Electricity & Magnetism (PAS103)

(Credit: 4, Duration: 10-15 weeks, Instructor: Dr. Padmnabh Rai)

Objectives & Academic Requirements: The emphasis of course is to teach basics of electricity and magnetism and their applications in solving problems of interest to physicists. The students are to be examined entirely on the basis of problems (seen/unseen) and assignments.Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student may not be permitted to appear in the examination.

Course Contents:

1. Electric Field& Electric Potential: Electric field, Electric field lines, Electric flux, Gauss' Law with applications to charge distributions (spherical, cylindrical and planar symmetry),Conservative nature of Electrostatic Field, Electrostatic Potential, Laplace's and Poissonequations, The Uniqueness Theorem, Potential and Electric Field of a dipole, Force and Torque on a dipole, Electrostatic energy of system of charges, Electrostatic energy of a charged sphere, Conductors in an electrostatic Field, Surface charge and force on a conductor, Capacitance of a system of charged conductors, Parallel-plate capacitor, Capacitance ofan isolated conductor, Method of Images and its application to: (1) Plane Infinite Sheetand (2) Sphere. (10 Lectures)
2. Dielectric Properties of Matter: Electric Field in matter, Polarization, PolarizationCharges, Electrical Susceptibility and Dielectric Constant, Capacitor (parallel plate,spherical, cylindrical) filled with dielectric, Displacement vector (D), Relations between (E, P and D), Gauss' Law in dielectrics. (5 Lectures).
3. Magnetic Field: Magnetic force between current elements and definition of MagneticFieldB, Biot-Savart's Law and its simple applications (straight wire and circular loop), Current Loop as a Magnetic Dipole and its Dipole Moment (Analogy with ElectricDipole), Ampere's Circuital Law and its application to (1) Solenoid and (2) Toroid, Properties of B(curl and divergence), Vector Potential, Magnetic Force on (1) pointcharge (2) current carrying wire (3) between current elements, Torque on a current loopin a uniform Magnetic Field. (10 Lectures)
4. Magnetic Properties of Matter: Magnetization vector (M), Magnetic Intensity(H),Magnetic Susceptibility and permeability, Relation between B, H, M, Ferromagnetism, B-H curve and hysteresis. (5 Lectures)
5. Electromagnetic Induction: Faraday's Law, Lenz's Law, Self-inductance and MutualInductance,

Reciprocity Theorem, Energy stored in a Magnetic Field, Introduction toMaxwell's Equations, Charge Conservation and Displacement current. (5 Lectures)

6. Electrical Circuits: AC Circuits (Kirchhoff's laws for AC circuits), Complex Reactanceand Impedance, Series LCR Circuit: (1) Resonance, (2) Power Dissipation and (3) Quality Factor, and (4) Band Width, Parallel LCR Circuit. (5 Lectures)

References:

1. Introduction to Electrodynamics, D.J. Griffiths, Prentice Hall (1998).
2. Electricity and Magnetism, E. M. Purcell, McGraw-Hill Education (2015).
3. Feynman Lectures Vol.2, R.P.Feynman, R.B.Leighton, M. Sands, Pearson Education (2008).
4. Elements of Electromagnetics, M.N.O. Sadiku, Oxford University Press (2010).
5. Electricity and Magnetism, J. H. Fewkes& J. Yarwood, Vol. I, Oxford Univ. Press (1991).

Evaluation Criteria:

1. Mid-Term Examination: The weightage of mid-term exam will be 25% (50 marks) and tentative schedule will be 5th week of the academic secession.
2. End-Term Examination: The weightage of end-term exam will be 50% (100 marks) and tentative schedule will be 10thweek of the academic secession.
3. Internal Assessment: The weightage of internal assessment will be 25% (50 marks). The evaluation will be based on assignments, problems solving and quizzes.

Electricity & Magnetism Lab (PAS 103 L)

Course Name: Electricity & Magnetism Lab

Course Code: PAS 103 L

Credits: 2

Duration: 10-15 weeks

Instructor:Dr. Padmnabh Rai

List of Experiment:

1. Use a Multi-meter to measure (a) Resistances, (b) Capacitances, and (c) AC and DC Voltages.
2. To measure the magnetic field along the axis of a circular coil and verify Biot-Savart law.
3. To verify the law of resistance in series and parallel combination by using Multi-meter and breadboard.
4. Find the voltage drop and current across lead resistance by using Thevenin and Norton theorem in network circuit.
5. To plot the AC phase shift in resistance-capacitor (RC) and resistance-inductor (RL) circuit by usingexpeyes instrument.
6. To plot the graph of transient response of RL, RC, LCR circuit by using expeyes instrument.
7. To get triangular wave by integrating squire wave and differentiated to get spikes at the transition in RC circuit by using expeyes instrument.
8. To study AC phase shift, transient response, and integration & differentiation of squire wave by using CRO and function generator.

References:

6. Introduction to Electrodynamics, D. J. Griffiths, Prentice Hall (1998).
7. Electricity and Magnetism, E. M. Purcell, McGraw-Hill Education (2015).
8. Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, Asia Publishing House (1971).
9. A Text Book of Practical Physics, I. Prakash & Ramakrishna, 11th Ed, Kitab Mahal (2011).
10. Advanced level Physics Practicals, Michael Nelson and Jon M. Ogborn, 4th Edition, reprinted, Heinemann Educational Publishers (1985).
11. Engineering Practical Physics, S. Panigrahi and B. Mallick, Cengage Learning (2015).

Course Contents

Course Code: PAS 104 (Theory) Course

Name: Waves and Oscillations Credits

Equivalent: 4 Credits

Course Objectives: The emphasis of course is to introduce students to concepts and phenomena related to waves and oscillations. The application of these concepts to real life examples will be discussed.

Attendance Requirements:

Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student may not be permitted to appear in the examination.

Attendance:

Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student will not be permitted to appear in examination.

Evaluation Criteria:

The overall evaluation of the students shall be for 200 marks distributed as per following scheme.

1. Mid Term Examination 25% (50 marks)
   At the end of 5th week the midterm examination shall be held for duration of *two hours* and shall consist of 50 marks question paper. The question paper shall consist of three sections. Section A (10 marks) shall contain 5 to10 very short answer type questions of 2/1 marks each, all being compulsory. Section B (20 marks) shall contain 6 short answer type questions of 5 marks each, out of which students have to attempt any 4. Section C (10 marks) shall consist of 2 compulsory long answer type questions of 10 marks each. The questions in section C shall have internal choice.
2. End Term Examination 50% (100 marks)
   At the end of 10th week the end term examination shall be held for duration of *three hours* and shall consist of 100 marks question paper. The question paper shall consist of three sections. Section A (20 marks) shall contain 10 to 20 very short answer type question of 2/1 marks each, all being compulsory. Section B (30 marks) shall contain 9 short answer type questions of 5 marks each, out of which students have to attempt any 6. Section C (50 marks) shall consist of 5 compulsory long answer type questions of 10 marks each. Every question in section C shall have internal choice.
3. Continuous Internal Assessment 25% (50 Marks):
   Consisting of assignments/quizzes/presentation/live projects, shall contribute 20% of the total 200 marks i.e. (40M) and 5% of the marks (i.e. 10M) towards internal assessment shall be on the basis of attendance.

UNIT-I Oscillations (31 Lectures)

Basic concepts of Simple Harmonic Oscillations (SHM): Equation of motion and its solution, Amplitude, frequency, time period, phase, velocity and acceleration. Kinetic and potential energy and their time averages. Reference circle and rotating vector representation of SHM. (4 Lectures)

Free Oscillations of Systems with One Degree of Freedom: mass-Spring system, Simple Pendulum, Torsional Pendulum, Oscillations in a U-Tube, Compound pendulum (Centres of Percussion and Oscillation) and Bar Pendulum. (5 Lectures)

Superposition of Two Collinear Harmonic oscillations: Linearity and Superposition Principle. (1) Oscillations having equal frequencies and (2) Oscillations having different frequencies (Beats). (5 Lectures)

Superposition of Two Perpendicular Harmonic Oscillations: Frequency Ratios 1:1 and 1:2 using graphical and Analytical Methods. Lissajous Figures and their uses.

(5 Lectures)

System with Two Degrees of Freedom: Coupled Oscillators. Normal Coordinates and Normal Modes. Energy Relation and Energy Transfer. Normal Modes of N Coupled Oscillators. (6 Lectures)

Damped and Forced Oscillations: Damped Oscillations: Damping Coefficient, Log Decrement, Transient and Steady States, Amplitude, Phase, Resonance, Sharpness of Resonance, Power Dissipation and Quality Factor. Helmholtz Resonator.

(6 Lectures)

UNIT-II Waves (19 Lectures)

Wave Motion: Plane and Spherical Waves. Longitudinal and Transverse Waves. Plane Progressive (Travelling) Waves. Wave Equation. Particle and Wave Velocities. Differential Equation. Pressure of a Longitudinal Wave. Energy Transport. Intensity of Wave.
Water Waves: Ripple and Gravity Waves. (5 Hours)

Velocity of Waves: Velocity of Transverse Vibrations of Stretched Strings. Velocity of Longitudinal Waves in a Fluid in a Pipe. Newton's Formula for Velocity of Sound. Laplace's Correction. (6 Hours)

Superposition of Two Harmonic Waves: Standing (Stationary) Waves in a String (Fixed and Free Ends) Analytical Treatment. Phase and Group Velocities, Changes with respect to Position and Time. Energy of Vibrating String, Transfer of Energy, Normal Modes of Stretched

Strings. Plucked and Struck Strings. Melde's Experiment. Longitudinal Standing Waves and Normal Modes. Open and Closed Pipes. Superposition of *N* Harmonic Waves.

(8 Hours)

Key Texts:

1. Vibrations and Waves by A. P. French.(CBS Pub. & Dist., 1987)
2. The Physics of Waves and Oscillations by N.K. Bajaj (Tata McGraw-Hill, 1988)

Reference texts:

3. Vibrations and Waves, Banjamin Crowell, Light & Matter Series (www.lightandmatter.com)
4. Fundamentals of Waves & Oscillations By K. Uno Ingard (Cambridge University Press, 1988)
5. An Introduction to Mechanics by Daniel Kleppner, Robert J. Kolenkow (McGraw-Hill, 1973)
6. Waves: BERKELEY PHYSICS COURSE (SIE) by Franks Crawford (Tata McGrawHill, 2007).

Course Contents

Course Code: PAS 104L
Course Name: Waves and Oscillations (Lab)
Credits Equivalent: 2 Credits
Course Objectives: To demonstrate the ideas of waves and oscillations and their applications in day to day life.

List of Experiments

1. To find and compare force constant of different springs and obtain spring constant when connected in series and parallel.
2. To determine damping coefficient, logarithmic decrement of a damped harmonic oscillator.
3. To study resonance in forced harmonic oscillator
4. To study beats formation due to superposition of two harmonic oscillations
5. To find out angular frequency of individual normal modes (symmetric and asymmetric) of coupled harmonic oscillator.
6. To calculate acceleration due to gravity using Kater's pendulum.
7. To determine frequency of electrically maintained vibrator using transverse mode and then study effect of length and tension in string using Melde's experiment.
8. To study superposition of waves using computer programming.
9. Observation of Lissajous figures: using computer program and CRO.
10. To determine the frequency of symmetric and asymmetric oscillations of a double pendulum.

Reference Books:

7. D.P. Khandelwal, "A laboratory manual for undergraduate classes" (Vani Publishing House, New Delhi).
8. S.P. Singh, "Advanced Practical Physics" (Pragati Prakashan, Meerut).
9. Worsnop and Flint- Advanced Practical physics for students.
10. "Practical Physics" R.K Shukla, Anchal Srivastav

Course Code: PAS 202
Course Name: Thermal Physics
Course Instructor: Dr. Ayan Chatterjee
Course Duration: 10 weeks

Credits Equivalent: 4 Credits (One credit is equivalent to 10 hours of lectures/organised classroom activity/contact hours; 5 hours of laboratory work/practical/field work/Tutorial/teacher-led activity and 15 hours of other workload such as independent individual/group work; obligatory/optional work placement; Reading / listening to self-learning modules, literature survey / library work; data Collection /field work; writing of papers/projects/dissertation/thesis/seminars, etc.)

Course Objectives: The study of thermal physics and its applications pervades much of the modern undergraduate course in physics. Virtually all undergraduates are expected to become familiar with the principles of thermodynamics and Kinetic theory, and their applications to real life examples.. This following material is the subject of this course.

Attendance Requirements:

Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student may not be permitted to appear in the examination.

Evaluation Criteria:

The overall evaluation of the students shall be for 100 marks distributed as per following scheme.

1. Mid Term Examination 25% (50 marks)
2. End Term Examination 50% (100 marks)
3. Continuous Internal Assessment 25% (50Marks): Consisting of assignment/quizzes/presentation/ live projects, shall contribute 20% of the total 200 marks and 5% of the marks towards internal assessment shall be on the basis of attendance.

COURSE CONTENTS

1. Kinetic Theory of Gases: (20 Lectures)

Basic assumptions of kinetic theory, Ideal gas approximation, and deduction of perfect gas laws. Maxwell's distribution law (both in terms of velocity and energy), root mean square and most probable speeds. Experimental proof. (6)
Finite size of molecules: Collision probability, Distribution of free paths and mean free path from Maxwell's distribution. Clausius and Maxwell's derivation of mean free path. (4)
Degrees of freedom, equipartition of energy: application to specific heat, Dulong and Petit's law.(1)

Transport Phenomena: Viscosity, thermal conduction and diffusion in gases. Brownian Motion: Einstein's theory, Perrin's work, determination of Avogardo number.(4)

Real Gases: Nature of intermolecular interaction, deviations from ideal gas law, isotherms of real gases. van der-Waal's equation of state, Other equations of state, critical constants of a gas, law of corresponding states; Virial Coefficients, Boyle temperature; limitations of van der- Waal's equation of state.(5)

2. Thermodynamics: (20 Lectures)

Basic Concepts: Microscopic and macroscopic points of view : thermodynamic variables of a system, State function, exact and inexact differentials. Thermal equilibrium,. Zeroth Law and the concept of temperature. (2)

First Law of Thermodynamics: Thermodynamic equilibrium, internal energy, external work, quasistatic process, first law of thermodynamics and applications including magnetic systems, specific heats and their ratio, isothermal and adiabatic changes in perfect and real gases. (5)

Second Law of Thermodynamics: Reversible and irreversible processes, indicator diagram. Carnot cycles-efficiency, Carnot's theorem. Kelvin's scale of temperature, relation to perfectgas scale, second law of thermodynamics – different formulations and their equivalence, Clausius inequality, entropy, change of entropy in simple reversible and irreversible processes, entropy and disorder; equilibrium and entropy principle. (7)

Thermodynamic Functions: Enthalpy, Helmholtz and Gibbs' free energies; Legendre transformations, Maxwell's relations and simple deductions using these relations; thermodynamic equilibrium and free energies. Porous plug experiment and the Joule- Thomson effect. (6)

Text Books:

1. A treatise on heat: M.N. Saha and B. Srivastava, Indian Press,1958.
2. Heat and thermodynamics: M. Zemansky, McGraw Hill, 1981.
3. Kinetic theory of gases: J. Jeans, Cambridge University Press.

Reference Books:

1. Thermostatics: H. Callen, Wiley, 1960.
2. Kinetic theory of gases: Loeb, Chicago university press.
3. Thermal physics: Kittel, Wiley, 1950.
4. Thermodynamics, M. Planck, Dover.

There are large numbers of books on thermodynamics and many of them are classics. You are encouraged to read from them too.

Course Code: PAS 301

Course Name: Quantum Mechanics

Course Instructor: Dr. Surender Verma

Course Contents

UNIT-I

Inadequecies in classical physics, Black body radiation: quantum theory of light, photoelectric effect, Compton effect, Frank-Hertz, experiment, Wave nature of matter: De Broglie hypothesis, wave-particle duality, Davisson-Germer experiment, Wave packets, group and phase velocities and relation between them, two slit experiment with electrons, probability, wave amplitude and wave function, Heisenberg uncertainty principle involving canonical pair of variables.

UNIT-II

Basic postulates and formalism: Energy, momentum and Hamiltonian operators, time independent Schrodinger equation for stationary states, properties of wave function, probability density and probability, continuity equation, conditions for physical acceptibility of wave function, normalization, linearity and superposition principles, eigenvalues and eigen functions, expectation values, wave function for a free particle.

UNIT-III

Eigenfunction and eigenvalues of a particle in a one-dimensional box, Bound state problems: General features of a bound particle system: one dimensional harmonic oscillator: energy levels, energy eigen function and zero point energy.

UNIT-IV

Quantum theory of Hydrogen atom: particle in a spherical symmetrical potential, Schrodinger equation, separation of variables, radial solutions and principal quantum number, orbital and magnetic quantum numbers, Quantization of energy and angular momentum, space quantization.

UNIT-V

Scattering problems in one-dimension: Finite potential step: reflection and transmission, stationary solutions, Probability current, attractive and repulsive potential barriers. Quantum phenomenon of tunneling: tunnel effect. Finite potential well (square well).

Text Books:

1. Introduction to Quantum Mechanics, D.J. Griffith, 2nd Ed. 2005, Pearson Education.
2. Concepts of Modern Physics, Arthur Beiser, Tata-McGraw Hill.
3. Quantum Mechanics, Robert Eisberg and Robert Resnick, 2nd Edn., 2002, Wiley.

Additional Books for Reference:

1. Quantum Mechanics, Leonard I. Schiff, 3rd Edn. 2010, Tata McGraw Hill.
2. Quantum Mechanics, Bruce Cameron Reed, 2008, Jones and Bartlett Learning.
3. Quantum Mechanics, Walter Greiner, 4th Edn., 2001, Springer.

Course Name: Nuclear and Particle Physics Course code: PAS318

Credit: 4 Total Lecture (40)

Course Contents:

Unit: I General Properties of Nuclei (6 Lecture)

Constituents of nucleus and their Intrinsic properties, quantitative facts about mass, radii, charge density (matter density), binding energy, average binding energy and its variation with mass number, main features of binding energy versus mass number curve, N/A plot, angular momentum, parity, magnetic moment, electric moments, nuclear excites states.

Unit: II Nuclear Models (6 Lectures)

Liquid drop model approach, semi empirical mass formula and significance of its various terms, condition of nuclear stability, two nucleon separation energies, Fermi gas model (degenerate fermion gas, nuclear symmetry potential in Fermigas), evidence for nuclear shell structure, nuclear magic numbers, basic assumption of shell model, concept of mean field, residual interaction, concept of nuclear force.

Unit: III Radioactivity decay (6 Lectures)

(a) Alpha decay: basics of α-decay processes, theory of α-emission, Gamow factor, Geiger Nuttall law, α-decay spectroscopy. (b) β-decay: energy kinematics for β-decay, positron emission, electron capture, neutrino hypothesis. (c) Gamma decay: Gamma rays emission & kinematics, internal conversion.

Unit IV: Nuclear Reactions (5 Lectures)

Types of Reactions, Conservation Laws, kinematics of reactions, Q-value, reaction rate, reaction cross section, Concept of compound and direct Reaction, resonance reaction, Coulomb scattering (Rutherford scattering).

Unit V Interaction of Nuclear Radiation with matter (5 Lectures)

Energy loss due to ionization (Bethe-Block formula), energy loss of electrons, Cerenkov radiation, Gamma ray interaction through matter, photoelectric effect, Compton scattering, pair production, neutron interaction with matter.

Unit VI Detector for Nuclear Radiations (6 Lectures)

Gas detectors: estimation of electric field, mobility of particle, for ionization chamber and GM Counter, Basic principle of Scintillation Detectors and construction of photo-multiplier tube (PMT), Semiconductor Detectors (Si and Ge) for charge particle and photon detection (concept of charge carrier and mobility), neutron detector.

Unit VII Particle physics: (6 Lecture)

Particle interactions; basic features, types of particles and its families, Symmetries and Conservation Laws: energy and momentum, angular momentum, parity, baryon number, Lepton number, Isospin, Strangeness and charm, concept of quark, model, color quantum number and gluons.

Electronic Circuits

Course Code: PAS405 Course Type: Core Open

Credits: 2

Course Objectives:

The course is designed to under the detail of the basics of diode its types, characteristics and applications (diode circuits) like rectifiers, Clipper, Clamper, comparator, sampling gate etc. Integrated circuits as analog system building blocks: including linear and nonlinear analog systems. Integrated circuits: digital system building blocks including adders etc.

Course Contents:

Unit 1: Transport Phenomena in Semiconductors (4 hours)

- Generation and recombination of charges
- Diffusion
- The continuity Equation
- Injected Minority charge carrier (low level injection)
- Potential variation with in a graded semiconductor

Unit 2: Junction Diode Characteristics (5 hours)

- Open circuit p-n junction diodes
- p-n junction as rectifier
- Current components in p-n junction diode
- Volt-ampere characteristics and its temperature dependence
- Diode resistance
- Space charge or transition capacitance, varactor diodes.

- Charge control description of diode
- Diffusion capacitance
- Junction diode switching times
- Breakdown diode
- Semiconductor photodiode
- Photovoltaic effect and light emitting diode

Unit 3: Diode Circuits (4 hours)

- Diode as circuit element
- The loade line concept
- piece wise linear diode model
- clipping circuit,
- clipping at two independent levels
- Clampers
- comparator, sampling gate
- rectifiers, and capacitor filter

Unit 4: Integrated Circuits as Analog System Building Blocks (3 hours)

- Basic Operational Amplifiers

- Differential amplifier and its transfer characteristics
- Frequency response of operational amplifiers

Unit 5: Analog Systems (4 hours)

- Linear Analog System: basic operational amplifier applications, differential dc amplifier, stable ac coupled amplifier, analog integration and differentiation, electronic analog computation, active filters.
- Non-Linear Analog System: comparators, logarithmic amplifiers, wave generators,

Prescribed Textbooks:

1. Integrated Electronics by Jacob Miliman and Cristos Halkias, Tata McGraw-Hill Edition
2. Electronic device and circuit theory by Robert L. Boylestad and Louis Nashelsky, Pearson Education.

Other Resources/Reference books:

1. Operational Amplifiers Design and Applications by Jerald G. Graeme, Gene E. Tobey, Lawrence P. Huelsman, McGraw-Hill.
2. Digital Electronic Principles by A. P. Malvino, Tata McGraw Hill..
   1. Electronic Devices and Amplifier Circuits by Steven T. Karris, Orchard Plications

Statistical Mechanics

Course Code: PAS 406A Course Type: Core Compulsory
Course Credits: 4
Course Objectives:

Connection between Thermodynamics and Statistical Mechanics, Develop statistical mechanics techniques such as ensemble theory and their application to ideal and real systems. Theory of Phase transition.

Course Contents

Unit-1: Classical Statistical Mechanics (5 hours)

- Foundation of statistical mechanics.
- Specification of state of a system
- Contact between statistics and thermodynamic.
- Classical ideal gas, entropy of mixing
- Sackur-tetrode equation and Gibb's paradox.

Unit-2: Ensemble Theory: Microcanonical, Canonical Ensemble (6 hours)

- Phase space, phase-space trajectories and density of states
- Liouville theorem
- Microcanonical ensemble: Classical Ideal gas.
- Canonical ensemble: canonical partition function(CPF, average energy in canonical ensemble,)
- Relation between CPF and Helmholtz free energy
- Equivalence of canonical and microcanonical ensembles.

Unit-3: Ensemble Theory: Grand Canonical Ensemble (5 hours)

- Factorization of Canonical Partition function: Classical ideal gas
- Maxwell velocity distribution, Equipartition theorem
- Grand canonical ensemble: Partition function
- Calculation of statistical quantities, particle density and energy fluctuations.

Unit-4: Quantum Statistical Mechanics: Statistical Distributions (6 hours)

- Density matrix, statistics of ensembles.
- statistics of indistinguishable particle.
- Harmonic oscillator at temperature T, Maxwell-Boltzmann
- Fermi-Dirac and Bose-Einstein statistics: in microcanonical and grand canonical ensemble

Unit-5: Quantum Gases (7 hours)

- Ideal quantum gases: Bose gas, Fermi gas equation of state, energy density

- Standard functions, non-degenerate case
- Degenerate Fermi gas, Sommerfeld expansion: chemical potential and specific heat of degenerate Fermi gas
- Pauli paramagnetism: low and high temperatures

- Bose-Einstein condensation: Pressure and specific heat.

Unit-6: Approximate Methods and Ising Model (7 hours)

- Cluster expansion for a classical real gas
- Virial equation of state
- Ising model, mean field theories of the Ising model one dimension
- Exact solutions in one-dimension.

Unit-7: Theory of Phase transition (4 hours)

- Landau theory of phase transition
- Critical indices
- Scale transformation and dimensional analysis.

Prescribed Text Books:

1. Statistical Mechanics, Kerson Huang, Wiley
2. Statistical Mechanics, R. K. Pathria and Paul D. Beale, Elsevier.

Other Resources/Reference books:

1. Statistical and Thermal Physics, F. Reif.
2. Statistical Physics, Landau and Lifshitz.
3. Statistical Mechanics, R. Kubo.

Advanced Quantum mechanics

Course Code: PAS 407A Course Type: Core Compulsory

Course Credit: 4

Credits Equivalent:

4 Credits (One credit is equivalent to 10 hours of lectures/organised classroom activity/contact hours; 5 hours of laboratory work/practical/field work/Tutorial/teacher-led activity and 15 hours of other workload such as independent individual/group work; obligatory/optional work placement; Reading/listening to self-learning modules, literature survey/library work; data collection/field work; writing of papers/projects/dissertation/thesis/seminars, etc.)

Course Objectives:

Quantum physics allows us to understand the nature of the physical phenomena which govern the behavior of solids, semiconductors, lasers, atoms, nuclei, sub nuclear particles, and light. In the present course, the basic formalism of the fundamentals of quantum physics will be discussed using an original approach which relies primarily on an algebraic treatment and on the systematic use of symmetry principles.

The study of quantum mechanics and its applications pervades much of the modern undergraduate course in physics. Virtually all physics students are expected to become familiar with the principles of non-relativistic quantum mechanics, with a variety of approximation methods and with the application of these methods to simple systems occurring in atomic, nuclear and solid state physics. This core material is the subject of this course.

Attendance Requirements:

Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student may not be permitted to appear in the examination.

Evaluation Criteria:

The overall evaluation of the students shall be for 100 marks distributed as per following scheme.

1. Mid Term Examination 25% (50 marks)
2. End Term Examination 50% (100 marks)
3. Continuous Internal Assessment 25% (50 Marks)
   Consisting of assignments/quizzes/presentation/live projects, shall contribute 20% of the total 200 marks and 5% of the marks towards internal assessment shall be on the basis of attendance.

Course Contents:

Unit 1: The overview of fundamentals of quantum mechanics (5 hours)

Schroedinger’s equation, stationary states, properties of the wavefunctions in one dimensions: degeneracy, parity, reality, number of nodes. Nature of the energy spectrum for arbitrary potential. Wave functions in position and momentum space.

Unit 2: Linear vector spaces and the Dirac notation. (5 hours)

Linear vector spaces, inner product spaces, dual spaces and the Dirac notation, linear transformations and their matrix representations, eigenvalue problems, properties of Hermitian and unitary operators, compartible and incompatible observables, generalisation to infinite dimensions. Uncertainty relation and it's proof.

Unit 3: Time independent perturbation theory (10 hours) First and second order corrections to the energy eigenvalues; First order correction to the eigenvector; Degenerate perturbation theory; Application to one-electron system – Relativistic mass correction, Spin-orbit coupling (L-S and j-j), Zeeman effect and Stark effect.

Unit 4: Variational method and the WKB aproximations (4 hours) He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom. Quantisation rule, tunneling through a barrier, discussion of α-decay.

Unit 5: Time-dependent Perturbation Theory (6 hours)

Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations — Fermi's Golden rule; Sudden and adiabatic approximations.

Unit 6: Scattering theory (10 hours)

Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer- Townsend effect; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering — Green's function in scattering theory; Lippman-Schwinger equation; Born approximation.

Prescribed Textbooks:

1. *Advanced quantum mechanics*, J. J. Sakurai Wiley
2. *Principles of quantum mechanics*, R. Shankar Plenum press.
3. *Introduction to Quantum Mechanics*, D. J Griffiths, Pearson Prentice Hall, (2005).

Other Resources/Reference books:

1. *Lectures on quantum mechanics*, P. A. M Dirac, Dover edition (2001).
2. *Introductory quantum mechanics*, Richard L. Liboff Addison-Wesley publishing company.
3. *Lectures on quantum mechanics* G. Baym, Addison Wesley.
4. *Quantum Mechanics* E. Merzbacher.
5. *Quantum mechanics*, B. Bransden and C. Joachain, Pearson.

Computer Simulations in Physics

Course Code: PAS 414

Course Type: Core Open

Course Credit: 2

Lab 1: Superposition of Waves

- Introduction to Scilab
- Fourier Series of square wave, triangle wave and other periodic waveforms

Lab 2: Construction of Wave packet

- using superposition of waves
- using Fourier transform

Lab 3: Solving the Time-Independent Schrodinger Equation using finite differences

- 1-D Finite Square Well potential using worksheet environment and using Scilab
- Comparision with analytically expected solutions

Lab 4: Propagator method

- Obtaining the energy eigen values using propagator method
    - Finite square well
    - Comparision with previous technique

Lab 5: Extension of Propagator method to

- Double Square well
- N-square wells

Lab 6: Matrix Methods

- Obtaining the energy eigen values and wavefunctions for
    - Finite sqaure well potential
    - Delta function potential

Lab 7: Extension of matrix method to

- Double well potential
- N-well potential

Lab 8: Matrix methods to solve

- Harmonic Oscillator using matrix methods
- Anharmonic Oscillator using matrix methods

Lab 9: Solving the Radial equation for Hydrogen atom using matrix methods

- Infinite Square well potential wavefunctions as basis functions
- Trying other basis functions

Reference: Department Lab Manual

Electronics Lab

Course Code: PAS- 415 Course Type : Core

Open Credits:

2

Lab 1: Negative Feedback Amplifiers and Instrumentation Amplifier

Lab 2: Regenerative Feedback System, Astable and Monostable Multivibrator Lab 3:

Integrators and Differentiators

Lab 4: Voltage Controlled Oscillator Lab

5: Phase Locked Loop

Lab 6: DAC and ADC

Lab 7: Introduction to Arduino kit : Flashing of LED lights Lab 8:

Interactive Traffic Lights

Lab 9: Temperature Alarm

Lab 10: Any interesting project using Arduino kit

References:

1. Learning to Design Analog Systems using Analog System Lab Starter Kit, Dr. K.R.K. Rao and Dr. C.P. Ravikumar, Texas Instruments, India
2. Internet for Arduino

Accelerator and Reactor Physics

Course Code: PAS 528 Course Type: Core Open

Course Credit: 2

Credits Equivalent: 2 Credits (One credit is equivalent to 10 hours of lectures / organised classroom activity / contact hours; 5 hours of laboratory work / practical / field work / Tutorial / teacher-led activity and 15 hours of other workload such as independent individual/ group work; obligatory/ optional work placement; literature survey/ library work; data collection/ field work; writing of papers/ projects/dissertation/thesis; seminars, etc.)

Course Objectives:
The course is designed to Review

- Introduction: Historical view and main parts
- Types Design and Working of Accelerators and Reactors
- Accelerators in CERN: LHC
- Applications and Nuclear Safeguards

Attendance Requirements:

Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student may not be permitted to appear in the examination.

Evaluation Criteria:

1. Mid Term Examination at the end of 5^{th} week for 70 marks:25% weightage
2. End Term Examination at the end of 10^{th} week for 100 marks (about 40 marks from portions before mid-term and 60 marks from portions after mid-term): 50% weightage
3. Continuous Internal Assessment: 8 Assignments consisting of 4 or 5 problems to be solved at the end of every week other than 5^{th} and 10^{th}. Best 6 performances will be considered for evaluation which makes up for the remaining 25% of the total 100 marks.

Course Contents:

Unit 1: Accelerators (3 hours)

- Historical Developments, Layout and Components of Accelerators
- Electrostatic Accelerators, Linear Accelerators, SLAC
- Phase Stability, Low Energy Circular Accelerators

Unit 2: High Energy Accelerators (4 hours)

- Synchro-cyclotron, Proton Synchrotrons
- Colliding Beam Accelerators: Tevatron and Storage Rings

- Accelerators at CERN, Large Hadrons Collider (LHC)

Unit 3: Neutron Physics (3 hours)

- Neutron Sources, Absorption and Moderation of Neutrons
- Neutron Reaction and Cross-sections
- Neutron Capture

Unit 4: Nuclear Reactors (7 hours)

- Energy and Characteristics of Fission, Nuclear Chain Reaction
- Physics of the Nuclear Reactor and Critical Size of a Reactor
- Types, Design and Working of Fission Reactors
- Characteristics of Fusion, Thermonuclear Reactions, Fusion Reactors, Design of Fusion Power Plant

Unit 5: Applications & Nuclear Safeguards (3 hours)

- Indian Accelerators & Reactors, Nuclear Power, Reactor Safety, Domestic and International Nuclear Safeguards and Nuclear Waste Management.

Prescribed Textbooks:

1) D. C. Tayal: Nuclear Physics, Himalaya Publishing House Pvt. Ltd.
2) Kenneth S. Krane : Introductory Nuclear Physics, John Wiley & Sons, 1988.
3) S.Y. Lee: Accelerator Physics, World scientific, 2004.
4) W.M. Stacey: Nuclear Reactor Physics, Wiley-VCH Verlag GmbH & Co.
5) H. Staneley: Principles of Charged Particle Acceleration, John Wiley & Sons.
6) H. Wiedemann: Particle Accelerator Physics I, Springer, 1999.
7) B.R. Martin: Nuclear and Particle Physics, John Wiley & Sons Ltd. 2006.
8) Particle Data Group

Computational Physics Laboratory

Course Code: PAS 427 Course Type: Core Open
Course Credit: 2

Statistical Mechanics Simulations:

Worksheet based Simulations:

Lab 1: Microstates, Macrostates and Steady-state equllibrium
Lab 2: Ergodic Hypothesis Demonstration

Simulations in Scilab:

Lab 3: Boltzmann Distibution: P(E) vs E

Lab 4: Boltzmann Speed Distribution and Maxwell's velocity distribution

Lab 5: Joule's Expansion and Entropy

Quantum Mechanics Simulations:

Lab 6: Solving the Time-Dependent Schrodinger Equation and obtaining the spreading of Gaussian wavepacket

Lab 7: Studying the Scattering of Gaussian wavepacket

Lab 8: Scattering from a step potential and a barrier potential

Computational Physics

Course Code: PAS 428 A Course Type: Core Compulsory
Course Credit: 4

Course Contents:

Unit 1: Ordinary Differential Equations: (8 hours)

- Euler method, Application to Radioactivity, Air drag and Projectile motion
- Euler-Cromet Method, Application to SHO
- Predictor-corrector method (Heun's) method, Application to Damped Harmonic Osicllator
- Second order Runge-Kutta method, Application to Forced Oscillations
- Study of Panetary motion
- Higher-order Runge-Kutta method; Application to Coupled Oscillations

Unit 2: Partial Differential Equations: (8 hours)

- Finite Difference methods: Elliptic Equations- Laplace equation, solution techniques and boundary conditions;
- Parabolic Equations- Heat Conduction Equation, explicit and implicit methods
- Crank-Nicholson Method; Application to Schrodinger equation.
- Finite Element Method: General approach and applications in One-dimension;
- Application to problems in Electromagnetics.

Unit 3: Random Variables and Random Processes: (4 hours)

- Random variables, several random variables; Statistical averages, function of a random variable, moments, characteristic function, joint moments; Transformation of random variables; Sequences of random variables; central limit theorem (without proof);
- Random processes; Stationarity; Mean, correlation and covariance functions; autocorrelation function and properties , cross-correlation functions; Ergodicity; Power spectral density; Gaussian process and its properties;

Unit 4: Random Processes and Monte-Carlo Methods: (6 hours)

- Random number generation-uniform and non-uniform distributions;
- Monte Carlo Integration- Hit and miss, Sample mean integration,
- Metropolis Method;
- Computer "Experiments" - applications of Monte-Carlo methods to problems in physics;
- Variational Monte-Carlo tecnique: Application to solving for the ground state of quantum mechanical systems in 1D and 2D

Unit 5: Fast Fourier Transforms and Spectral Methods: (6 hours)

- Discrete Fourier Transform,

- Fast Fourier Transform,
- Sande Tukey Algorithm
- Pseudospectral technique to solve the Schroedinger equation
- Application to study few 1D potentials

Theoretical Nuclear Physics

Course Code: PAS 527 Course Type: Elective Specialization
Credits: 4

Course Objectives: The course is designed to study the following:

1. Interaction of nuclear radiation like charged particles, neutrons, gamma and positron with matter and how these radiations are detected.
2. Study of decay laws, theory and use in the structure exploration of nuclei.
3. Nuclear reactions, kinematics, reaction cross-sections, different types and theories developed.
4. Nuclear Fission, characteristics and applications.
5. Basic fusion process it characteristics, solar fusion etc.

<u>Course Contents:</u>

Unit 1: Interaction of nuclear radiation with matter ` (10 hours)

- Interaction of charged particles with matter
- Interaction of neutrons with matter: energy loss and energy distribution after collision
- Interaction of gamma radiation with matter: attenuation of gamma rays, Compton Effect, photoelectric effect and pair production.
- Interaction of positron with matter
- Detection of nuclear radiation

Unit 2: Radioactive Decay (10 hours)

- Radioactive decay law, Quantum theory of radiative decays, production and decay of radioactivity, Growth of Daughter activities.
- Alpha decay: energetic, decay constant, hindrance factors, alpha particle spectra
- Fermi theory of β-decay, Electron and positron energy spectra, electron capture decay, parity non conservation in β-decay, nuclear structure information from β-decay.
- Theory of γ-decay and internal conversion and nuclear structure information from γ-decay

Unit 3: Nuclear reactions (12 hours)

- Cross-sections, reciprocity theorem, Elastic scattering and method of partial waves, relationship between differential and scattering amplitude.
- Free particle, turning the potential on, scattering amplitude and elastic scattering cross-section, reaction cross-section.
- Scattering by simple potential, square well potential.

- Theory of resonance: General aspects, logarithmic derivative and cross-section, Breit-Wigner formula, R-Matrix theory.

Unit 4: Nuclear Fission and Fusion (8 hours)

- Fission: Characteristics of Fission, Energy In Fission, Fission and Nuclear Structure, Controlled Fission Reactions, Fission Reactors, Radioactive Fission Products, Fission Explosives.
- Basic fusion processes, characteristics of fusion and solar fusion.

Prescribed Text Books:

1. Introductory Nuclear Physics, K. S. Krane, John Wiley& Sons Ltd
2. An Introduction to Nuclear Physics, W. N. Cottingham, D. A. Greenwood, Cambridge University Press.
3. Elements of Nuclear Physics, Walter E. Meyerhof, McGraw-Hill Book Company.

Other Resources/Reference books:

1. Fundamentals In Nuclear Physics from Nuclear Structure to Cosmology Jean-Louis Basdevant, James Rich, Michel Spiro, Springer
2. B.R. Martin, Nuclear and Particle Physics, John Wiley& Sons Ltd.
3. R.R. Roy and B.P. Nigam, Nuclear Physics: Theory and experiment, New age International (P) limited, Publishers.

Molecular Simulations in Material Science

Course Code: PAS-552 Course Type: Elective Specialization
Course Credit: 4

Credits Equivalent: 4 Credits (One credit is equivalent to 10 hours of lectures / organised classroom activity / contact hours; 5 hours of laboratory work / practical / field work / Tutorial / teacher-led activity and 15 hours of other workload such as independent individual/ group work; obligatory/ optional work placement; literature survey/ library work; data collection/ field work; writing of papers/ projects/dissertation/thesis; seminars, etc.)

Course Objectives: This course provides an introduction to modelling and simulation approaches in material science. The course will cover systematic introduction to the theory and algorithms used to implement various approaches in solving many body problems in classically and quantum mechanically. The classical part will cover well known molecular dynamics methods and quantum mechanical part will be based upon density functional based approach. This approach is an exciting new idea that allows designing of materials with desired properties from the bottom up approach.

Attendance Requirements:
Students are expected to attend all lectures in order to be able to fully benefit from the course. A minimum of 75% attendance is a must failing which a student may not be permitted to appear in the examination.

Evaluation Criteria:

1. Mid Term Examination 25% (50 marks)
   At the end of 5th week the midterm examination shall be held for duration of *two hours* and shall consist of 50 marks question paper. The question paper shall consist of three sections. Section A (10 marks) shall contain 5 to10 very short answer type questions of 2/1 marks each, all being compulsory. Section B (20 marks) shall contain 6 short answer type questions of 5 marks each, out of which students have to attempt any 4. Section C (10 marks) shall consist of 2 compulsory long answer type questions of 10 marks each. The questions in section C shall have internal choice.
2. End Term Examination 50% (100 marks)
   At the end of 10th week the end term examination shall be held for duration of *three hours* and shall consist of 100 marks question paper. The question paper shall consist of three sections. Section A (20 marks) shall contain 10 to 20 very short answer type question of 2/1 marks each, all being compulsory. Section B (40 marks) shall contain 12 short answer type questions of 5 marks each, out of which students have to attempt any 8. Section C (40 marks) shall consist of 4 compulsory long answer type questions of 10 marks each. Every question in section C shall have internal choice.
3. Continuous Internal Assessment 25% (50 Marks)
   Consisting of assignments/quizzes/presentation/live projects, shall contribute 20% of the total 200 marks i.e. (40M) and 5% of the marks (i.e. 10M) towards internal assessment shall be on the basis of attendance.

Course Contents:

Unit-1: Understanding the real materials (4 hours)

- Real solids and Hamiltonian for electrons in multiatomic system.
- Challenges for obtaining quantum mechanical solution.

- Born Oppenheimer approximation,
- Free electron and independent electron approximations

Unit-2: Schrödinger Equation for a many electron system (6 Hours)

- Challenge of electron-electron interaction and Hartree approximation
- Limitations of Hartree approximation and Slater determinant
- Hartree-Fock approximation and deriving Hartree-Fock equations equations: Variational approach,
- Ground state energy, ionization energy and Koopmans theorem. Excited states and transition energy (ignoring relaxation effects).
- Hartree Fock equations and transition energies in closed shell systems.
- Hartree-Fock-Slater and Hartree-Fock-Roothaan methods. Beyond one electron approximation.

Unit-3: Basis sets (8 hours)

- Plane waves, as basis function and their limitations
- Tight binding approximation
- Orthogonal plane wave method (OPW)
- Frozen core approximation and pseudopotential method,
- Cellular method: its successes and failures
- Muffin tin potentials, augmented plane wave method, (APW)
- Linearized augmented plane waves (LAPW).
- Slater type orbitals, Gaussian type orbitals, Numerical basis functions.

Unit-4: Electron gas (4 Hours)

- Basic elements of free electron gas, Jellium Model
- Homogeneous electron gas in Hartree-Fock approximation.
- Fully polarized ferromagnetic electron gas. Wigner crystallization.
- Electronic properties and phase diagram of homogeneous electron gas.

Unit-5: Basics of density functional theory (8 Hours)

- Basics of funcaional analysis. Orbital free density functional theory: Thomas Fermi theory.
- Hohenberg Kohn theorems.
- Kohn Sham (KS) equations.
- KS equations in Plane wave form. *k*-point sampling.
- Exchange and correlation holes, Exchange correlation functional: Local density approximation.
- Gradient correction methods: Generalised gradient approximation (GGA).
- Basic idea of meta-GGA, hyper-GGA. Band structure and density of states of some standard materials.
- DFT as Materials modelling tool. Limitations of density functional theory.

Unit 6: Fundamentals of Molecular dynamics simulations (10 hours)

- Molecular Dynamics Methodology-Force Field,
- Molecular dynamics potentials, force calculation,
- Long Range Forces and cut off radius
- Integrating Algorithms
- Boundary conditions, Periodic Box and Minimum Image Convention, Non Bonded Interaction
- Temperature Control and thermostats in molecular dynamics

- Pressure Control and Barostats in molecular dynamics
- Estimation of Pure Component Properties
- Radial Distribution Function and its significance

- Molecular Dynamics Packages.

Prescribed text books:

1. *Solid State Physics*, Guiseppe Grosso and Guiseppe Pastori Parravicini, Academic Press

2. *Methods Of Electronic Structure Calculations*, Springborg Michael, John Wiley and Sons

3. *The Art of Molecular Dynamic Simulations*, D. C. Rapaport, Cambridge University Press

Other Resources/Reference books:

1. *Introduction to Computational Chemistry*, Frank Jensen, 2nd edition, John Wiley and Sons Ltd.
2. *Solid State Physics*, Guiseppe Grosso and Guiseppe Pastori, Academic Press.
3. *Solid State Physics*, Neil W. Ashcroft and N. David Mermin, Cengage Learning India Pvt Ltd.
4. *The Electronic Structure Of Solids*, B.R. Coles and A. D. Caplin, Edward Arnold publishers
5. *Electronic Structure: Basic Theory And Practical Methods*, Richard M. Martin, Cambridge University press
6. *Introduction To Computational Physics*, T. Pang, Cambridge University press
7. *A Bird's-Eye View of Density-Functional Theory*, Klaus Capelle, arXiv:cond-mat/0211443 (2006)
8. *The Density Functional Formalism, Its Applications And Prospect*, R.O. Jones and O. Gunnarsson, Reviews of Modern Physics, Vol. 61, No. 3, July 1989
9. *Iterative Minimization Techniques For Ab Initio Total-Energy Calculations: Molecular Dynamics And Conjugate Gradients*, M.C. Payne et al. Reviews of Modern Physics, Vol. 64, No. 4, October 1992
10. Nobel Lecture: *Electronic Structure Of Matter-Wave Functions And Density Functional*, W. Kohn, Rev. Mod. Phys., Vol. 71, No. 5, October 1999
11. *The ABC of DFT*, Kieron Burke and friends, "*http://chem.ps.uci.edu/~kieron/dft/book/*"

Nanomaterials & Technology

Course Code: PAS 516

Course Type: Elective Open

Course Credit: 2

Course Objectives:

- Applications in solving problems of interest to physicists.
- Explore the potential application of physics at nanoscale regime.

Course Contents:

Unit 1: Nanoscale Systems (8 hours)

- Nanostructures and Nanoscale Devices
- Quantization in Nanostrctures
  - Quantization in Heterojunction Systems (Quantum Well)
  - Lateral Confinement (Quantum Wires and Quantum Dots)
  - Electronic States in Quantum Wires and Dots
- Magnetic Field Effects in Quantum Confined Systems
- Transmission in Nanostructures
  - Tunnelling in Planar Barrier Structures
  - Current in Resonant Tunnelling Diodes
- Landauer Formula &The Multi-channel Case

Unit 2: Synthesis of Nanomaterials (6 hours)

- Top-down and Bottom-up Approach
  - Zero-dimensional nanostructures (nanoparticles)
  - One-dimensional nanostructures (nanowires)
  - Two-dimensional nanostructures (thin films)
  - Special nanomaterials (fullerene, carbon nanotube, graphene)
- Physical Vapour Deposition (PVD)
  - Pulsed Laser Deposition
  - Thermal Evaporation
  - E-beam Evaporation
  - DC & RF Sputtering
  - Molecular Beam Epitaxy (MBE)
- Chemical vapour deposition (CVD)
- Lithography
  - Photolithography
  - Electron Beam Lithography (EBL)
  - Focussed Ion Beam

Unit 3: Characterization of Nanomaterials (6 hours)

- X-Ray Diffraction
- Optical Microscopy
- Electron Microscopy
    - Scanning Electron Microscopy

    - Transmission Electron Microscopy
- Scanning Probe Microscopy
    - Atomic Force Microscopy
    - Scanning Tunnelling Microscopy

Other Resources/References books:

1. Transport in Nanostructures, D. K. Ferry, Cambridge University Press (2009).
2. Principals of Nano-optics, L. Novotny and B. Hecht, Cambridge University Press (2006).
3. Quantum Transport: Atom to Transistor, S. Datta, Cambridge University Press (2005).
4. Nanostructures & Nanomaterials, G. Cao, World Scientific (2015).
5. The Science and Engineering of Microelectronic Fabrication, S. A. Cambell, OUP (2001).
6. E. N. Kaufmann, Characterization of Materials, Wiley (2003).

Project

Course Code: PAS 548 Course Type: Élective

Spécialisation Course Credit: 4

To be Developed