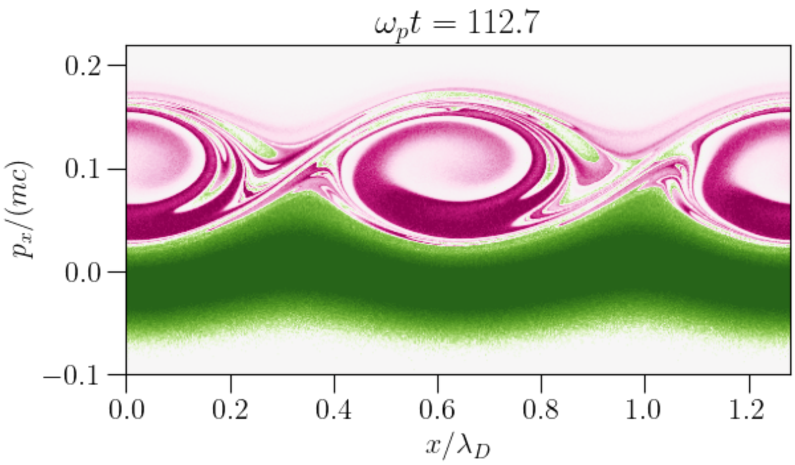
Title : **Kinetic theory of plasmas**	
Acronym : TC3	
UECoordinator : Jean-Luc RAIMBAULT, Laboratoire de Physique des Plasmas (LPP)	
Teaching staff : Mickaël GRECH, Pierre MOREL, Jean-Luc RAIMBAULT	
Pre-requisites : First year of MSc in Physics or Engineering Schools.	
Credits : 3 ECTS	
Language : French/English	



Nonlinear stage of the ump on tail instability (green : background plasma, pink : beam).

This course is divided into three parts presented below.

I. Kinetic theory : the foundations

Keywords : Phase space, density probability, distribution function; Kinetic equations (Liouville, Klimontovich, Boltzmann, Vlasov), BBGKY hierarchy, Hydrodynamic moments; Vlasov-Poisson and Vlasov-Maxwell models, Conservation laws, Linear theory (waves and instabilities), Wave-particle interaction, Landau damping; Coulomb collisions, Collision operators, Collision frequency, Diffusion coefficients, Conductivity, Heating and transport

This course aims to lay the basis of the kinetic theory of plasmas. It focuses on classical, non relativistic and fully ionized plasmas.

A first part introduces the notions of phase space, density probability and distribution functions, as well as the Klimontovich and Liouville equations that describe the exact evolution of the plasma. We then discuss the approximations and procedures allowing to derive, from these exact descriptions, the most useful statistical descriptions of kinetic plasmas: the plasma kinetic equation (accounting for collisions) and the Vlasov equation (for collisionless plasmas). This introductory part ends with the derivation of the hydrodynamic equations and a discussion of the links between the kinetic and hydrodynamic descriptions.

The second part of this lecture focuses on collisionless plasmas, as described by the Vlasov-Poisson (electrostatic) and Vlasov-Maxwell (electromagnetic) systems. The general properties of these descriptions are discussed: equilibrium and steady-state solutions, conservation of entropy, momentum and energy, etc. Their linearization is then discussed in details, and kinetic effects on waves and instabilities is addressed. A particular attention is paid to the Landau damping of electrostatic waves in the framework of linear theory (dispersion relation and damping rate) and nonlinear effects (particle trapping) are, though briefly, discussed.

The third and last part addresses the kinetic theory of collisional plasmas. Only elastic, Coulomb collisions are considered. The notions of cross-section, mean-free-path, collision frequency and diffusion coefficients are introduced. Various collision operators (Boltzmann, Fokker-Planck, Landau in particular) are then discussed and applied to the study of various important processes such as conductivity or heat transport.

II. Application to magnetic fusion plasmas : transport and relaxation in tokamak plasmas

Keywords : Principles of fusion and magnetic confinement – Magnetic equilibrium – Gyrokinetic Theory – Landau collision operator – Neoclassical theory – Collisional and non collisional relaxations – Micro-instabilities – Angle-action variables – Resonances – Zonal flows and geodesic acoustic modes.

The objective of the course is to study the phenomena of reorganisation of the distribution function of plasma particles, undergoing for example heating, in velocity space (relaxation) or in position space (transport). In particular, hot, low collisional, and especially fully ionised plasmas are studied here. Such plasmas are encountered in thermonuclear fusion, but also in the universe.

After introducing the basic principles of a thermonuclear fusion reactor, the case of magnetic confinement is studied in depth. The presence of a strong magnetic field allows the construction of the gyrokinetic theory and the fluid equations derived from it. The main micro-instabilities, associated with the magnetized plasma, can then be studied in the gyrokinetic framework.

The Landau collision operator is presented, and its consequences in terms of particle and heat transport is deduced in the framework of the neoclassical theory. In the presence of particles or heat sources, or instabilities, the relaxation mechanisms of the distribution function are presented in an action-angle formalism. The development of large-scale structures, their interest for confinement and their persistence over long times are finally discussed.

III. Application to cold plasmas : Introduction to the kinetic theory of discharges

Keywords : 2 terms approximation. Boltzmann collision operator and Lorentz models. Electronic transport coefficients. EEDF (Electron Energy Distribution Function) equation. Local and non-local approximations of the EEDF equation.

In cold plasmas, most of the electrical power is absorbed by the electrons which dissipate this energy by elastic and inelastic collisions with neutrals. Due to the low ionization rates observed in cold plasmas, electron-electron collisions are rare and the electron distribution function deviates significantly from a Maxwellian equilibrium distribution. This non-equilibrium character of electrons is the main reason for a kinetic description of the heating and transport of electrons in the cold plasmas studied in this course.

The dominant collisions for electrons in cold plasmas being electron-neutral collisions, the electron distribution function is quasi-isotropic. A spherical harmonic expansion of the electron distribution function is therefore convenient that leads to the so-called 2-term approximation.

We then study the elastic and inelastic electron-neutral collisions in detail using the Boltzmann collision operator. The low m/M mass ratio allows to simplify this operator in the framework of the so-called Lorentz models. Explicit expressions for the collision terms, in the kinetic or fluid frameworks, are obtained.

Using the kinetic approach developed in the framework of the 2-term approximation, we obtain general expressions for the electron transport coefficients in weakly ionized plasmas, magnetized or not, in stationary or time-dependent situations. In particular, explicit expressions of the mobility, diffusion and thermal diffusion coefficients, as well as their energy analogues, are obtained.

Finally, we establish the general expression of the evolution equation of the isotropic part of the electron distribution function (EEDF) in the position-energy phase space. From this equation, we discuss 2 approximations, valid respectively at high and low pressures, the so-called local and non-local approximations of the EEDF. Explicit solutions of the EEDF equation under these two approximations are given in the case of dominant electron-neutral elastic collisions, which lead to the Druyvesteyn distribution function in the case of the local approximation, and to the generalized Boltzmann relations in the case of the non-local approximation.