PHYSICAL SCIENCES

Programme Code: PHYS04

Programme Outcome:

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower to take up research in frontier areas of physics
- Building human resource in carrying out R&D in physical and nuclear sciences
- Training of manpower in working in interdisciplinary subjects with physics as one of the subjects

Syllabus for IPR's Ph.D. Program

Trimester-I

Sr. No	Code	Subjects	Lecture hrs.	Credits
1	06-PHYS04-BPP-C	Basic Plasma Physics	32	2
2	06-PHYS04-EPP-C	Experimental Plasma Physics	32	2
3	06-PHYS04-MM-C	Mathematical Methods	16	1
4	06-PHYS04-NM-R	Research Methodology: Numerical Methods	16	1
5	06-PHYS04-001-E to 06-PHYS04-013-E	Elective*	16/32	1/2
Total credits in TRIMESTER -I			**112/128**	**7/8**

Trimester-II

Sr. No	Code	Subjects	Lecture hrs.	Credits
1	06-PHYS04-APP-C	Advanced Plasma Physics	32	2
2	06-PHYS04-PPM-C	Plasma Production and Measurement	32	2
3	06-PHYS04-RM-R	Research Methodology and Publication Ethics	24	2
4	06-PHYS04-001-E to 06-PHYS04-013-E	Elective*	16/32	1/2
5	06-PHYS04-001-PR	Project (Part-A)	-	2

Total credits in TRIMESTER -II			**104/120**	**9/10**

Trimester-III

Sr. No	Code	Subjects	Lecture hrs.	Credits
1	06-PHYS04-002-PR	Project (Part-B)	-	4
Total credits in TRIMESTER -III			**--**	**4**

List of Elective subjects (in Trimester I/II)

Sr. No	Code	Subjects	Lecture hrs.	Credits
1	06-PHYS04-001-E	Physics of Laser-Plasma Interaction	32	2
2	06-PHYS04-002-E	Advanced Tokamak Physics	32	2
3	06-PHYS04-003-E	Advanced Tokamak Diagnostics	32	2
4	06-PHYS04-004-E	Fuelling and plasma-wall interaction in Tokamaks	16	1
5	06-PHYS04-005-E	Heating and Current drive in Tokamaks	16	1
6	06-PHYS04-006-E	Waves in guided media	16	1
7	06-PHYS04-007-E	Plasma Material Interaction	16	1
8	06-PHYS04-008-E	Physics of Low Temperature Plasma	16	1
9	06-PHYS04-009-E	Electromagnetic Theory	16	1

10	06-PHYS04-010-E	Classical Mechanics	16	1
11	06-PHYS04-011-E	Statistical Mechanics	16	1
12	06-PHYS04-012-E	Fluid Mechanics	16	1
13	06-PHYS04-013-E	Basic Tokamak Physics	16	1

Total Credits: 20/22 (Core: 9, RM and PE: 3, Project: 6, Elective: 2/4)

CORE COURSE CO-ORDINATORS

Course	Coordinators	Email	Contact
Basic Plasma Physics	Dr Mrityunjay Kundu and Dr Jinto Thomas	mkundu@ipr.res.in / jinto@ipr.res.in	+91-96872 64149 / +91-99245 30700
Experimental Plasma Physics			
Mathematical Methods			
Research Methodology: Numerical Methods			
Advanced Plasma Physics			
Plasma Production and Measurement			
Research Methodology and Publication Ethics			

ELECTIVE COURSE CO-ORDINATORS

Course	Coordinators	Email	Contact
Physics of Laser-Plasma Interaction	Dr Mrityunjay Kundu and Dr Jinto Thomas	mkundu@ipr.res.in / jinto@ipr.res.in	+91-96872 64149 / +91-99245 30700
Advanced Tokamak Physics			
Advanced Tokamak Diagnostics			
Fuelling and plasma-wall interaction in Tokamaks			
Heating and Current drive in Tokamaks			
Waves in guided media			
Plasma Material Interaction			
Physics of Low Temperature Plasma	Dr Mrityunjay Kundu and Dr Jinto Thomas	mkundu@ipr.res.in / jinto@ipr.res.in	+91-96872 64149 / +91-99245 30700
Electromagnetic Theory			
Classical Mechanics			
Statistical Mechanics			
Fluid Mechanics			

Basic Tokamak Physics			

Note

- Faculties will take “special classes” (zero credit) to introduce his/her research areas.
- Projects will be floated just after the Trimester-I review for discussion and selection.
- Running any elective subject in any particular academic calendar year depends on the availability of the teachers on the subject.
- Present set of elective subjects is not limited to the list mentioned above.
- New elective subject(s) can be introduced by the IPR academic committee if any faculty proposes.
- The faculty is given the flexibility to choose topics from the syllabus. Depending on the student’s level of appreciation of a given subject, faculty may cover at least 70-80% of the prescribed syllabus.

CORE COURSES

06-PHYS04-BPP-C: Basic Plasma Physics (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Introduction:**
  Definition of plasma, description of collective behaviour in contrast to single particle behaviour, derivation of plasma frequency (slab model), Debye length (description of Boltzmann distribution can be given here), conditions for collective behaviour (Physical basis for these conditions), binary collisions (derivation of Rutherford scattering), derivation of collision frequency νei (large angle collisions, cumulative effect of many small angle collisions, Coulomb logarithm), discussion of collective behaviour revisited with relationship between various conditions (discussion of $k\lambda D << 1$, plasma parameter).

- **Single Particle Motion:**
  Lorentz force equation, Non-relativistic motion of a charged particle in constant electric and magnetic field: motion in constant $\vec{E}$ field, constant $\vec{B}$ field (derivation of cyclotron frequency, Larmor radius), motion in crossed $\vec{E}$ and $\vec{B}$ field, drift in a combined magnetic field and a general force field (non-magnetic), Motion in non-uniform $\vec{B}$ field (guiding centre approximation): Grad B drift ($\nabla B \perp B$), curvature drift, $\nabla B \parallel B$ (magnetic mirrors, invariance of μ, concept of adiabatic invariance), Uniform $\vec{B}$ and spatially varying $\vec{E}$ field (Finite Larmor radius effects), Time and space varying $\vec{E}$ field (Ponderomotive force), Time varying magnetic field (adiabatic compression), Time varying $\vec{E}$ field (polarization drift)

- **Dielectric Description Of a Plasma:**
  Derivation of wave equation, dielectric constant for a cold unmagnetized plasma, normal modes (electrostatic and electromagnetic) in a cold unmagnetized plasma, dielectric constant for a cold magnetized plasma, High frequency waves in a cold magnetized plasma: waves parallel to the magnetic field (left and right circularly polarized modes, whistler mode, cut off, resonance,Faraday rotation), waves perpendicular to the magnetic field (ordinary mode, extra-ordinary mode, cut off, Cotton-Mouton effect), CMA diagram.

- **Fluid Description:**
  Heuristic derivation of fluid equations (continuity equation, momentum equation), equation of state, complete set of two fluid equations, Fluid drift perpendicular to B→ (diamagnetic drift), High frequency electrostatic waves in an unmagnetized plasma (Langmuir waves, Bohm-Gross waves), High frequency electrostatic waves in a magnetized plasma (upper hybrid oscillation), High frequency electromagnetic modes in an unmagnetized and magnetized plasma, Low frequency electrostatic waves in unmagnetized and magnetized plasma: ion-acoustic wave, ion cyclotron wave, lower hybrid oscillation.

- **MHD Description:**
  Derivation of single fluid equations from two fluid equations, complete set of equations for ideal MHD, Force and motion in Ideal MHD, MHD waves (Alfven wave, magnetosonic wave), MHD energy.

Course Outcomes:

- Definition of plasma, description of collective behaviour in contrast to single particle behaviour.
- Lorentz force equation, nonrelativistic motion of a charged particle in constant electric and magnetic field.
- Fluid Description of Plasma, Waves in Plasma and MHD Description

References:

1. Introduction to Plasma Physics and Controlled Fusion, F.F. Chen, Springer Nature, 2016.
2. Fundamentals of Plasma Physics, J.A. Bittencourt, Springer-Verlag New York Inc., 2004.
3. Plasma Physics: An Introductory Course, R.O. Dendy, Cambridge University Press, 1995.
4. Introduction to Plasma Physics, R.J Goldston, P.H Rutherford, CRC Press, 1995.

06-PHYS04-EPP-C: Experimental Plasma Physics (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Fundamentals of Vacuum Science:**
  Concept of vacuum and vacuum measurements pressure and flow measurements, different range of Vacuum. Concepts of vapour pressure, different types of pressure measurement devices and different pumps. Concepts of mass flow rate, conductance, pumping speed, volume flow rate, through-put.
- **Fundamentals of Gaseous Discharge:**
  Different types of collisions and collision parameters, charge Particles under constant electric field (E/p), ionization and charge exchange processes. thermionic emission, field emission, electron multiplication.
- **Gas Discharges:**
  DC discharges DC breakdown at low pressure, Paschen law and its experimental validation, condition for self-sustenance. I-V characteristics of DC discharge: Corona discharge, normal and abnormal glows, arc discharge, etc. Regions of DC glow discharge like Cathode dark space, positive column and anode glow.
  AC Discharges RF capacitive discharge, RF inductive discharge, ECR and wave based (Helicon) discharge, DBD discharges
- **Plasma Sheaths and various electrostatics probes:**
  Ion and electron sheaths, Bohm criteria, significance of pre-sheath, familiarity with different types of sheathsChild Langmuir, Matrix sheath Current-Voltage characteristics of a single Langmuir probe, double Langmuir probe.
- **Equilibrium Discharge Properties:**
  D.C and A.C plasma conductivity, plasma resistivity, mobility and diffusion with/without mag- netic field, Ambipolar diffusion
- **Spectroscopic Diagnostics:**
  Basic introduction to spectrum and spectral lines based on Atomic and Molecular structure, Introduction to Emission, Absorption and Fluorescence spectroscopy, Einsteins coefficients for transitions, Understanding of different spectroscopic models (Corona, CR model, LTE model).

Course Outcomes:

- Fundamental Gas Processes i.e. Maxwell- Boltzmann distribution, Mean Free Path, Collision Cross Section, and Frequency, Elastic and Inelastic Collisions, Ionization by Electron Impact, X-rays, Nuclear Radiation and Photoionization,
- Charged Particles in a Gas.
- Self-sustaining Discharge i.e. Glow Discharge, Breakdown under Special Conditions, Arc Discharge.
- Plasma Sheath and Diagnostics Experimental Plasma Devices.

References :

1. Gas Discharge Physics, Yuri P. Raizer, Springer-Verlag Berlin and Heidelberg GmbH and Co., 2011.
2. Principles of Plasma Discharges and Materials Processing, Michael A. Lieberman and Alan J. Lichtenberg, Wiley-Interscience, 2005.
3. Principles of Plasma Diagnostics, I. H. Hutchinson, Cambridge University Press, 2005.
4. Glow Discharge Processes: Sputtering and Plasma Etching, Brian Chapman, Wiley-Interscience, 1980.

06-PHYS04-MM-C: Mathematical Methods (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Ordinary Differential Equations (ODE):**
First order equations, Uniqueness theorem, Lipschitz condition, Equations with separated and sep- arable variables, Homogeneous first order equations, Equations reducible to homogeneous form, First order linear equations, Bernoullis equation, Exact differential equations, Second order linear homogeneous equations, Wronskian, Liouvilles formula, Second order linear homogeneous equa- tions with constant coefficients, Equations equidimensional in x (Euler equations), Reduction of order, Second order linear non-homogeneous equations, Method of variation of parameters, Greens function method, Method of undetermined coefficients (for equations with constant coefficients), Nonlinear equations, Ricatti equation, Autonomous equations, Equations equidimensional in y, Scale invariant equations. Stability for a linear system of ODEs.

- **Approximate Methods for solving ODE:**
Power series method, Picards method, Perturbative method, Poincare-Lindstedt Method, WKB method.

- **Complex Analysis:**
Introduction to complex variables, function of a complex variable, Analytic functions, Derivatives of a complex function, Cauchy-Riemann conditions (Cartesian and polar form), Branch points, Complex integration, Cauchy's theorem or Cauchy-Goursat theorem, Cauchy's integral formula, Higher derivatives of analytic functions, Taylor and Laurent series, Singularities (poles and es- sential singularity), Residues, Cauchy Residue theorem, Contour integration, Calculation of real
integrals, Trigonometric integrals, ∫ ∞ f (x)eikx, Jordan's lemma, Integrals with poles on real axis,
Cauchy principal value, Integrals of multivalued functions (branch points and cuts), Summation of series using Contour integration. Conformal Mapping and its application to the solution of Laplace equation.

- **Partial Differential Equations (PDE):**
Introduction, Principle of superposition, Some important equations (wave equation, heat conduc- tion or diffusion equation, Laplace equation, Poisson's equation etc.), Classification of PDE's (elliptic, parabolic and hyperbolic type and reduction to canonical form), Boundary conditions (Dirichlet, Neumann and Cauchy Boundary conditions), Methods of solution of a first order and second order PDE, Method of characteristics, Separation of variables technique, Integral transform techniques.

- **Integral Transforms:**
Fourier integral, Fourier transform and its inverse, Parsevals equation, Laplace transform, Shift theorem, Transforms of derivatives, Convolution theorem, Delay theorem, Dirac delta function and its transform, Inverse Laplace transform (using contour integration; general inversion formula), Laplace inverse of functions with branch points, Solution of ODEs and PDEs using integral trans- forms, Solution of Volterra and Fredholm integral equations using integral transform techniques.

Course Outcomes:

- Ordinary Differential Equations (ODE)
- Approximate Methods for solving ODE
- Complex Analysis
- Difference Equations (DE)

References:

1. Mathematical Methods for Physicists, Arfken, Weber, and Harris, Elsevier 2012.
2. Advanced Mathematical Methods for Scientists and Engineers I: Asymptotic Methods and Pertur- bation Theory, Carl M. Bender, Steven A. Orszag, Springer, 1999.
3. Advanced Engineering Mathematics, Erwin Kreyszig, Wiley, 2006.

06-PHYS04-NM-R: Research Methodology: Numerical Methods (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Solution of Algebraic Equations:**
  Gaussian elimination, Gauss-Jordan elimination, LU decomposition and its applications, Tridiag- onal and band diagonal system of equations, Singular value decomposition, iterative improvement of a solution .

- **Root finding and nonlinear set of equations:**
  Introduction, bracketing and bisection, Secant method, false position method, Newton Raphson method, Roots of polynomial, Newton-Raphson method for nonlinear system of equations.

- **Modeling of Data:**
  Introduction, Chi-square Fitting, Goodness of fit, Variances and co-variances of the parameters, Fitting data to a straight line, General linear least square.

- **Integration of Ordinary Differential equations:**
  Introduction, Taylors series method, Eulers method, Runge-Kutta Methods, Predictor-correction method, Boundary value problems, Finite-Difference method.

- **Fast Fourier transform (FFT) and its applications:**
  Introduction to FFT, Discrete Fourier Transform, Leakage and windows, Box-Car window, Han- ning window, Convolution and correlation, Auto power spectra, cross power spectra and coherence spectra, Data smoothing, Bi-spectral analysis.

Course Outcomes:

- Numerical methods i.e. Taylor series and its application, Eigenvalue problems, Modeling of Data, Integration of Ordinary Differential equations
- Fast Fourier transform (FFT) and its applications
- Programming for particle motion simulation considering large number of particles.

References:

1. Numerical Recipes: The Art of Scientific Computing, William H. Press , Saul A. Teukolsky , William T. Vetterling , Brian P. Flannery, Cambridge University Press, 2007.
2. Numerical Methods for Scientists and Engineers, H. M. Antia, Birkhauser Verlag AG, 2002.
3. Numerical Methods in Engineering & Science with Programs in C, C++ & MATLAB, B.S.Grewal, Khanna Publishers, 2013.

06-PHYS04-APP-C: Advanced Plasma Physics (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Non-Equilibrium Classical Statistical Mechanics:**
  Study of Brownian motion, Random walk model, Langevins force equation, fluctuation-dissipation theorems, Fokker-Planck equation, Introduction to driven-dissipative systems.
- **Fundamentals of plasma kinetic theory:**
  Concepts of Distribution function, Maxwell-Boltzmann Distribution (Determination of the Constant Coefficients, moments of Maxwell-Boltzmann Distribution, RMS, Most probable speed, Speed and Energy distribution function.)
  Many body description for plasma, The Klimontovich Dupree system of equations, BBGKY Hierarchy, Liouville equation, Boltzmann equation, Moments of the Boltzmann Equation (derivation of fluid equations), Vlasov Equation, Fokker-Planck Equation, Properties of Vlasov Equation, Linear Equilibrium Solutions.
- **Vlasov theory of Waves and instabilities:**
  Derivation of electrostatic waves from linearized Vlasov-Poisson system of equations (Langmuir wave, Ion Acoustic Wave) and linear Landau Damping, kinetic two-stream instability and negative energy waves, kinetic theory of magnetized hot plasmas.
- **Nonlinear Vlasov equilibria and waves:**
  Nonlinear (nonperturbative) electrostatic waves, BGK equilibrium, wave-like nonlinear Vlasov states and trapped particle equilibria, integral and differential formulations, non-linear dispersion relation.

Course Outcomes:

- Understand non-equilibrium classical statistical mechanics and stochastic processes, including Brownian motion and fluctuation-dissipation.
- Master plasma kinetic theory, including Boltzmann, Vlasov, and Fokker-Planck equations.
- Analyze linear and nonlinear plasma waves, instabilities, and equilibria in electrostatic and magnetized plasmas.
- Apply kinetic theory concepts to real plasma systems and driven-dissipative phenomena.

References:

1. Fundamentals of plasma physics, Jos´e A Bittencourt, Springer Science & Business Media, 2013.
2. Principles of plasma physics, Nicholas A Krall and Alvin W Trivelpiece, McGraww-Hill Book Company, 1973.
3. Introduction to Plasma Theory, D. R. Nicholson, Krieger Pub Co, 1992.

06-PHYS04-PPM-C: Plasma Production and Measurements (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Experimental Electronics:**
  Application of operational amplifier, summing amplifier (AC+DC), differential amplifier, inverting and non-inverting amplifier, design of regulated DC power supply.
- **Experimental demonstration of vacuum system:**
  Operation of rotary and diffusion pumps. Creating vacuum and its measurements, leak detection, estimation of pumping speed.
- **Characteristics of DC Discharge:**
  Validation of Paschen law of Gas breakdown, Measurements of current-voltage (DC impedance) characteristics of a discharge and demonstration of glow discharge regions.
- **B-dot probe measurement:**
  Design understanding and construction of a B-dot Probe and its measurement principle, Probe Calibration experiment and frequency response.
- **Single Langmuir Probe:**
  Design understanding and construction of a Single Langmuir Probe, Obtaining I-V Characteristic of a Langmuir probe in plasma, measurement of different plasma parameters.
- **Measurements of plasma potential using Emissive Probe:**
  Design understanding and construction of an Emissive Probe, Measurements of plasma potential using an emissive probe.
- **Excitation of Ion Acoustic Waves in Plasma and ion acoustic speed measurement:**
  Design of launcher and receiver for exciting and detecting ion acoustic wave. Measurement of dispersion relation of ion acoustic wave.
- **Spectroscopic measurements:**
  Arrangement of an experimental setup for optical emission spectroscopy. Detection of neutral and ionic species in plasma.

Course Outcomes:

- Apply operational amplifier circuits and design regulated DC power supplies for precision electronic measurements.
- Operate vacuum systems, measure vacuum parameters, detect leaks, and estimate pumping performance.
- Analyze plasma characteristics using Langmuir and emissive probes, measure plasma potential, and validate fundamental plasma discharge laws.
- Excite and measure plasma waves, determine ion acoustic speed and dispersion relations, and perform spectroscopic diagnostics of neutral and ionic species.

06-PHYS04-RM-R: Research Methodology and Publication Ethics (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Research design and methods (14 lectures)**

  - **Objectives and types of research:**
    Motivation and objectives - Research methods. Types of research Descriptive and Analytical; Applied and Fundamental; Quantitative and Qualitative; Conceptual and Empirical.

  - **Research Formulation:**
    Defining and formulating the research problem - Selecting the problem - Necessity of defining the problem - Importance of literature review in defining a problem - Literature review Primary and secondary sources - reviews, treatise, monographs-patents - web as a source - searching the web - Critical literature review - Identifying gap areas from literature review - Development of working hypothesis.

  - **Research design:**
    Basic Principles - Need of research design - Features of good design Important concepts relating to research design - Observation and Facts, Laws and Theories, Prediction and explanation, Induction, Deduction, Development of Models. Developing a research plan - Exploration, Description, Diagnosis. Experimentation: Proper approach - Importance of recording observation, maintaining the records, sample history, transparency in data recording. Determining experimental and sample designs.

  - **Statistical treatment of data and errors:**
    Value of Statistics; Errors and Statistics - Limitation of analytical methods; Accuracy; Precision; Classification of errors; Minimization of errors; Significant figures and computations; Standard Deviation; Normal Distribution; Comparison of results - students t test; F-test; Chi Square test; propagation of errors.

  - **Writing thesis and research papers:**
    Structure and components of scientific reports - Types of report - Technical reports and thesis - Significance - Different steps in the preparation Layout, structure and Language of typical reports - Illustrations and tables - Bibliography, referencing and footnotes - Oral presentation - Planning - Preparation - Practice - Making presentation - Use of visual aids - Importance of effective communication, Manuscript drafting based on Experimental data and Literature Survey. Where to publish?, impact factor of journals, citation databases, Metrics

  - **Intellectual Property Rights (IPR):**
    Integrating IPR in the innovation value-chain, Basic understanding of tools of IPR such as patents, copyright, designs registrations, etc. Role of IPR in collaborative work, technology acquisition, transfer, commercialisation & trade.

- **Research ethics and Publication ethics (10 Lectures)**

  - **Research ethics:**
    Philosophy and ethics, Ethics with respect to Science and research, Intellectual honesty and research

integrity, Scientific misconducts- fabrication, falsification and plagiarism, redundant publications- duplicate and overlapping publications, selective reporting and misrepresentation of data, Environmental impacts - Ethical issues - ethical committees - Commercialization.

- **Publication ethics:**
  Definition, introduction and importance, Best practices, standards setting initiatives and guidelines, Conflict of interest, Publication misconduct, Violation of publication ethics, authorship and contributorship, Identification of publication misconduct, complaints and appeals, predatory journals and publishers, Reproduction of published material - Plagiarism Citation and acknowledgement - Reproducibility and accountability.

Course Outcomes:

- Understand different types of research, their objectives, and appropriate methodologies.
- Formulate research problems, perform critical literature review, identify gaps, and develop working hypotheses.
- Design experiments and research plans with proper data recording, sample handling, and statistical treatment of errors.
- Prepare and present scientific reports, theses, and manuscripts, and understand publication processes and metrics.
- Apply principles of Intellectual Property Rights (IPR) in research, innovation, and commercialization.
- Practice research ethics, maintain scientific integrity, and avoid misconduct in data reporting and publications.
- Understand publication ethics, authorship norms, plagiarism issues, and reproducibility standards.

References:

1. Science and methods by Henry Poincare, translated in English by Francis Maitland Source: www.archive.org/details/sciencemethod00poinuoft, 1914.
2. Research Methodology: Methods and Techniques. C.R. Kothari, New Age International 2000.
3. The Ethics of Science, An Introduction, David Resnick, Taylor and Francis, 2005.
4. Research Methods for Science, M. P. Marder, Cambridge University Press , 2011.
5. Research Methodology, R. Paneer Selvam, Prentice Hall India Learning Private Limited, 2013.
6. Ethics in Scientific Research, An Examination of Ethical Principles and Emerging Topics, Cortney Weinbaum, Eric Landree, Marjory S. Blumenthal, Tepring Piquado, Carlos Ignacio Gutierrez, 2019.
7. How to Write and Publish a Scientific Paper, R.A. Day, Cambridge University Press, 1992.
8. Avoiding plagiarism, self-plagiarism, and other questionable writing practices: A guide to ethical writing, Miguel Roig, 2015.
9. An introduction to Research Methodology, B.L. Garg, R. Karadia, F. Agarwal, and U.K. Agarwal, RBSA Publishers, 2002.
10. Research Methodology, S.C. Sinha, and A.K. Dhiman, Ess Publications, 2002.

ELECTIVE COURSES

06-PHYS04-001-E: Physics of Laser-Plasma Interaction (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Introduction to Basics of Plasmas:**
  Collective behaviour, Debye length, Plasma frequency, Binary collision, Coulomb logarithm, Col- lision frequency, Fluid Equations (Continuity, Momentum, Energy/Equation of State), Maxwell's Equations.
- **Waves in Unmagnetized Homogeneous Plasmas:**
  Plasma oscillation, Bohm-Gross waves, Ion-acoustic waves, Electromagnetic waves, Wave equation in a medium, Dielectric constant (ϵ), Susceptibility (χ), Characteristic modes of oscillation (plasma oscillation, e.m. wave), Ion acoustic wave (derivation using susceptibility).
- **Propagation of E.M. Wave through Inhomogeneous Plasmas:**
  Normal incidence (Exact solution with linearly varying density), WKB analysis with general inhomogeneity, Oblique incidence (S-polarized, Exact solution with linearly varying density), Oblique incidence (P-polarized, Resonance absorption)
- **Collisional Absorption of Light Wave:**
  Collisional damping of e.m. wave propagating through a homogeneous plasma, Collisional damping of e.m. wave propagating through an inhomogeneous plasmas (normal and oblique incidence (S- polarized light).
- **Parametric Instabilities:**
  Ponderomotive Force, Oscillating two-stream and Ion-acoustic Decay instability, Dispersion re- lation and calculation of growth rate, Stimulated Raman Scattering, Dispersion relation and calculation of growth rate, Stimulated Brillouin Scattering, Dispersion relation and calculation of growth rate.
- **Plasma Heating:**
  Collisional damping of electron plasma wave, Landau damping, Large amplitude electron plasma wave, Wave Breaking
- **Relativistic Effects:**
  Single Particle motion in Intense Electromagnetic Wave, Radiation Reaction Force (Landau- Lifshitz Equation of Motion), Relativistic Ponderomotive force, Relativistic Dielectric response and Self-focussing, Interaction of Relativistically Intense Laser Pulse with Underdense Plasmas (Wake wave, Akhiezer-Polovin Mode), Interaction of Relativistically Intense Laser Pulse with Overdense Plasmas (Relativistic $\vec{j} \times \vec{B}$ heating, Vacuum heating)

Course Outcomes:

- Understand basic plasma concepts including collective behavior, Debye length, plasma frequency, collisions, fluid equations, and Maxwell's equations.
- Analyze wave propagation in unmagnetized plasmas: plasma oscillations, Bohm-Gross waves, ion-acoustic waves, and electromagnetic wave modes.
- Study EM wave propagation in inhomogeneous plasmas, including normal and oblique incidence, WKB

analysis, and resonance/absorptive effects.
- Explore collisional absorption and damping of EM waves in homogeneous and inhomogeneous plasmas.
- Examine parametric instabilities: ponderomotive force, two-stream and ion-acoustic decay, stimulated Raman and Brillouin scattering with growth rate calculations.
- Understand plasma heating mechanisms: collisional and Landau damping, large amplitude waves, and wave breaking.
- Analyze relativistic effects: single particle motion in intense EM fields, radiation reaction, relativistic ponderomotive forces, self-focusing, and laser-plasma interactions in underdense and overdense regimes.

References:
1. "The Physics of Laser-Plasma Interactions",William L. Kruer, Frontiers in Physics Series, 1987
2. "Short Pulse Laser Interactions with Matter", Paul Gibbon, Imperial College Press, 2005
3. "High Power Laser-Matter Interaction", Peter Mulser and Dieter Bauer, Springer Tracts in Mod- ern Physics 238, 2010
4. "The Interaction of High-Power Lasers with Plasmas", Shalom Eliezer, IOP Series in Plasma Physics, 2002

06-PHYS04-002-E: Advanced Tokamak Physics (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Thermonuclear Fusion:**
Basic theory of fusion, Cross-section, Power balance & Ignition, Lawson criterion, Concept of magnetic confinement, Mirror machine & Tokamak, Basic configuration of tokamak, Plasma pro- duction, Tokamak operation: pulsed & steady state. Spherical tokamak and Stellarator.

- **Tokamak Equilibrium:**
Toroidal and poloidal magnetic fields, Concept of flux function and flux surfaces, Grad-Shafranov equation, Definition of β, Rotational transform, Safety factor, Magnetic shear, Shafranov shift, Plasma shaping, Elongation, Triangularity, Trapped particles, Banana orbits.

- **Confinement and Transport:**
Classical transport, Neoclassical transport, Bootstrap current, Anomalous transport, Turbulence and zonal flows. Pfirsch-schlu¨ter current and diffusion, L-mode, Transport barriers, H-mode, L-H transition, Confinement scaling laws: Ohmic scaling, L-mode scaling, H-mode scaling. Radiation losses, Radiation due to Impurities. Runaway electrons.

- **MHD Theory and Macroinstabilities:**
Definition, Energy principle, MHD theory of stability, Ideal MHD instabilities, Plasma resistivity, Resistive instabilities. Kink instability, Ballooning modes, Tearing modes, Magnetic islands, Neo- classical tearing modes. Sawtooth oscillation, Fishbone instability, Toroidal Alfven Eigenmodes, Edge Localized Modes, Resistive wall mode. Disruption physics.

- **Microinstabilities:**
Introduction, Drift waves, Ion temperature gradient mode, Trapped electron mode, Electron temperature gradient mode, Micro/Drift-tearing modes, and Kinetic ballooning mode. GyroBohm scaling.

- **Plasma Wall Interaction:**
Introduction, Plasma sheath, Scrape-Off Layer, Recycling, Erosion. Limiter and Divertor con- cepts. Heat load.

- **Plasma Heating:**
Ohmic heating, Auxiliary heating. RF heating. Ion Cyclotron Resonance, Electron Cyclotron Resonance, and Lower Hybrid Resonance heating. NBI heating, α particle heating. Current drive.

- **Tokamak Diagnostics:**
Introduction, Measurements of: Magnetic equilibrium, Plasma current, Loop Voltage, Plasma shape, Safety factor profile, Plasma density and temperature, Distribution functions, Flows, Ra- diation from plasma, Plasma Rotation, Impurity Profiles, MHD activities, Instabilities and Fluc- tuations.
Passive & Active diagnostics. Electric diagnostics, Magnetic diagnostics, Spectroscopic diagnostics (Visible & UV), Thomson Scattering, ECE, Bolometry, Charge exchange diagnostics, Motional Stark effect, Interferometry, Microwave, Infrared and X-ray diagnostics.

- **Important Tokamaks:**
Indigenous tokamaks: ADITYA & SST. Design parameters, Milestones, Achievements.
International Tokamaks: JET & MAST, DIII-D & NSTX, ASDEX-U, JT-60SA, EAST, KSTAR, TCV, ITER: Design parameters, Milestones, Achievements.

- **Tokamak Reactor Design:**
  Main components: Superconducting Magnets, Vacuum Chamber, Blanket Module, Divertor, Cryostat Assembly, (Heat exchanger, Turbine, Generator). Reactor Power, Fuel resources, So- cial and economic factors, Future.

Course Outcomes:

- Understand fundamentals of thermonuclear fusion, Tokamak equilibrium, plasma confinement, transport, and heating methods.
- Analyze plasma instabilities, MHD and microinstabilities, plasma-wall interactions, and disruption physics.
- Learn Tokamak diagnostics, key indigenous and international Tokamaks, and their design, milestones, and achievements.
- Understand Tokamak reactor design, including main components, power, fuel resources, and socio-economic considerations.

References:

1. "Tokamaks", John Wesson, Clarendon Press-Oxford 2004
2. "Fusion Physics", Edited by: M. Kikuchi, K. Lackner, M. Q. Tran, IAEA Vienna, 2012
3. "Collective Modes in Inhomogeneous Plasmas", Jan Weiland, IOP Publishing Ltd, 2000
4. "Ideal MHD", J P Freidberg, Cambridge University Press, 2014
5. "The Theory of Toroidally Confined Plasmas", Roscoe B. White, Imperial College Press,UK, 2001.

06-PHYS04-003-E: Advanced Tokamak Diagnostics (32 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
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Course Details:

- **Introductions to Fusion Devices:**
  Tokamaks, stellarators, reverse field pinch, Z-pinch, inertial confinement devices, Hybrid concepts, tokamak components and nomenclatures, Ohmic transformer, toroidal and poloidal fields, plasma pressure and magnetic pressure, equilibrium, toroidal and poloidal beta, small and large aspect ratio tokamak. Case Study: diagnostics details of Aditya-U, SST1, EAST, JT60-SA.

- **Magnetic field Diagnostics:**
  Maxwells equation, magnetic field through a coil, One turn loop and Rogowsky coil, Calibration techniques, Hall & Faraday effect, Poloidal flux measurement and detection of MHD, plasma posi- tion and symmetry measurement, Sine-cosine coil, diamagnetic measurement, Case study: basic experimental measurement paper from early tokamaks (T3, START, JFT-2, TFTR, ADITYA).

- **Particle Diagnostics:**
  Concept of particle flux, Debye shielding, Collisionality, Sheath thickness, effect of magnetic field, gridded energy analyzers, bolometric probe, neutral particle measurement, charge exchange, neu- tral transport, example paper of neutral particle measurement, probing with neutral particles, beam attenuation, charge exchange, heavy ion beam probe, fast ion diagnostics, neutron diagnos- tics, Case study: experimental papers on NPA, Fast Ion, HIBP in tokamaks.

- **Millimeter Wave Diagnostics:**
  Waves in homogenous plasma, Appelton-Hartree formalism, wave propagation in magnetic field, non-uniform plasma and WKB approximation, CMA diagram, O-mode & X-mode waves, den- sity measurement through interferometry, Michelson, Mach-Zehnder, Fabry-Perot interferometry, issues in phase shift, homodyne, heterodyne, super heterodyne techniques, Faraday rotation, po- larization measurement, inversion techniques, Reflectometry. Case study: experimental papers on density profile measurements, pedestal measurements in H-mode.

- **Radiation Diagnostics:**
  Cyclotron radiation from electron, Broadening: Doppler, relativistic, radiation, and collisional., radiation transport, absorption, emission, wave polarization effect, effect of varying magnetic fields, Cerenkov emission, Radiation through bremsstrahlung (classical and quantum effect, Gaunt factor), recombination radiation, X-ray imaging, thermal (soft X-ray) and non-thermal (Hard X-ray) measurements, types of detection systems and relevant instrumentation, Bolometry and imaging, Case Study: Experimental techniques, data analysis and interpretation of the radiation measurements.

- **Spectroscopy Diagnostics:**
  Edge plasma characteristics: limiter & divertor, composition of edge plasma, atomic & molecular processes, collisions & cross sections, electron impact ionization, recombination, excitation in edge plasma, electron molecular-ion collision, example of these processes in He, and C impurity ions, spectral line and continuum spectrum, continuum: bremsstrahlung, properties of spectral line : central wavelength, intensity & line width, Intensity - population mechanisms of excited level via LTE, Corona & collisional radiative model, line profile: natural, Doppler, pressure, Reabsorption, line shift and split: Doppler and Zeeman, applications to basic and fusion plasma: measurements of electron and density temperature measurement, rotation velocity and Z effective, magnetic field measurement through Zeeman polarization spectroscopy. Case Study: Experimental techniques, data analysis and interpretation in a tokamak.

- **Physics study with diagnostics: Case studies:**
  Plasma equilibrium, G-S equation, plasma parameters as flux functions, profile estimation of plasma beta, internal inductance, current density and safety factor. Effect of current profile modification and transport/impurity control, H-mode pedestal studies, L-I-H transition, ELMs, Zonal flow and limit cycle oscillations.

Course Outcomes:

- Understand different fusion devices, Tokamak components, equilibrium parameters, and case studies of Aditya-U, SST1, EAST, JT60-SA.
- Learn magnetic, particle, millimeter-wave, radiation, and spectroscopy diagnostics techniques for measuring plasma parameters and interpreting data.
- Apply diagnostics to study plasma physics: equilibrium, beta profiles, current density, H-mode pedestal, ELMs, zonal flows, and transport control.
- Analyze experimental case studies to connect diagnostic measurements with fusion plasma behavior and performance.

References:

1. Wesson, Tokamaks, Clarendon Press-Oxford 2014
2. Hutchinson, Principles of Plasma Diagnostics, Cambridge U. Press, 1990
3. Janev, Atomic and molecular processes in fusion edge plasmas, Plenum Press, 1995
4. Kikuchi, Fusion Physics, IAEA Vienna, 2012
5. Freidberg, Ideal MHD, Cambridge University Press, 2014
6. Knoll, Radiation detection, radiation shielding, and radiation effects, ISBN 0471073385, 9780471073383

06-PHYS04-004-E: Fuelling and plasma-wall interaction in Tokamaks (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Plasma Fuelling:**
  Ionization and recombination, pressure and mean free path, connection length, particle and energy confinement, LCFS and separatrix, Tokamak SOL, sheath, extrinsic fuelling: gas puff, molecular beam injection, solid pellet injection, impurity injection, intrinsic fuelling: Wall as pump and source.
- **Cryogenic pellet fuelling:**
  Cryogenically cooled pellets (H2, D2) as particle source, Pellet-plasma interaction, gas dynamic equations and ablation models, cloud characteristics and shielding mechanism, particle homogenization and fuelling efficiency, pellets for plasma control and diagnostic, Basics of cryogenics and its role in vacuum, heat transfer methods: conduction, convection, radiation. Material properties relevant to vacuum and cryogenics. Phase diagram, gas condensation, pellet production technique, Instrumentation for pellet production and acceleration, diagnostic for pellet-plasma interaction. Case Study: pellet fuelling in tokamaks
- **Plasma facing materials:**
  Low Z and high Z impurity, tokamaks with carbon and all metal wall, tungsten and beryllium wall, limiter and divertor material, physical and thermal characteristics of PFCs, heat removal and diagnostics, material testing, neutron activation, effect of neutron on material characteristics, ODS and RAFMS materials for fusion reactors, neutron sources and IFMIF, Challenges of materials for Fusion reactors: energy content, pulse duration, duty factor, ELMs, tritium handling, Case Study: material choice in ITER
- **Plasma material interaction:**
  Particle fluxes and energies, basic particle-material interaction: reflection, implantation, defects, reemission, Plasma interaction with wall: physical and chemical sputtering, radiation enhanced sublimation, wall deposition, erosion, and recycling, hydrogen processes in metals: diffusion, trap- ping, precipitation, retention, Case Study: limiter and divertor interaction in Aditya/U, ASDEX, DIIID, fuel retention in TFTR carbon wall,
- **Wall damages and control:**
  Disruptions, VDEs, runaway electrons, ELMs, dusts and flakes in tokamaks, disruption and ELMs mitigation, RMP, wall conditioning and coating, GDC, EC and IC wall conditioning, lithiumiza- tion and boronization, Introduction to plasma edge, sputtering modelling

Course Outcomes:

- Definition of plasma, description of collective behaviour in contrast to single particle behaviour.
- Lorentz force equation, nonrelativistic motion of a charged particle in constant electric and magnetic field.
- Fluid Description of Plasma, Waves in Plasma and MHD Description

References:

1. Federici, Nuclear Fusion, Vol. 41, No. 12R (2001)
2. Pellet fuelling, S. L. Milora, Nuclear Fusion, Volume 35, Issue 6, pp. 657-754 (1995).
3. Pellet-plasma interactions in tokamaks, Physics Reports 206, No. 4 (1991) 143196. North-Holland
4. Pellet injection technology, S. K. Combs Rev. Sci. Instrum. 64 (7), 1993

5. Physical processes of the interaction of fusion plasmas with solids, Hofer & Roth, Academic Press 1996
6. Plasma-material interaction in controlled fusion, Naujoks, Springer 2006

06-PHYS04-005-E: Heating and Current Drive in Tokamaks (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
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Course Details:

- **Introduction:**
  Tokamaks and stellartors, ignition condition and reaction cross section, confinement time, particle and energy loss, Ohmic heating and limitation. Case Study: Ohmic heating experiments in tokamaks (Aditya and JET)
- **Ion Cyclotron Heating:**
  Absorption of magneto sonic waves, R & L cut off, evanescent layer, wave tunnelling, cold plasma approximation, slow and fast waves, hot plasma dielectric tensor, absorption mechanisms, wave polarization, second harmonic heating, high harmonic heating, minority heating and ion-ion hy- brid heating, direct electron heating, Introduction to experimental system: Selection of source frequency and power, transmission lines, Antenna-plasma coupling, wave shaping through an- tenna array, matching network, introduction to codes for study of antenna-plasma coupling, wave propagation and absorption in tokamaks, full wave simulation, Plasma start-up and wall condi- tioning. Case study: basic experimental papers from tokamaks (ASDEX, Alcator C-mod).
- **Electron Cyclotron Heating:**
  O-mode & X-mode, cut off & resonances, CMA diagram and wave accessibility, fundamental and second harmonic heating, single pass absorption, mode conversion, EBW heating and current drive, preionization and start-up, fully non-inductive current drive, fast particle generation and control, NTM stabilization, Experimental set-up: Gyrotron as an oscillator, waveguide, launcher, polarization control, access to thermal and non-thermal population. Case study: Study of EC resonances in TCV, EBW heating in COMPAS-D.
- **Current drive by Waves:**
  Dispersion relation, propagation, landau damping, accessibility and spectral gap, experimental set-up: Klystron, waveguide, grill antenna, evolution of launchers in tokamaks, phasing, reflection coefficient, current drive efficiency, current profile modification, fast electron behaviour, LHCD, ECCD, FWCD, wave propagation in toroidal geometry, ray tracing: Case study: Early current drive experiments in JFT-2 tokamak, Phase reflection experiment in a grill antenna.
- **Heating & CD by Neutral beams and alpha:**
  Basic beam-plasma interaction, multi-step ionization, charge exchange, ionization cross section by ions and impurities, Lorentz ionization, importance of Beam injection geometry, Energy transfer mechanism, energetic particle particles orbits, Current Drive efficiency, fast ion behaviour at high temperature, distribution function, banana drift, ripple loss, alpha heating, Experimental method: ion source, extraction, acceleration, beam steering,negative and positive ion beam, negative ion for ITER Case study: First beam driven current experiments in DITE, TFTR, JT 60U.

Course Outcomes:

- Understand plasma fuelling methods: intrinsic and extrinsic fuelling, gas puff, pellet injection, molecular beam injection, and particle/energy confinement in Tokamak SOL.
- Learn cryogenic pellet fuelling: production, acceleration, ablation, cloud shielding, homogenization, diagnostics, and application in plasma control.
- Study plasma-facing materials: low-Z/high-Z walls, limiters/divertors, thermal/physical properties, neutron effects, and material choices for ITER.
- Analyze plasma–material interactions and wall control: sputtering, erosion, hydrogen retention, disruptions,

ELMs, wall conditioning, and mitigation techniques.

References:

1. Stix, Waves in Plasma, AIP, 1992
2. Wesson, Tokamaks, Clarendon Press-Oxford 2014
3. Kikuchi, Fusion Physics, IAEA Vienna, 2012
4. M. Bornatici et al 1983 Nucl. Fusion 23 1153
5. Ushigusa, JAERI, 1339, 1999
6. Yamamoto, PRL 1980
7. M. Brambilla, Nucl. Fusion 16, 47 (1976).

06-PHYS04-006-E: Waves in Guided Media (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.i

Course Details:

- **Revision of mathematics for waves:**
  Vector algebra, coordinate systems (Cartesian, cylindrical, polar) and transformation, differenti- ation and integration of scalar and vector functions.

- **Electric and magnetic fields:**
  Coulombs law and electric field from charge distribution, Gausss law and calculation of potential, materials in electric field (conductor, dielectric, polarization, permittivity), Maxwells equation, eddy current.

- **Wave propagation:**
  Wave and wave equation, complex pointing vector, propagation of wave in materials (lossy dielec- tric, propagation in conductor, skin depth, dispersion and polarization, reflection and transmission of waves.

- **Transmission line:**
  Resistance, inductance and capacitance per unit length, transmission line equation, practical trans- mission lines (lossless, long, distortion-less, low resistance), field picture of lines, load reflection coefficient, line impedance, vswr, lossless matched and terminated lines, resonant transmission lines, Case study: application to tokamak and linear plasma devices.

- **Smith chart and impedance matching:**
  The smith chart, smith chart as an admittance chart, impedance matching, single and double stub matching, quarter wavelength transformer matching, transients with capacitive and inductive loading, Case Study: Impedance matching in tokamaks EAST, Alcator C-mod

- **Waveguides:**
  TE, TM, TEM modes, TE propagation in parallel plates, rectangular waveguide, attenuation in WG (dielectric loss, wall loss, cut off), cavity resonators, quality factors and applications. Case Study: Design and simulation of rectangular waveguide for tokamak experiment.

Course Outcomes:

- Definition of plasma, description of collective behaviour in contrast to single particle behaviour.
- Lorentz force equation, nonrelativistic motion of a charged particle in constant electric and magnetic field.
- Fluid Description of Plasma, Waves in Plasma and MHD Description

References:

1. Ida, Engineering electromagnetics, Springer 2021
2. Chapman, Theory and problems of transmission lines, New York McGraw-Hill 1968
3. Moreno, Microwave transmission design data, Boston Aptech house, 1998

06-PHYS04-007-E: Plasma Material Interaction (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
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Course Details:

- **Structure and Properties of Materials:**
  Atomic Bonding and Crystal structure, Metallic bond, unit cell, atomic packing, interstitial sites, Miller indices, crystal orientation, Crystal defects in metals viz. vacancy, dislocations etc., Prop- erties of materials: Electrical, Thermal, Magnetic, Optical and Mechanical properties of materials. Surface properties like roughness, surface free energy, wettability, surface corrosion etc.
- **Plasma Material Interaction in Low Temperature Plasma:**
  Basics of Plasma material interaction, plasma sheath, plasma etching, plasma sputtering, Plasma immersed ion implantation (PIIII), Plasma Nitriding, Surface nano-patterning, Introduction to different reactive species in plasma. Basics of thin film growth, Physical Vapour Deposition (PVD), Chemical Vapour Deposition (CVD), Pulsed Laser Deposition (PLD) E-beam PVD, Plasma en- hanced PVD and CVD etc.
- **Introduction to Plasma Material Interaction in Tokamak:**
  Particle fluxes and energies, basic particle-material interaction: reflection, implantation, defects, trapping, reemission, Recycling in tokamaks, Erosion and deposition, Scrape-Off Layer, Limiter and Diverter concepts. Material modification by high power load in tokamak
- **Material Characterisations:**
  Surface Characterisations: Operating principle of Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Scanning Tunnelling microscope (STM) and Transmission Electron Microscopy (TEM). Operating principle of Surface Profilometer, contact angle Goniometer and hardness tester. Crystallographic and identification: X-ray diffraction (XRD), Energy dispersive X-ray spectroscopy (EDX), inductively coupled Plasma Mass Spectroscopy (ICPMS) and X-ray Photoelectron spectroscopy (XPS) Optical Characterisation: Operating principle of Fourier trans- form Infrared Spectroscopy (FTIR), Ellipsometry, UV-visible spectroscopy (UV-Vis) and Raman spectroscopy Magnetic Measurements: Operating principle of Magneto-Optic Kerr Effect (Moke) spectroscopy, Vibrating sample magnetometer (VSM) Electrical and Thermal Measurements: Re- sistivity measurement by Four probe method, Thermal conductivity measurement etc.

Course Outcomes:

- Revise mathematical tools for waves: vector algebra, coordinate systems, differentiation and integration of scalar and vector functions.
- Understand electric and magnetic fields: Coulomb's law, Gauss's law, Maxwell's equations, material response, and eddy currents.
- Learn wave propagation and transmission lines: wave equations, propagation in lossy/conducting media, reflection/transmission, transmission line theory, VSWR, impedance, and resonant lines.
- Study impedance matching and waveguides: Smith chart, stub and quarter-wave matching, TE/TM/TEM modes, cavity resonators, attenuation, and tokamak applications.

References:

1. Materials Characterisation : Introduction to Microscopic and Spectroscopic Methods by Yang Leng
2. Principles of Plasma Discharges and Material Processing by M Lieberman and A. Lichtenberg
3. Plasma-material Interaction In Controlled Fusion by Naujoks, Springer 2006

06-PHYS04-008-E: Physics of Low Temperature Plasmas (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Introduction:**
  Typical discharges in presence of constant electric field, Classification of discharges, Sheaths in plasmas, Drift of electrons in weakly ionized gas, Conductivity of ionized gas, Electron energy, Diffusion of electrons, Ion motion
- **Interaction of Electrons in an Ionized Gas with Oscillating Electric Field:**
  Motion of electrons in oscillating fields, Electron energy
- **Atomic Collisions:**
  Elastic and Inelastic collisions, Collision Parameters, Ionization, excitation and elastic scattering cross sections for electrons in Ar, Ion-atom charge transfer and elastic scattering
- **DC Sheath:**
  Collisionless Sheath, Bohm Sheath Criterion, Presheath, Collisional Sheath, Matrix Sheath, Child's Law Sheath, Generalized Criterion for Sheath Formation
- **Brief Introduction of Different Heating Mechanisms:**
  Ohmic Heating, Stochastic Heating, Resonant wave-particle interaction heating, Secondary Elec- tron Emission Heating
- **Capacitive Discharges:**
  Homogeneous Model, Plasma and Sheath Admittance, Ohmic and Stochastic Heating, Inhomo- geneous Model, Collisionless Sheath Dynamics, Child's Law, Sheath Capacitance, Ohmic and Stochastic Heating

Course Outcomes:

- Understand basic plasma discharges: classification, sheaths, electron drift and diffusion, ion motion, and conductivity of weakly ionized gases.
- Study electron dynamics in oscillating fields and their energy distribution in plasmas.
- Learn atomic collisions in plasmas: elastic/inelastic collisions, ionization, excitation, charge transfer, and cross sections.
- Analyze plasma sheaths and heating mechanisms: collisionless/collisional sheaths, Child's law, Bohm criterion, Ohmic, stochastic, and resonant heating, including capacitive discharges.

References:

1. "Principles of Plasma Discharges and Materials Processing", Michael A. Lieberman, Allan J. Lichtenberg
2. "Gas Discharge Physics", Yuri P. Raizer

06-PHYS04-009-E: Electromagnetic Theory (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Electrostatics:**
Review of Electrostatics, Work and Energy in Electrostatics, Poisson and Laplace equations, Uniqueness of solution using Dirichlet or Neumann boundary conditions, Green theorem, formal solution of electrostatic boundary value problem with Green function, method of images, separa- tion of variables, multipole expansion. Electrostatic fields in matter.

- **Magnetostatics:**
Review of magnetostatics, Biot-Savart law, Ampere's Law, Vector Potential, Multipole expansion, Magnetic fields in matter, Methods for solving boundary value problem in magnetostatics,

- **Electrodynamics:**
Maxwells equations (in free space and in matter), Boundary conditions, Electromagnetic Energy and Momentum, Poynting's theorem, Maxwell stress tensor, Wave equation, Gauge transformation (Coulomb and Lorentz gauge), reflection and refraction at a plane between dielectrics, reflection at a plane conducting boundary.

- **Electromagnetic wave in bounded region:**
General wave behaviour along guiding structure (TEM, TE, TM modes), rectangular waveguide, coaxial transmission line, dielectric waveguides, cavity resonator.

- **Radiation:**
Radiation from localized oscillating source (dipole radiation), Radiation from an arbitrary source, Radiation by an accelerated particle: Lienard-Wiechert potentials and field, power radiated by an accelerated charge.

- **Relativistic electrodynamics:**
Lorentz Transformations, Four Vectors, Covariant and contra- variant tensors, Electrodynamics in Tensor Notation. Relativistic Potentials. Invariance.

Course Outcomes:

- Master electrostatics and magnetostatics: Poisson & Laplace equations, Green's functions, method of images, multipole expansions, Biot-Savart law, Ampere's law, and fields in matter.
- Understand electrodynamics: Maxwell's equations, boundary conditions, Poynting theorem, Maxwell stress tensor, wave equations, and reflection/refraction.
- Analyze electromagnetic waves in bounded structures: TEM, TE, TM modes, waveguides, coaxial lines, dielectric guides, and cavity resonators.
- Study radiation and relativistic electrodynamics: dipole & arbitrary source radiation, Liénard-Wiechert potentials, Lorentz transformations, four-vectors, and covariant electrodynamics.

References:

1. Classical Electrodynamics, John David Jackson, Wiley Publication,1998.
2. Introduction to Electrodynamics, David J. Griffiths, Cambridge University Press, 2017.

106-PHYS04-010-E: Classical Mechanics (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Lagrangian mechanics:**
  Review of Newtonian mechanics, Constraints, principal of virtual work, DAlemberts principle, Generalized coordinates. Lagranges equation of motion and its applications, e.g., Spherical pendulum, particle in EM fields etc., principle of least action, conservation laws.

- **Rigid Body:**
  Eulerian angles, Euler's equations, study of symmetric top.

- **Hamiltonian mechanics:**
  Legendre transform, Hamiltons equation and its applications, e.g. spherical pendulum, electro- magnetic interactions etc.

- **Canonical transformations (CT):**
  Definition, generating functions, properties and examples of CT, Poisson bracket (PB) represen- tation, invariance of PB under CT.

- **Hamilton Jacobi Theory:**
  Hamiltons principal function, Hamilton Jacobi equation, action-angle variable, adiabatic invari- ants.

Course Outcomes:

- Apply Lagrangian mechanics: generalized coordinates, D'Alembert's principle, equations of motion, principle of least action, and conservation laws.
- Analyze rigid body dynamics: Euler angles, Euler's equations, and symmetric top motion.
- Use Hamiltonian mechanics: Hamilton's equations, Legendre transform, and applications to particles and EM fields.
- Explore advanced methods: canonical transformations, Poisson brackets, Hamilton-Jacobi theory, action-angle variables, and adiabatic invariants.

References:

1. Classical Mechanics, Herbert Goldstein, Pearson Education, 2011.
2. Classical Mechanics, Narayan Rana, Pramod Joag, McGraw Hill Education, 2017.
3. Mechanics, Course of Theoretical Physics, L D Landau, E.M. Lifshitz, Butterworth-Heinemann, 1982.

06-PHYS04-011-E: Statistical Mechanics (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
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Course Details:

- **Equilibrium Classical Statistical Mechanics:**
  Foundations and Postulates, Microcanonical and Canonical ensemble with simple examples, Toy models & Introduction to phase transitions, Role of range of interaction.
- **Non-Equilibrium Classical Statistical Mechanics:**
  Study of Brownian motion, Random walk model, Langevins force equation, fluctuation-dissipation theorems, Fokker-Planck equation, Introduction to driven-dissipative systems.
- **Numerical Statistical Mechanics:**
  Chaos and low degrees of freedom statistical mechanics, Monte Carlo Simulations, Molecular Dynamics and Noose-Hoover Statistical Mechanics.
- **Advanced Classical Statistical Mechanics:**
  Introduction to Entropy Fluctuation Theorems, Introduction to Non-extensive systems, Intro- duction to Linear Response Theory and Onsager's Regression Hypothesis, Introduction to Large Deviation Theory based Statistical Mechanics.

Course Outcomes:

- Understand equilibrium statistical mechanics: ensembles, toy models, phase transitions, and interaction effects.
- Analyze non-equilibrium systems: Brownian motion, Langevin equation, fluctuation-dissipation, and Fokker-Planck dynamics.
- Apply numerical methods: Monte Carlo simulations, molecular dynamics, and Nosé-Hoover techniques.
- Explore advanced topics: entropy fluctuation theorems, non-extensive systems, linear response, and large deviation theory.

References:

1. Statistical Mechanics, R.K. Pathria , Paul D. Beale Academic Press Inc.(London) Ltd, 2021.
2. Monte Carlo Simulations in Statistical Physics - An Introduction, K Binder, 5th Ed, SpringerLink (2010)
3. W. G. Hoover, Computational Statistical Mechanics (Elsevier, Amsterdam, 1991).
4. W. G. Hoover, Time Reversibility, Computer Simulation, and Chaos (World Scientific, Singapore, 1999)
5. R S Ellis, Entropy, Large Deviation and Statistical Mechanics, SpringerLink (2006)
6. Statistical Mechanics, Kerson Huang,, Wiley, 2008.
7. Fundamentals of Statistical and Thermal Physics, Reif F , Waveland Press, 2010.

06-PHYS04-012-E: Fluid Mechanics (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
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Course Details:

- **Dimensional analysis and its application:**
  Techniques to generate dimensionless quantity:- Rayleighs Indicial method, Buckingham Π (PI) method; Introduction of dimensionless quantities like: Reynolds no., Froudes no., Eulers no., Webers no., Machs no., Relation between model and 1:1 size prototype, Model analysis, Similitude theory.

- **Types of flow with their mathematical description :**
  Ideal flow, Real flow, Newtonian flow, Non-Newtonian flow, Steady and Unsteady flow, Uniform and Non-uniform flow, Laminar and Turbulent flow, Compressible and Incompressible flow, Ro- tational and Irrotational flow, 1D-2D-3D flows.

- **Dynamics of flow:**
  Bernoullis theorem and its applications in real system

- **Kinematics of linear flow of incompressible fluid:**
  Introduction to Eulerian frame, Lagrangian frame, Specification of the flow field, Concept of convective field, Continuity equation, Velocity Potential function and Stream function, Flow net and their applications to analyze for superimposed flow, Vorticity distribution (line and sheet vortices). Navier- Stocks equation, Expression for stress tensor.

- **Kinematics of rotational flow of incompressible fluid:**
  Flow at large Reynoldss number, Vorticity dynamics, Kelvins circulation theorem, Lagranges theorem, Vorticity laws for inviscid fluid (having no viscosity).

- **Instabilities:**
  Introduction to Rayleigh-Taylor instability, Kelvin-Helmholtz instability in fluid.

Course Outcomes:

- Apply dimensional analysis and similitude theory to generate dimensionless numbers (Reynolds, Froude, Euler, Weber, Mach) and relate models to prototypes.
- Classify and mathematically describe different types of fluid flows: ideal/real, Newtonian/non-Newtonian, steady/unsteady, laminar/turbulent, compressible/incompressible, rotational/irrotational.
- Analyze flow dynamics using Bernoulli’s theorem, continuity equation, velocity and stream functions, flow nets, vorticity, and Navier–Stokes equations.
- Study rotational flow, vorticity dynamics, circulation theorems, and fluid instabilities like Rayleigh–Taylor and Kelvin–Helmholtz.

References:

1. Fluid Mechanics, E.M. Lifshitz , L D Landau, Elsevier Exclusive, 2010.
2. Vectors, Tensors and the Basic Equations of Fluid Mechanics, Rutherford Aris, Dover Publications Inc., 1990.

06-PHYS04-013-E: Basic Tokamak Physics (16 Lecture Hrs)

Coordinators: Dr Mrityunjay Kundu and Dr Jinto Thomas
mkundu@ipr.res.in and jinto@ipr.res.in

Course Details:

- **Thermonuclear Fusion and Magnetic Confinement:**
  Theory of fusion, Power balance & Ignition, Lawson criterion, Concept of magnetic confinement fusion, Inertial confinement fusion.
  Mirror machine & Tokamak. Basic configuration of Tokamak, Plasma production, Tokamak op- eration: pulsed & steady state.
- **Tokamak Equilibrium:**
  Magnetic fields, Flux functions & flux surfaces, Grad-Shafranov equa- tion, Plasma β, Safety factor, Magnetic shear, Shafranov shift, Plasma shaping. Trapped particles, Banana orbits.
- **Confinement and Transport:**
  Classical transport, Neoclassical transport, Bootstrap current, Anomalous transport, Turbulence and zonal flows. L-mode, Transport barriers, H-mode, L-H transition. Radiation losses, Runaway electrons.
- **MHD Theory and Macroinstabilities:**
  MHD theory of stability, Ideal MHD instabilities, Resistive instabilities. Kink instability, Bal- looning modes, Tearing modes, Sawtooth oscillations. Disruption physics.
- **Microinstabilities:**
  Drift waves, Ion temperature gradient mode, Trapped electron mode, Electron temperature gra- dient mode, Micro/Drift-tearing modes, and Kinetic ballooning mode.

Course Outcomes:

- Understand principles of thermonuclear fusion, magnetic confinement, Tokamak configuration, and plasma production/operation.
- Analyze Tokamak equilibrium, flux surfaces, plasma shaping, safety factor, magnetic shear, and particle orbits.
- Study plasma confinement and transport mechanisms, including classical/neoclassical transport, turbulence, L-H transition, and radiation effects.
- Examine MHD stability, macro- and micro-instabilities such as kink, ballooning, tearing modes, sawtooth oscillations, and drift/temperature-gradient-driven modes.

References:

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