PLASMA PHYSICS AND NUCLEAR FUSION

Corso di Laurea Magistrale in Ingegneria Energetica / Energy Engineering

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Materials:

- Lecture notes: see http://gaps.ing2.uniroma1.it/atzeni/ (click on "didattica")
- Short portions of S. Atzeni and J. Meyer-ter-Vehn, The Physics of Inertial Fusion, Clarendon-Oxford, 2004.
- Two useful additional texts:
  R. J. Goldstone and P. H. Rutherford, Introduction to Plasma Physics, Taylor & Francis, 1995;
  G. Pucella e S. E. Segre, *Fisica dei Plasmi*, Zanichelli, Bologna, 2010 (in Italian)

1 - Definition of plasma. Collective effects. Natural and artificial plasmas

- Saha equation for ionization equilibrium
- Debye shielding and quasi-neutrality. Debye length
- Plasma oscillations and plasma frequency: double layer model and fluid model
- Ideal and correlated plasmas, classical and quantum plasmas
- Natural and man-produced plasmas. Characteristic parameters

2 - Charged particle motion in external electric and magnetic fields. Drifts.

- Uniform magnetic field: Larmor radius, cyclotron frequency
- Uniform electric and magnetic fields: $\boldsymbol{E} \times \boldsymbol{B}$ drift
- Non uniform magnetic field:
  - grad $\boldsymbol{B}$ orthogonal to $\boldsymbol{B}$ (grad $\boldsymbol{B}$ drift)
  - curvature drift
  - grad $\boldsymbol{B}$ parallel to $\boldsymbol{B}$: first adiabatic invariant
- Examples: magnetic mirror; need for "rotational transform" in toroidal configurations

3 - Coulomb collisions

- Collisions in center of mass system
- Collision parameter, scattering angle
- Rutherford cross-section
- Collision frequencies, mean-free-paths
- Relaxation times and energy equilibration times
- Electrical resistivity: collisional model; runaway electrons

4 - Radiation emission

- General aspects. Larmor formula
- Cyclotron radiation
- Bremsstrahlung

5 - Plasmas and controlled nuclear fusion. Principles

- Fusion reactions, cross sections, reactivity
- Main reactions between hydrogen isotopes (DD, DT)
- Thermonuclear fusion
- Steady-state power balance of a thermonuclear plasma: ideal ignition temperature, Lawson criterion, $n\tau T$ criterion
- Principles of main confinement schemes (magnetic and inertial)

6 - From kinetic models to fluid models and MHD

- Boltzmann equation and Vlasov equation
- Moments of Boltzmann equation; fluid equations
- Two-fluid plasma model
- Single-fluid plasma model and magnetohydrodynamics (MHD)
- Resistive and ideal MHD
- Qualitative discussion on the range of application of MHD

7 - Simple applications of MHD

- Magnetic field diffusion
- ***B*** lines freezing
- Fluid drifts orthogonal to ***B***
  - Diamagnetic drift and diamagnetic current
  - $\boldsymbol{E} \times \boldsymbol{B}$ drift

8 - Particle and energy transport

- Classical treatment of diffusion coefficient
- Diffusion coefficient for magnetized and unmagnetized plasma
- Discussion: anomalous transport

9 - Plasma waves

- Wave equation and wave solutions; group and phase velocity
- Linear perturbation theory and dispersion relation
- Waves in a fluid plasma. Linear theory. Electrostatic and electromagnetic waves.
- Electron plasma waves (Bohm-Gross waves)
- Electromagnetic waves in unmagnetized plasmas
  - Dispersion relation. Cut-off and critical density.
  - Collisional absorption (with application to laser-plasma interaction)
  - Basic concepts on plasma created by the interaction of an intense laser pulse with a solid: ablation, ablative pressure. Application to inertial confinement fusion: ablation-driven implosion
- Basic concepts on parametric processes
- Alfvén waves

10 - MHD equilibrium

- General remarks. Orthogonality between B lines and pressure gradient, and between current lines and pressure gradient; magnetic surfaces, current tubes.
- Principles of Zeta- and Theta-pinch.

11 - Introduction to Inertial Confinement Fusion

- Essential requirements: compression and hot-spot ignition
- Laser-driven inertial confinement. Direct and indirect drive.
- Estimate of main parametes
- Key physics issues
- Notions on lasers for fusion

12 - Introduction to Magnetic Confinement Fusion

- Close and open configurations
- Toroidal configurations. Toroidal field, poloidal field, vertical field. Tokamak and Stellarator.
- Main elements of a tokamak.
- Key physics issues

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