COURSE CODE: 10592723

COURSE NAME: TECHNOLOGY AND PHYSICS OF FUSION ENERGY (6 CFU)
PHYSICS SECTION (3 CFU)

SEMESTER & YEAR: Fall (September-December), II year

INSTRUCTOR: Renato Gatto.

PREREQUISITES: 1st level degree (laurea triennale) in Engineering or Physics. The "Plasma Physics and Nuclear Fusion" taught by Prof. Stefano Atzeni is strongly recommended.

OFFICE HOURS: After class, or by appointment (contact the Instructor by email).

COURSE AIMS: The objective of the first part of the course is to provide a qualitative and semi-quantitative understanding of the physical principles at the basis of the magnetic confinement of high-temperature plasmas, focusing on the peculiarities of the tokamak device.

LEARNING OUTCOMES: The student is expected to become familiar with the main physical aspects of the tokamak approach to controlled fusion, as well as with the computer codes used to model tokamak plasma discharges and to assist experimental operations.

TEXTBOOK: "Plasma Physics and Fusion Energy", by J. Freidberg, plus additional references and lecture notes provided by the Instructor.

RECOMMENDED READINGS: "Tokamaks" by Wesson. "Introduction to Plasma Physics" by R.J Goldston abd P.H. Rutherford. "Fusion - An Introduction to the Physics and Technology of Magnetic Confinement Fusion" by W.M. Stacey.

GRADING POLICY:

-ASSESSMENT METHODS: Oral exam 80%, Project 20%.

-ATTENDANCE REQUIREMENTS: Attendance is strongly recommended.

- ADDITIONAL INFORMATION: There will be a visit to the FTU (Frascati Tokamak Upgrade) facility at the Frascati ENEA Research Center.

MAIN TOPICS of the PHYSICS SECTION

1. Introduction to controlled fusion. Fundamentals of magnetic confinement of high-temperature plasmas. Fusion power: cross section and reactivity.
2. Power balance in a fusion reactor: D-T fusion, radiation, transport, and auxiliary heating powers. Ideal ignition and real ignition. The physics Q factor. Critical $p\ \tau_{\rm E}$ curve for ignition vs T.

3. Thermal stability. The dW/dt vs T curve. The role of auxiliary heating. Heating to ignition.

4. The tokamak. Its components and its principle of operation. Central solenoid, toroidal magnetic field coils, poloidal magnetic field coils. Induced current, bootstrap current, current drive. Reactor parameters (the ITER case).

5. Basic properties of plasmas: Debye shielding, plasma oscillations, collisionality parameter, magnetized plasma. Gyro-motion, drift velocities ($E \times B$, $\nabla B + R_c$, mirror force). Diamagnetic drift and current.

6. Plasma description: two-fluid model, single-fluid model (MHD). Plasma equilibrium. General concepts: flux surfaces, magnetic pressure, magnetic tension.

7. Radial equilibrium in the Z-pinch, θ-pinch, screw-pinch. The β factor.

8. Toroidal force balance: the three forces, and the need of a vertical magnetic field.

9. Rotational transform ι, the q factor. General concepts of magnetized plasma stability. Interchange instability, kink instability, concept of favorable and unfavorable curvature. Qualitative examples.

10. The general formulation of the ideal MHD stability problem. The method of linearization. The linearized momentum equation: the eigenvalue problem. Stability properties of the θ-pinch and of the Z-pinch.

11. Overview of transport phenomena in tokamaks: classical transport, neo-classical transport, turbulent transport. Scaling laws of magnetic confinement. The L (low) and H (high) confinement mode. Advanced tokamak regime with high bootstrap current fraction.

12. Stability of the circular tokamak: Surface current model, pressure balance matching condition.

13. Stability of the circular tokamak: equilibrium β-limit, stability criterion to current-driven (kink) modes, stability criterion to pressure-driven (kink-ballooning) modes. Troyon β-limit. Stability of the elongated tokamak.

14. Overview of computer codes to study the equilibrium, stability and temporal evolution of magnetized fusion plasmas.

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