UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Plasma Physics II

2122-1-F1701Q091

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.

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.

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.

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.

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.

Chapter 6: Introduction to controlled thermonuclear fusion

Main reactions of interest for controlled thermonuclear fusion, role of alpha particles and neutrons in the deuteriumtritium 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 Degree in Physics

Teaching form

Frontal lessons with homework assignment. Lectures will be in English.

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
- (Dolan) T.J. Dolan “Fusion Research”, Pergamon Press ISNB 0-08-025565-5
- (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
- (Bekefi) G. Bekefi, **“**Radiation Processes in Plasmas”, Wiley, New York
- (Bittencourt) J.A. Bittencourt, Fundamentals of Plasma Physics, Third Edition, Springer
- (Chen) F.F. Chen, Introduction to Plasma Physics and Controlled Fusion, 2^{nd} ed. Vol.1, Plenum Press NY

Semester

Second semester

Assessment method

Oral exam with homework assessment

1) Homework assessment

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

2) Oral exam

The structure of the oral exam is as follows. The student can choose three topics of the course he would like to discuss in detail at the exam. Each topic shall belong to a different course chapter. Out of those three topics, during the exam the examiner will choose at least one, which the student must be able to discuss in all its details, including the demonstrations that have been presented during the lectures. The next questions will instead be 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.

Office hours

By appointment via email