“Plasma physics 2” - syllabus – a.y. 2020/2021

Teacher: M. Nocente

Chapter 1: Introduction to plasma physics

Definition of “plasma” and examples of plasmas found in nature and produced in the laboratory. Logical framework of plasma physics. Some basic plasma phenomena: Debye shielding, role of small and large angle Coulomb collisions, momentum and energy transfer in like and unlike particle Coulomb collisions.

References

- Bellan, chapter 1 (introduction to plasma physics)

Chapter 2: Single particle motion in electric and magnetic fields

Drift formalism for the motion of charged particle in magnetic and electric fields. Lagrangian and Hamiltonian formalism and exact constants of motion. Adiabatic invariant of a pendulum with a slowly changing length and its extension to a general periodic system. Adiabatic invariants for the motion of charged particles in magnetic and electric fields. Invariance of the magnetic moment and its application to mirror machines. Second and third adiabatic invariants and their applications. Toroidal confinement machines: tokamaks and stellarators. Flux surfaces, rotational transform and safety factor of a tokamak. Passing and trapped particles in a tokamak. Guiding centre trajectory for passing and trapped particles in a tokamak.

References

- Bellan, ch. 3.5.1 to 3.5.4 and 3.5.6 (drift formalism)
- Bellan, ch. 3.2, 3.3, 3.4.1 (Lagrangian and Hamiltonian formalisms; adiabatic invariants)
- Bellan, ch. 3.5.7 to 3.5.9 (adiabatic invariants).
- Pucella, page 26-36 (charged particle orbits in a tokamak)

Chapter 3: Collisions and Fokker-Planck theory

General properties of collisions in fully ionized plasmas. Derivation of the Fokker-Planck equation. Friction and isotropy terms in the Fokker Planck equation for small angle Coulomb collisions. Slowing down equation for the average velocity. Resistive and runaway regimes. Slowing down of a charge that has a velocity between the thermal electron and ion velocities and consequences for plasma heating. Calculation of the resistivity of a plasma and of the Dreicer electric field for the production of runaway electrons. Alpha particle slowing down distribution function and alpha particle diagnostics.

References

- Bellan, ch. 13
- Goldston, ch. 14.5

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 collisions in plasmas: random walk model of diffusion, diffusion equation, diffusion coefficients in magnetized and unmagnetized plasmas. General properties of diffusion in weakly ionized plasmas. Two fluid model for the diffusion in weakly magnetized plasmas without a magnetic field. Diffusion in fully ionized plasmas: role of like and unlike particle collisions. Particle and energy diffusion coefficients and comparison with their experimental values. Elements of neoclassical transport theory: contribution of passing and trapped particles to transport. Bootstrap current. Elements of turbulent transport and related experimental observations.

References

- Goldston, ch. 12.1 to ch. 12.4 (diffusion in weakly ionized plasmas)
- Freidberg, ch. 14.2.3 to ch. 14.2.5 (diffusion in fully ionized plasmas)
- Freidberg, ch. 14.4 (neoclassical transport – briefly outlined).
- Freidberg, ch. 14.5.2 (turbulent transport and experimental observations – briefly outlined)

Chapter 6: Introduction to thermonuclear fusion

Fusion reactions. Role of alpha particles and neutrons in deuterium-tritium reactions. Classical and quantum models for the fusion cross section. Reaction rate and reactivity. Processes that contribute to plasma heating and cooling. Energy confinement time. Lawson criterion. Operational regimes of a fusion power plant: ideal ignition, ignition and power amplification. Thermal and electric gain factor Q. Status of the research on thermonuclear fusion.

References

- Freidberg, ch. 3 and ch. 4.1 to 4.6 (introduction to thermonuclear fusion)

Reference books

- (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
- (Hutchinson) I. H. Hutchinson, “Principles of plasma diagnostics”, ed. Cambridge University Press