UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Plasma Physics II

2425-1-F1701Q091

Aims

The course aims at providing the students with a description of collisional effects in plasmas, radiation emission and some elements of tokamak physics and thermonuclear fusion.

Contents

Basic plasma properties and introduction to collisional processes in plasmas, introduction to the collisional kinetic theory, emission of radiation from plasmas, particle and energy transport from collisions, elements of tokamak physics, basics of thermonuclear fusion.

Detailed program

Chapter 1: Introduction to plasma physics
Review of some basic plasma properties: 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.

Chapter 2: 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.

Chapter 3: 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.

Chapter 4: 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.

Chapter 5: Elements of Tokamak Physics
Toroidal confinement devices: tokamaks and stellarators. Magnetic surfaces, rotational transform and safety factor of a tokamak. Passing and trapped particle orbits in a tokamak. Tokamak equilibrium: Grad-Shafranov equation. Elements of neoclassical and turbulent transport in tokamaks. Emission of nuclear radiation.

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.

Prerequisites

Mathematics and Physics courses of the Bachelor's Degree in Physics. Some previous knowledge of plasma physics is recommended, but not mandatory.

Teaching form

Frontal lessons with homework assignment. Lectures will be in English and will include:

- 16 in-person lectures (2 hours each; 32 hours in total)
- 5 remote lectures (2 hours each; 10 hours in total)

Textbook and teaching resource

Reference textbooks

- (Bellan) Paul M. Bellan, “Fundamentals of plasma physics”, ed. Cambridge University Press, 2006
- (Pucella) G. Pucella e S. E. Segre, “Fisica dei plasmi”, ed. Zanichelli, 2009

- (Goldston) R.J. Goldson e P.H. Rutherford, “Introduction to Plasma Physics”, IOP Publishing Ltd, 1995
- (Freidberg) J.P. Freidberg, “Plasma physics and fusion energy”, ed. Cambridge University Press, 2007
- (Chen) F.F. Chen, Introduction to Plasma Physics and Controlled Fusion, 2nd ed. Vol.1, Plenum Press NY

Semester

Second 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 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 the 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. If the number of students attending the course is limited (not more than 10), the exam will be oral and it will have the same structure of the written test specified above.

Office hours

By appointment via email

Sustainable Development Goals

QUALITY EDUCATION | AFFORDABLE AND CLEAN ENERGY | DECENT WORK AND ECONOMIC GROWTH