“Plasma physics 2” - syllabus – a.y. 2021/2022

Teacher: M. Nocente

Chapter 1: Introduction to plasma physics

Review of some basic properties of a plasma: distribution function and density, collective phenomena, Debye shielding. Main properties of elastic collisions in plasmas: role of small and large angle Coulomb collisions, momentum and energy transfer in like and unlike particle Coulomb collisions. Inelastic collisions (short notes).

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 particles in magnetic and electric fields. Lagrangian 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. Overview and challenges of the main external heating methods for a fully ionized plasma: neutral beam injection and wave heating. Alpha particle slowing down distribution function and alpha particle diagnostics.

References

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

Chapter 4: 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. Diffusion in fully ionized plasmas: role of like and unlike particle collisions. Particle and energy diffusion coefficients and comparison with their experimental values. Very brief outline of neoclassical and turbulent transport.

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 – very briefly outlined).
- Freidberg, ch. 14.5.2 (turbulent transport and experimental observations – very briefly outlined)

Chapter 5: 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. Gain factor Q.

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