



UNIVERSITÀ  
DEGLI STUDI DI MILANO-BICOCCA

## SYLLABUS DEL CORSO

### Fisica dei Plasmi II

2021-1-F1701Q091

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#### Aims

The course aims at providing the students an introduction to plasma physics and thermonuclear fusion

#### Contents

Introduction to plasma physics, charge particle motion in a magnetic field, introduction to collisional processes in plasmas, introduction to the collisional kinetic theory, basics of nuclear fusion in tokamak devices, physics principles of selected diagnostic techniques for tokamak plasmas.

#### Detailed program

##### *Chapter 1: Introduction to plasma physics*

Introduction, general properties of a plasma and main plasma parameters. Quasi neutrality. Debye length. Coulomb collisions in plasmas. Rutherford cross section. Large and small angle collisions. Neutral particle collision cross section. Collision frequencies. Simple transport phenomena in plasmas: resistivity and ambipolar diffusion. Current in a vacuum tube. Arc discharge.

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## **Chapter 2: Particle motion in magnetic and electric fields**

Drift formalism of the particle motion in electric and magnetic fields. Magnetic moment invariance and its applications to mirror machines. Lagrangian formalism and exact constants of motion: rotational invariance and its application to tokamak confinement. Adiabatic invariants: adiabatic invariant of a pendulum; the action integral as an adiabatic invariant. Second and third adiabatic invariant for the motion of a charged particle in a magnetic field. Toroidal confinement configurations: tokamaks and stellarators. Magnetic surfaces, rotational transform and safety factor of a tokamak. Passing and trapped particles in a tokamak. Guiding centre motion of a passing and trapped particle in a tokamak.

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## **Chapter 3: Coulomb collisions in plasmas and charged particle slowing down**

Main properties of collisions in fully ionized plasmas. Formal derivation of the Fokker-Planck equation. Isotropy and friction terms in the Fokker-Planck equation for small angle Coulomb collisions. Slowing down equation for the average particle velocity. Slowing down of a charged particle in a plasma: resistive and runaway regimes. Slowing down of a charged particle having a velocity between the thermal ion and electron velocities. Calculation of the plasma resistivity and of the Dreicer electric field for runaway electron production starting from the Fokker-Planck equation. Calculation of the steady state alpha particle slowing down distribution from the Fokker-Planck equation.

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## **Chapter 4: Emission of radiation from plasmas**

Introduction to radiation emission processes in plasmas. Emission of radiation from a free charge: bremsstrahlung and cyclotron emission. Electromagnetic potentials for a free charge in arbitrary motion. Poynting vector and radiative components of the electric and magnetic fields for non relativistic charged particles. Total radiated power

and its angular distribution. Cyclotron emission: total radiated power and its frequency spectrum. Emission at the fundamental cyclotron frequency and its harmonics. Total power radiated by bremsstrahlung. Elements of transport of radiation in a plasma: emission and absorption processes. Optical thickness.

*References*

- Pucella, ch. 12.1, and 12.7 (introduction and transport of radiation)
- Freidberg, ch. 3.5 and appendix B (bremsstrahlung and radiation from an accelerating charge)
- Hutchinson, ch. 5.2.1 (cyclotron radiation)

**Chapter 5: Collisional transport**

Diffusion due to charged particle collisions: random walk model, diffusion equation, diffusion coefficients in magnetized and non magnetized plasmas. General properties of diffusion in weakly ionized plasmas. Two fluid model for weakly ionized plasmas without magnetic field: calculation of the ambipolar electric field and diffusion coefficient. Introduction to diffusion in fully ionized plasmas: role of like and unlike particle collisions. Particle diffusion due to electron-ion collisions in fully ionized plasmas: calculation of the diffusion coefficient and comparison with experimental data. Diffusion of energy in fully ionized plasmas: role of ion-ion, electron-electron and ion-electron collisions and their thermal diffusivities. Comparison between theory and experiment. Introduction to neoclassical transport: contribution of passing and trapped charges to particle and energy transport in toroidal geometry. Bootstrap current. Brief introduction to some experimental aspects of turbulent transport.

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**Chapter 6: Introduction to controlled thermonuclear fusion**

Main reactions of interest for controlled thermonuclear fusion, role of alpha particles and neutrons in the deuterium-tritium reaction, classical and quantum reaction cross section. Calculation of the reactivity and of the reaction rate, processes that contribute to plasma heating and plasma cooling. Energy confinement time, Lawson criterion, thermonuclear reactor regimes: ideal ignition, ignition and power amplification. Thermal and electric gain factor Q.

*References:*

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**Reference textbooks**

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## Prerequisites

Mathematics and Physics courses of the Bachelor Degree in Physics

## Teaching form

Frontal lessons on theory and problem solving. Lectures will be in English.

*Note: During the Covid-19 crisis period, lectures will be recorded from remote and available for download offline. Some events (eg. student reception and counselling) may be held in real time.*

## Textbook and teaching resource

### Reference textbooks

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## Semester

First semester

## Assessment method

Homework evaluation and final oral exam

## 1) Homework evaluation

The student will be assigned homework to solve during lectures. The student must solve his assignments and present his own solution of the homework at the oral exam. The student can ask the teacher for clarifications on his assignments.

## 2) Oral exam

The structure of the oral exam is as follows. The student can choose a topic of the course and must be able to discuss the topic he has chosen in all its details, including the demonstrations that have been presented during the lectures. The next questions are instead more general and on some of the other topics discussed during the lectures. The student is not expected to know these other topics in all their details, but must still be able to discuss the most important results and their implications. This more general part will start from the discussion of the solution of the assignments done by the student.

*Note: During the Covid-19 crisis period exams will be from remote. They will be held using the WebEx platform and a link will be made publicly available on the course e-learning page for students and attendees who would like to participate in them.*

## Office hours

By appointment via email

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