UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

# COURSE SYLLABUS

# Elements of Plasma Physics

**2526-3-E3001Q076**

## Aims

The course aims to teach the fundamental introductory elements of plasma physics.

- Knowledge and understanding: knowledge of the main elements of plasma physics and understanding of the mathematical models that describe them.
- Applied knowledge and understanding: knowledge of the main elements of plasma physics, related phenomenology, and some experiments in which they are applied.
- Judgement autonomy: ability to independently assess the limitations of plasma description models in relevant phenomena.
- Communication skills: ability to clearly describe certain phenomena related to plasma physics, the models that describe them, and their limitations.
- Learning skills: ability to learn basic elements of plasma physics at a level suitable for solving simple quantitative problems.

## Contents

Definition of plasma and some basic parameters; single particle description and motion of a charged particle in a plasma; the plasma as a charged fluid; magnetohydrodynamic equilibria and plasma confinement; elements of plasma waves; elements of collisions in plasmas.

## Detailed program

*1) Definition of plasma and some basic parameters*

Definition of plasma and some basic parameters: ionization stage and Saha equation, quasi-neutrality, Debye screening, plasma frequency, distribution function and temperature.

*2) Single particle description: motion of a charged particle in a plasma*

Motion of a charged particle in an electric and magnetic fields and drift velocities.

Motion in non uniform magnetic fields: drifts due to the gradient of the magnetic field and due to line curvature.

Motion in time dependent fields: polarization drift.

General relation between periodic motions and adiabatic invariants: the case of the simple pendulum.

Applications of adiabatic invariants to plasmas: gyromotion and magnetic moment. Mirror machines.

Second and third adiabatic invariants and their applications.

*3) The plasma as a charged fluid*

Derivation of the equations that describe the plasma as a charged fluid: equations for the conservation of mass and momentum. Diamagnetic drift.

Single fluid equations and magnetohydrodynamics (MHD).

*4) Magnetohydrodynamics equilibria and plasma confinement*

MHD equilibrium equations and their general properties: current and magnetic flux surfaces; magnetic pressure and tension.

Some magnetic equilibrium configurations, their properties and limitations: z-pinch, theta-pinch, screw-pinch.

Equilibrium and force balance in toroidal configurations.

Brief introduction to MHD instabilities.

*5) Elements of plasma waves*
Summary of some basic properties of waves: Fourier representation, phase and group velocity, dispersion relation, uncertainty principle.

Two fluid description of electrostatic and electromagnetic waves in uniform and non magnetized plasmas.

Alfvén waves in the MHD framework for uniform plasmas.

Brief description of some experimental aspects of the propagation of waves in plasmas.

## Prerequisites

Mathematics and Physics courses of the first two years of the Bachelor's Degree in Physics

## Teaching form

Frontal lectures and homework assignment. Lectures will be in Italian and will include:
• 17 in-person lectures (2 hours each; 34 hours in total)
• 7 remote lectures (2 hours each; 14 hours in total)

## Textbook and teaching resource

F.F. Chen, Introduction to Plasma Physics and Controlled Fusion, 2nd ed. Vol.1, Plenum Press NY

Paul M. Bellan, “Fundamentals of plasma physics”, ed. Cambridge University Press, 2006

J.P. Freidberg, “Plasma physics and fusion energy”, ed. Cambridge University Press, 2007

G. Pucella e S. E. Segre, “Fisica dei plasmi”, ed. Zanichelli, 2009

## Semester

I semester

## Assessment method

Written test made of two sections. The test may be followed by a short oral assessment. In the first section of the written test, the student will have to write a short essay on a topic among those available in a list published on the e-learning page. The essay should be detailed and must include all the relevant mathematical proofs. At least three days before the date of the exam, the student will have to write an e-mail to the teacher when they specify their own selection of three topics (belonging to different chapters) among those found in the list mentioned above. On the day of the exam, the teacher will choose one topic out of the three chosen by the student for the first section of the test. The second section of the test will consist of two short exercises. Each exercise will be based on solving one of the homework assignments with the addition of some further general questions on their theoretical background. The student will not need to include mathematical proofs of the equations required to solve these exercises or to discuss the theoretical background. During the exam, the student is not allowed to use books or personal notes, but can use a printed version of the formulary made available on the e-learning page. Each section of the test will be scored up to 16 points. The final mark will be the rounded up sum of the scores obtained in each of the two sections. If the final score is greater than 30, the final mark will be "30 cum laude". For each section, the score is assigned as follows: 70% will be based on the content and the remaining 30% will be based on the clarity of the text. Content and clarity of the text must both be acceptable for the student to pass the exam. A minimum total score of 15 is required to participate in the short oral assessment. If the total score is greater or equal to 20, the student can accept it as it is by sending an email to the teacher, without need for a short oral assessment. The short oral assessment will be a discussion of those topics which were found to be more deficitary based on the written test. The exam will be in Italian, or English, if asked by the student.

#### Grading of evaluations

18-19: Preparation on a limited number of topics from the course syllabus, with limited ability to address and apply them to problem-solving. In the case of the oral exam, these abilities only emerge with the help and questions from

the instructor. Presentation skills and vocabulary are not always correct, with limited critical thinking abilities.

20-23: Preparation on a portion of the topics in the course syllabus, with the ability to apply knowledge to solve only simpler problems. Correct vocabulary is used, although not entirely accurate or clear, and presentation skills are occasionally uncertain.

24-27: Preparation on a wide range of topics covered in the course syllabus, with the ability to apply knowledge to solve problems of intermediate difficulty. Correct vocabulary is used, and there is competence in the use of disciplinary language.

28–30/30L: Complete and thorough preparation on the topics of the exam syllabus, with the ability to critically analyze topics and apply knowledge to solve even fairly complex problems. Full mastery of disciplinary vocabulary and rigorous, well-structured presentation skills.

## Office hours

By appointment via email

## Sustainable Development Goals

QUALITY EDUCATION | DECENT WORK AND ECONOMIC GROWTH