Magnetic Confinement Fusion

- Date range: September – October
- Lecturers: P. Beyer (AMU), X. Garbet (CEA/IRFM), M. Huguet (former deputy director JET)
- Remark: This lecture gives an overview of the physics and engineering issues in magnetic confinement fusion. Not all subjects are fully treated in detail, the aim is to show the ensemble of interconnected topics.
- Content:

  1. Thermonuclear Fusion & Magnetic Configuration
     - Thermonuclear fusion
     - Charged particle motion in electromagnetic fields
     - Magnetic configuration for confinement
  2. Equilibrium and MHD Stability
     - Magnetic configuration of a tokamak
     - Plasma equilibrium
     - Plasma + external coils: need for a vertical field
     - MHD stability
  3. Confinement and Transport
     - Confinement of individual particles
     - Neoclassical transport
     - Radiative losses
     - Anomalous transport
  4. Plasma Heating and Current Drive
     - Ohmic heating
     - Neutral Beam Injection
     - Wave propagation
  5. Plasma Edge Physics
     - Model of scrape-off layer
     - Particle and momentum parallel transport: the sheath and pre-sheath physics
     - A simplified model of the Scrape-Off Layer
     - Orders of magnitude
     - Operational regimes of a divertor
     - Impurities
  6. Engineering aspects of a Tokamak: The Magnet System
     - Toroidal confinement: Stellarators and Tokamaks
     - The tokamak magnetic configuration
     - Structural aspects of tokamak magnets
     - Superconducting magnets
     - Description of the ITER magnets
  7. Engineering aspects of Neutral Beam Injection
     - Basic concepts of neutral beam injection

  - The main components of a NB injector
  - Beam losses and power deposition in the ITER beam line components
  - Neutral beam line vessel and vacuum pumping
  - Interfaces with the tokamak
  - ITER neutral beam cell
  - Summary of NB performance

8. Engineering aspects of a Tokamak: Vacuum vessel and in-vessel components
  - The vacuum vessel
  - Engineering aspects of plasma facing components
  - Limiters
  - ITER first wall
  - Divertor design
  - Tritigen blanket
  - Safety and engineering aspects of tritium handling

Plasma-Wall Interaction – Discharge Plasmas

- Date range: September – October
- Lecturers: G. Cartry (AMU), N. Dubuit (AMU), A. Escarguel (AMU), M. Muraglia (AMU)
- Summary:

  This course is made of lectures presenting low-temperature plasma physics and technology, plasma behavior close to a wall, heat and particles fluxes to the wall in plasmas, fluid and kinetic models of plasmas, plasma diagnostics.

  Based on the lectures, the students develop a 0D fluid model describing noble gas low-temperature plasma behavior. The model allows the computation of electron density and temperature as a function of plasma external control parameters (power, pressure. . .). This numerical activity is supervised by a teacher.

  Outcome of the model are obtained by the students independently and benchmarked through measurements of electron density and temperature in a laboratory plasma reactor using Langmuir probes. This practical activity is supervised by a teacher.

  A numerical activity supervised by a teacher is devoted to Langmuir probe data processing The course is completed by optical spectroscopy measurements of a low-temperature laboratory plasma. This practical activity is supervised by a teacher

- Content:

  1. Introduction to low-temperature plasma physics and technology
  2. 0D Fluid model of a low-temperature plasma in noble gas
  3. Plasma behavior close to a wall, heat and particles fluxes
  4. Experimental data processing
  5. Langmuir probe measurements on experimental plasma reactor
  6. Optical spectroscopy measurements on low-temperature plasma reactor

Atomic and Molecular Physics, Spectroscopy

- Date range: September – October
- Lecturers: O. Peyrusse (AMU), P. Theulé (AMU), J. Rosato (AMU), N. Fedorczak (CEA / IRFM) , R. Guirlet (CEA / IRFM)
- Summary:

  This lecture aims at developing competences in mesuring, interpretation and modeling of the radiation emitted by atoms and molecules. This lecture hast two branches: one oriented towards modeling ant one towards mesuring and interpretation. The two branches are preceded by a common bloc of 30h providing the knowledge necessary for the understanding of atomic and molecular spectra in gases and plasmas. Then, the modeling branch provides advanced theoretical knowledge whereas the option on mesures and interpretation concerns the experimental techniques of detection and spectral dispersion of radiation.
- Content:
  1. Atomic physics
  2. Molecular physics
  3. Theory of line broadening
  4. Detection, diagnosctics
  5. Interpretation methods

Power Sources and Materials in Extreme Environments

- Date range: October – December
- Lecturers: P. Maugis (AMU), J.-M. Layet (AMU), D. Wagner (Max-Planck Institut für Plasmaphysik, Garching)
- Content:
  1. High Power Microwaves: Generation and Transmission
     - Microwave Tubes
     - Modes and Mode Conversion in Rectangular and Circular Waveguides
     - Waveguide Mode Converters
     - Quasi-Optical Mode Converters
  2. Physical chemistry and mechanics of materials:
     - Basic terms
     - Electronic structure
     - Thermodynamics
     - Metallurgy – magnetism
  3. Strong heat flux:
  4. Strong neutron flux:

Superconductors for Fusion

- Date range: October – December
- Lecturers: J.-L. Duchâteau (CEA / IRFM)
- Content:
  1. Introduction to superconductivity: superconductivity, the strange magnetic properties of type II superconductors, critical field and critical temperature, applications: the era of NbTi, superconducting strands, critical current densities, load line, current sharing temperature, temperature margin, superconducting materials in ITER, losses
  2. Fusion and Superconductivity: from JET to Tore Supra and ITER, "Large Coil Task", Tore Supra, EAST, KSTAR, W7-X, JT-60SA, introducing DEMO
  3. Quench protection and detection: hot spot criterion, quench protection circuit, quench detection
  4. Dimensionning of superconducting magnets for fusion: rôle of plasma magnetic field in fusion reactor performance, radial extension of the toroidal field system, central solenoid
  5. Cable in conduit conductors (CICC): CICC to face fast energy deposition specific for fusion magnets, forced flow helium to remove cryogenic losses, temperature difference between annular channel and central hole, performance of CICC, joints between CICC, economical aspects
  6. ITER magnet system: why superconducting magnets ; toroidal field, central solenoid, poloidal field systems ; model coils ; thermal load; economical aspects

Magnetohydrodynamics in Plasmas

- Date range: October – December
- Lecturers: O. Agullo (AMU), M. Faganello (AMU), M. Muraglia (AMU)
- Content:
  1. MHD equations, waves and conserved quantities (Alfvén theorem, helicity, cross-helicity)
  2. Energy principle for equilibrium stability
  3. Kink instability in ideal MHD, using the energy principle
  4. Tearing instability in resistive MHD
  5. Beyond the energy principle: Kelvin-Helmholtz instability in unmagnetized and magnetized plasmas
  6. Hydrodynamics and Alfvénic turbulence (Spectra, mechanisms for the energy cascade, induced transport, from Kolmogorov to balanced cascades)

Plasma Kinetics, Turbulence, Transport

- Date range: October – December
- Lecturers: N. Dubuit (AMU), R. Guirlet (CEA / IRFM), R. Dumont (CEA / IRFM)
- Content:

  1. Turbulence and transport
     - Drift velocity of particles and fluids
     - Drift wave instability with and without magnetic field
     - Generic intability of the “interchange” type
     - Quasi-linear transport
     - Non-linear saturation mechanisms and control of turbulence
     - Invariance principles and scaling laws
     - Reduced models of critical gradient transport
  2. Heating and current generation
     - The tokamak as transformer: from transitory operation to continuous regime
     - Different current sources: configuration current and forced current
     - Ray tracing and Fokker-Planck calculation for the electron cyclotron wave and the hybrid wave
     - Heating by the electron cyclotron wave
     - Experimental results and diagnostics

$\boxed{\text{Laser Created Plasmas}}$

- Date range: October – December