plasma

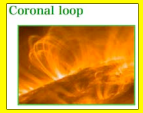
Fluid approach... **fluid element** is a fundamental object (its internal structure is not considered)



Typical scales:

Length... L_{system} (system size)

e.g., 100,000 km ~ 10^8 m for a coronal loop



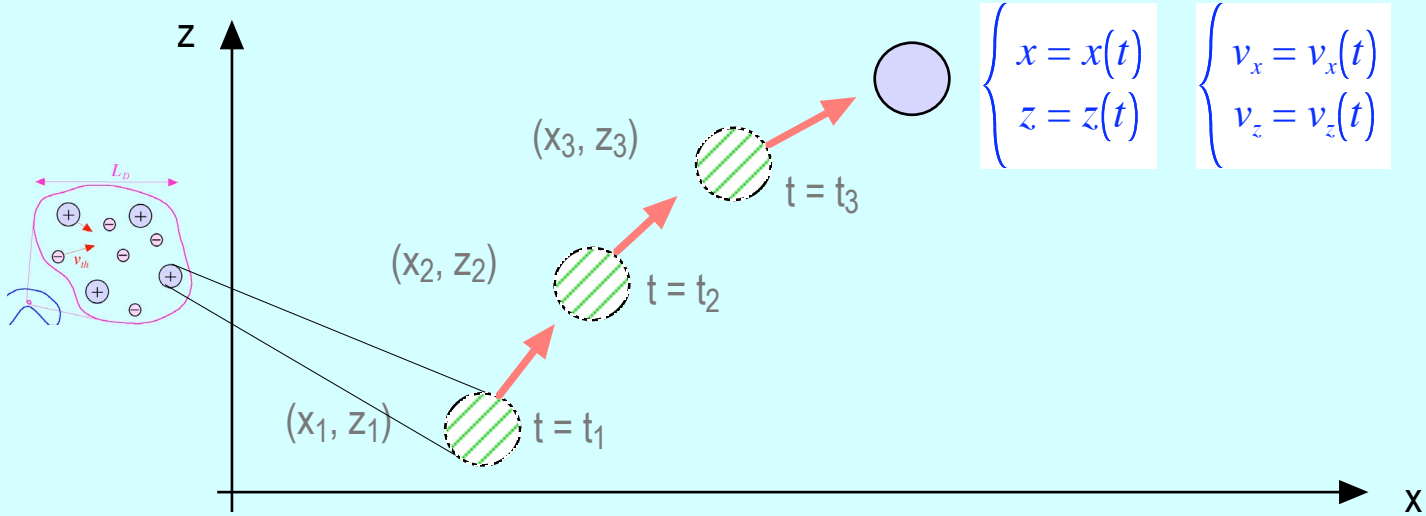
Time... L_{system} / v_A (Alfvén transit time)

e.g. 100 s for a coronal loop (v_A ~ 1000 km/s)

Basic equations in kinetic & fluid approaches

Kinetic approach... Focus on position and velocity of each particle at every time

=> **Mechanical equation**



$$\begin{cases} x = x(t) \\ z = z(t) \end{cases} \qquad \begin{cases} v_x = v_x(t) \\ v_z = v_z(t) \end{cases}$$

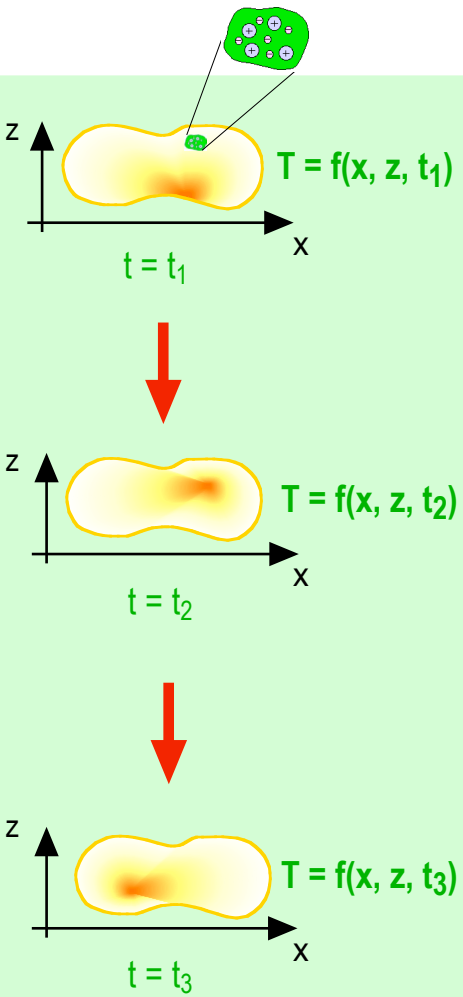
In the kinetic approach, we consider the physical state of each **particle** represented by its **position** and **velocity**.

The mechanical equation is a differential equation where **time** is the only independent variable (**ordinary differential equation**, ODE).

$$\begin{cases} \dfrac{dx}{dt} = v_x(t) \\ \dfrac{dz}{dt} = v_z(t) \end{cases} \qquad \begin{cases} m\dfrac{dv_x}{dt} = F_x(x(t), z(t), v_x(t), v_z(t), t) \\ m\dfrac{dv_z}{dt} = F_z(x(t), z(t), v_x(t), v_z(t), t) \end{cases}$$

Fluid approach... Focus on mass density, flow velocity, pressure, temperature of each fluid element in space-time (these are statistically averaged quantities derived from position & velocity distributions of particles)

=> **Fluid dynamics equations**



In the fluid approach, we consider the physical state of each **fluid element** represented by **statistically averaged quantities** such as **density**, **flow velocity**, **pressure**, and **temperature**. For example, temperature changes with position and time, so it is expressed as a function of position and time:

$$T = f(x, z, t)$$

Temperature field

continuously distributed in space-time

Particles do not fill up the space, whereas fluid elements do that.

An equation for the temperature field is a differential equation where **position** and **time** are independent variables (**partial differential equation**, PDE).

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} \right)$$