DEPARTMENT OF PHYSICS

PONDICHERRY UNIVERSITY

CURRICULUM FOR

2-Year MSc (Physics)

Under CBCS regulations

[for 3-year BSc (Physics) qualified students]

(For students admitted from the academic year 2024-25)

MARCH 2024

Eligibility for Admission

3-year Bachelor of Science degree (BSc) majoring in Physics with Mathematics as a mandatory subject (minor or ancillary) with at least 55% of marks in aggregate or equivalent.

(OR)

4-year BScBEd (Integrated Bachelor of Science Education) degree under NCTE regulations majoring in Physics with Mathematics as a mandatory subject (minor or ancillary) with at least 55% of marks in aggregate or equivalent.

SEMESTER – I

Hard / Soft Course	*Course Code*	*Credits*	*Title of the Course*
Hard	PHYS 410	3	Advanced Physics Laboratory – I
Hard	PHYS 411	4	Mathematical Physics – I
Hard	PHYS 412	4	Classical Mechanics
Hard	PHYS 413	4	Quantum Mechanics – I
Hard	PHYS 414	4	Electronic Devices and Circuits
Hard	PHYS 415	4	Solid State Physics – I
	Hardcore Total	**23**	

SEMESTER – II

Hard / Soft Course	*Course Code*	*Credits*	*Title of the Course*
Hard	PHYS 421	4	Statistical Physics – I
Hard	PHYS 422	4	Classical Electrodynamics
Hard	PHYS 423	4	Atomic and Molecular Physics
Hard	PHYS 424	4	Mathematical Physics – II
Hard	PHYS 425	4	Solid State Physics – II
Soft	PHYS 426	4	Nonlinear Optics
	Hardcore Total	**20**	

SEMESTER– III

Hard / Soft Course	*Course Code*	*Credits*	*Title of the Course*
Soft	PHYS 511	3	Laser Laboratory
Hard	PHYS 512	3	Condensed Matter Laboratory
Hard	PHYS 513	4	Statistical Physics – II
Hard	PHYS 514	4	Quantum Mechanics – II
Hard	PHYS 515	4	Nuclear Physics
Soft	PHYS 516	4	Laser Theory
	Hardcore Total	**15**	

SEMESTER – IV #

Hard / Soft Course	*Course Code*	*Credits*	*Title of the Course*
Project (Hardcore)	PHYS 520	20	MSc (PG) Research Dissertation Project**
	(Project work **OR** Five coursework*** in-lieu)		
Soft	PHYS 521	4	Magnetism and Magneto-transport Phenomena
Soft	PHYS 522	4	Plasma Physics and Controlled Fusion
Soft	PHYS 5xx	4	Elective – I ##
Soft	PHYS 5xx	4	Elective – II ##
Soft	PHYS 5xx	4	Elective – III ##
	Hardcore Total	**20**	

** Candidates with a minimum aggregate CGPA of 7.50 until the 2nd semester (without arrears) shall have the option to do the project work. If required, the project work may be executed in research institutes / other universities (*e.g.*, Indian Institute of Astrophysics).

*** Candidates not doing project work should take five coursework papers (20 credits) instead of project work.

The candidates doing the project work can also optionally take some elective papers.

A minimum of 78 credits, including all the hardcore courses, need to be earned for completion of the M.Sc. (Physics) course of 2 years duration.

LIST OF ELECTIVE PAPERS #

PHYS 523	Nonlinear Dynamics
PHYS 524	Quantum Field Theory
PHYS 525	Particle Physics
PHYS 526	Gravitation and Cosmology
PHYS 527	Numerical Methods

PHYS 531	Materials Characterization
PHYS 532	Materials Modelling and Simulation
PHYS 533	Measurement Systems

PHYS 541	Laser Spectroscopy
PHYS 542	Quantum Entanglement

PHYS 551	Astrophysics – I (under MOU* with IIA Bangalore)
PHYS 552	Astrophysics – II (under MOU* with IIA Bangalore)
PHYS 553	Astrophysics – III (under MOU* with IIA Bangalore)

Elective papers will be floated depending on the availability of the course teacher.

* *The number of students for this course will be as per the MOU with IIA Bangalore.*

* * * END of COURSE STRUCTURE * * *

Detailed Syllabus of

LABORATORY COURSES

(Lab Courses for Physics Department Students)

PHYS 410 - ADVANCED PHYSICS LABORATORY (3 CREDITS LAB)

(Choose five from General and five from Electronics experiments)

General Experiments:

1. Resistivity measurement by four probe method.
2. Study of Frank Hertz experiment.
3. Study of ferroelectric phase transition.
4. Study of Hall effect.
5. Constant Deviation Spectrometer.
6. Hysteresis loop of ferromagnetic materials.
7. Determination of magnetic susceptibility of a solid by Guoy's method.
8. Photoconductivity
9. Dielectric constant
10. Michelson Interferometer
11. Diffraction grating experiment
12. Zeeman Effect

Electronics Experiments

1. BJT – Common emitter amplifier.
1. BJT– Two-stage RC-coupled amplifier.
2. Characteristics of FET.
3. Study of unijunction transistor.
4. Study of phase shift oscillator.
5. Study of Hartley oscillator.
6. Study of Colpitt's oscillator.
7. Operational amplifier characteristics.
8. Frequency response of an operational amplifier.
9. Configurations of an operational amplifier.

Text Book

Lab Manual, Department of Physics, Pondicherry University.

Suggested Readings

[1] Rajopadhye and Purohit. A Text Book of Experimental Physics.
[2] Hayes and Horowitz. Students Manual for the Art of Electronics. Cambridge University Press.
[3] Sanish Kumar Gosh. A Text Book of Practical Physics. New Central Books.
[4] Holman. Experimental methods for engineers. Tata McGraw Hill.
[5] Maheswari. Laboratory manual for introductory electronics experiments. New Age International.
[6] Srinivasan and Balakrishnan. A textbook of practical physics. Vols. I, II. S. Viswanathan Pub.
[7] Chattopadhyay and Ratshit. An Advanced Course in Practical Physics. New Central Books.
[8] Ghosh. Advanced Practical Physics. 2-volume set.Sreedhar Publishers.

PHYS 511 – LASER LABORATORY **(3 Credits Lab)**

(Choose any ten experiments)

List of Optics / Laser Experiments

1. Numerical aperture of optical fiber and propagation of light through optical fiber.
2. Intensity profile of laser through optical fiber and determination of refractive index profile.
3. Refractive index by Brewster angle setup.
4. Study of Faraday effect using He-Ne laser with AC modulator.
5. Study of Electro-optic effect (Pockel effect) with AC modulator.
6. Study of Electro-optic effect (Kerr effect).
7. Study of Acousto-Optic effects.
8. Study of Second Harmonic generation.
9. Study of Passive Q switching in Nd:YAG laser.
10. Study of Active Q Switching in Nd YAG Laser.
11. Study of Laser bean characteristics (beam divergence, spot size, intensity.
12. profile) using He-Ne laser.
13. Estimating Coherence Length of the Given Light Source.
14. Digital holography.
15. Estimation of Stokes Parameter.

References

[1] Experimental Techniques In Condensed Matter Physics At Low Temperatures by Robert C. Richardson (Editor), Eric N. Smith (Editor), 2019.
[2] Springer Handbook of Condensed Matter and Materials by Werner Martienssen (Editor), Hans Warlimont (Editor), 2006.
[3] UV/VIS Spectrophotometry Fundamentals and Applications by A. De Caro and Haller Claudia, 2015.
[4] A Handbook of Electrical Measurement and Instrumentation by Sundar Rajan, Scholars Press, 2020.
[5] Handbook of X-ray Photoelectron Spectroscopy by Joln F Moulder, William F Stickle, Peter E Sobol, and Kenneth D. Bomben, publisher: Perkin-Elmer Corporation (USA), 1992.
[6] Experiments in Physics by R. Srinivasan, K. R. Priolkar and T. G. Ramesh (2018)

PHYS 512 – CONDENSED MATTER LABORATORY **(3 Credits Lab)**

(Choose any ten experiments)

List of Condensed Matter Physics Experiments

1. Powder X-ray diffraction pattern for crystalline material.
2. Infrared spectroscopy for crystalline material.
3. Raman spectrum for crystalline material.
4. Impedance spectroscopy study for a crystalline material.
5. UV-VIS spectroscopy for determination of optical band gap.
6. Analysis of M-H loop for a ferromagnetic material.
7. X-ray photoelectron spectroscopy for determination of charge state of metal ions.
8. Emission spectroscopy to study optical properties of a semiconductor.
9. Analysis of P-E loop for a ferroelectric material.
10. Study of I-V characteristics of a semiconductor device (Solar cell / LDR / Photo transistor).
11. Study of thermal and electrical conductivity of Copper to measure its Lorentz number.
12. Study of Magnetoresistance in Bismuth and p-Ge crystals.
13. Study of magnetostrictive coefficient of a ferromagnetic metal.
14. Study the dispersion relation for the monoatomic and diatomic lattices - Comparison with theory, and determination of the cut-off frequency of the mono-atomic lattice.

References

[1] Experimental Techniques In Condensed Matter Physics At Low Temperatures by Robert C. Richardson (Editor), Eric N. Smith (Editor), 2019.
[2] Springer Handbook of Condensed Matter and Materials by Werner Martienssen (Editor), Hans Warlimont (Editor), 2006.
[3] UV/VIS Spectrophotometry Fundamentals and Applications by A. De Caro and Haller Claudia, 2015.
[4] A Handbook of Electrical Measurement and Instrumentation by Sundar Rajan, Scholars Press, 2020.
[5] Handbook of X-ray Photoelectron Spectroscopy by Joln F Moulder, William F Stickle, Peter E Sobol, and Kenneth D. Bomben, publisher: Perkin-Elmer Corporation (USA), 1992.
[6] Experiments in Physics by R. Srinivasan, K. R. Priolkar and T. G. Ramesh (2018)

Detailed Syllabus of

THEORY PAPERS – 1st YEAR

(Theory Papers for Physics Department Students)

PHYS 411 - MATHEMATICAL PHYSICS – I (4 CREDITS / 1 TUTORIAL)

Unit I: Differential Equations (15 hours)
Classification of differential equations - Euler equation – Singular points of ODE - Frobenius method and series solution of second order ODE– Orthogonal functions - Strum-Liouville problem and orthogonal eigenfunction expansions – Application to solve boundary value problems - Partial differential equations in the curvilinear (cylindrical and spherical) coordinate systems – Heat equation, wave equation, and Laplace equation in cylindrical and spherical coordinate systems - Method of separation of variables to solve PDE's in 3D curvilinear coordinate systems.

UNIT II: Special Functions (15 hours)
Definition of improper integrals of first and second kind – Beta, Gamma, Delta, and Error functions and evaluation of improper integrals – Stirling's formula - Bessel, Hermite, Legendre, Associated Legendre, and Laguerre differential equations and their solutions by series method – Bessel functions of the first and second kind – Legendre polynomials, Legendre functions of the first and second kind - Spherical harmonics – Orthogonality conditions of special functions - Generating functions, Rodrigue formula, and Recurrence relations - Applications in physics.

Unit III: Complex Variables (15 hours)
The function of a complex variable – Mapping by exponential function – Differentiability and analyticity - Cauchy-Riemann conditions in polar coordinates – Analytic functions and harmonic functions – Logarithmic function and branch cuts – Terminology: Epsilon neighborhood, Open disk, Simple closed curve, Multiply connected domains, Meromorphic function, Entire function – Contour integrals using parametrization – Contour integrals involving branch cuts – Cauchy-Goursat theorem for multiply connected domain – Principle of deformation of contours – Cauchy integral theorem – Cauchy integral formula – *M-L* theorem – Morera theorem – Sequences and series – Absolute and uniform convergence of power series - Taylor, Maclaurin, and Laurent series expansion of complex functions – Circle of convergence and radius of convergence – Taylor theorem – Laurent theorem – Zeros and order of zeros – Simple pole and higher order poles – Removable and essential singularities – Cauchy residue theorem and applications – Evaluation of real integrals using complex-valued functions involving sine and cosines – Integration using intended contours – Cauchy principal value – Integration along branch cuts – Introduction to conformal mapping.

UNIT IV: Integral Transforms (15 hours)
Fourier analysis – Half range Fourier series – Complex notation for Fourier series - Parseval's identity – Convergence of Fourier series and Gibb's phenomenon – Solving Laplace equation using Fourier series – Fourier integral representation of functions – Fourier integral theorem – Finite and infinite Fourier transforms – Fourier sine and cosine transforms – Complex Fourier transforms – Scaling, shifting and more properties of Fourier transforms – Convolution theorem – Parseval relation – Solving partial differential equations using Fourier transforms – Laplace transforms - Linearity property – First and second shifting theorems – Scaling theorem – Laplace transforms of derivatives versus Differentiation of Laplace transforms – Laplace transform of integrals versus Integration of Laplace transforms – Laplace transform of (b) unit step, and (c) Dirac delta functions – Filtering property of delta functions – Laplace transform of periodic functions – Convolution theorem and integrals – Solving initial value problems, differential equations, and integrodifferential equations.

Textbooks
[1] V Balakrishnan. Mathematical Physics. Springer.
[2] Jain and Iyengar, Advanced Engineering Mathematics, Narosa.
[3] Haberman, Applied Partial Differential Equations, Pearson.

Supplementary Readings
[1] Jeffrey, Advanced Engineering Mathematics, Academic Press.
[2] Zill and Shanahan, Complex Analysis, Jones and Bartlett Publishers.
[3] Spiegel, Advanced Calculus, Schaum Series, McGraw Hill.
[4] Spiegel, Fourier Analysis, Schaums Series, McGraw Hill.

PHYS 412 - CLASSICAL MECHANICS (4 CREDITS / 1 TUTORIAL)

Unit I 12 hours

Mechanics of a system of particles – Conservation laws of linear and angular momenta for systems not subjected to external forces and torques – Constraints, degrees of freedom, generalized coordinates, and generalized potentials – Classification like holonomic, rheonomic, and scleronomous constraints - Virtual displacement and the principle of virtual work and D'Alembert's principle – Derivation of Lagrange equation from D'alembert's principle - Elements of the calculus of variations – Hamilton's least action principle - Lagrangian formulation - Derivation of Lagrange equations from Hamilton's principle - Applications to solve dynamical problems – Conservation theorems and symmetry properties – Norther's theorem.

Unit II 12 hours

Motion in a central field – Kepler's problem – Reduction to equivalent one-body problem – Equation of motion for Kepler's problem and first integrals – Classification of orbits – Review of equations for circle, ellipse, parabola, and hyperbola in cartesian and polar coordinates – Transforming cartesian equation of ellipse to polar form – Differential equation for the orbit and power-law potentials – Bertrand theorem – The Laplace-Runge-Lenz vector – The concept of superintegrable systems – Scattering in a central field – Laboratory and center of mass frame – differential scattering cross section – scattering by a central field.

Unit III 12 hours

Variational method – Legendre transformation and Hessian – Hamilton's equations – Cyclic coordinates and conservation theorems - Canonical transformations and applications – Generating functions – Infinitesimal contact transformations – Lagrange and Poisson brackets and canonical invariants – Angular momentum Poisson bracket relations – Hamilton-Jacobi theory with harmonic oscillator as an example.

Unit IV 12 hours

Degrees of freedom of a rigid body and kinematic links – Orthogonal transformations - Rigid body rotation – Finite and infinitesimal rotation of rigid bodies - Laboratory and rotating frame of reference - Euler angles - Transformation between rotating and stationary frames – Coriolis and centrifugal forces – Angular momentum and kinetic energy about a point of rotating rigid body - Moment of inertia tensor and Principal axis transformation – Euler's equations – Symmetric top precession – Theory of small oscillations – Normal coordinates and forced oscillations.

Unit V 12 hours

The special theory of relativity: Inertial frames – Lorentz transformations – Length contraction, Time dilation, and Doppler effect – Minkowski space – Index notation for vectors and tensors – Metric tensor – Einstein summation convection – Covariant and contravariant vectors - Energy momentum four vectors – Introduction to general relativity.

Textbooks

[1] Thornton and Marion. Classical Dynamics of Particles and Systems, Cengage Learning.
[2] Goldstein, Poole, Safko, Classical Mechanics, Addison Wesley.
[3] J C Upadhyaya. Classical Mechanics, Himalaya Publishing.
[4] P V Panat, Classical Mechanics, Narosa.
[5] David Morin, Special Relativity for the Beginner, CreateSpace Publishing.

Supplementary Reading

[1] David Morin, Classical Mechanics, Cambridge University Press.
[2] Synge and Griffith, Principles of Mechanics, McGraw Hill.
[3] Taylor, Classical Mechanics, University Science Books.
[4] Kibble and Berkshire. Classical Mechanics, Imperial College Press.
[5] Greenwood, Classical Dynamics, Prentice Hall.
[6] A K Raychaudri, Classical Mechanics, Oxford University Press.
[7] K G Gupta, Classical Mechanics of Particles and Rigid Bodies, Wiley.

PHYS 413 - QUANTUM MECHANICS - I **(4 CREDITS / 1 TUTORIAL)**

Unit – I **(12 hours)**

Review of Fourier transforms – Postulates of classical mechanics versus quantum mechanics - Dirac Bra and Ket notation – Expansion of vector in an orthonormal basis in Hilbert space – Matrix elements of linear operators – Adjoint of an operator – Unitary transformations – Eigenvalues and eigenvectors of complex Hermitian matrix – Simultaneous diagonalization of two Hermitian operators – Functions of operators: Calculation of exponential of an operator – Outer product and density matrix - Ehrenfest Theorem - Schrödinger picture – Heisenberg picture (matrix mechanics) – Interaction picture – Relation among different pictures – Commutator relations.

Unit – II **(12 hours)**

Solving the free particle problem in Dirac notation – Free particle propagator – Time evolution of the Gaussian packet – Continuity equation for probability current density - Definition of bound states and scattering states – Calculation of reflection and transmission coefficients for (a) Single-step potential, (b) Dirac-delta potential – Potential step – Infinite square well – Finite square well (or potential well) – Potential barrier and quantum tunneling effect – Discussion of degeneracy in the bound states in one-dimensional problems.

Unit – III **(12 hours)**

Taylor series expansion of potential – Quantum harmonic oscillator and normal modes – Solving the harmonic oscillator differential equation (Hermite polynomials) – Finding eigenfunctions and plotting – Calculation of energy eigenvalues – Solving the harmonic oscillator problem using operator method – Annihilation (lowering) and creation (raising) operators – Solution of a linear harmonic oscillator using (a) Schrödinger picture and (b) matrix mechanics – Matrix representation of harmonic oscillator operators – Schrodinger equation in the spherical coordinate system – Angular equation – Legendre polynomials and spherical harmonics – Radial equation – Spherical Bessel function and spherical Neumann function – Solution of hydrogen atom radial equation by power series method – Derivation of Bohr formula – Degeneracy of the hydrogen spectrum.

Unit – IV **(12 hours)**

Angular momentum in quantum mechanics – Angular momentum operator algebras – Ladder operators and the spectrum of eigenvalues – Commutation relations – Eigenvalues and Eigen functions of angular momentum operator – Matrix representation of angular momentum operators (basics concepts) – Spinor matrix and Pauli spin matrices – Addition (coupling) of angular momenta – Clebsch-Gordan coefficients.

Unit – V **(12 hours)**

Basics of discrete Symmetries – Symmetries, Conservation Laws, and degeneracy – Translational invariance – Time-translational invariance - Parity inversion (space inversion) – Time-reversal symmetry - Rotational Symmetry – Infinitesimal and Finite Rotations – Rotation Operator – Rotation Matrices – How operators transform under rotations? – Definition of scalar, vector, and tensor QM operators – Reducible and irreducible tensors and spherical tensors – Wigner-Eckart theorem.

Textbooks

[1] R Shankar, Principles of Quantum Mechanics, Springer.
[2] Liboff, Introductory Quantum Mechanics, Pearson Education.
[3] Ghatak and Lokanathan, Quantum Mechanics, Trinity Press.
[4] Griffiths, Introduction to Quantum Mechanics, Pearson Education.
[5] Zettili, Quantum Mechanics: Concepts and Applications, Wiley.

Supplementary Readings

[1] V Devanathan, Quantum Mechanics, Narosa Publishing House.
[2] Ashok Das, Lectures on Quantum Mechanics, World Scientific.
[3] Schiff, Quantum Mechanics, McGraw-Hill.

PHYS 414 - ELECTRONIC DEVICES AND CIRCUITS (4 CREDITS / 1 TUTORIAL)

Unit-I: Review of Semiconductor Physics 12 hours

Energy Bands in solids, Intrinsic and extrinsic Semiconductors, Transport phenomena in Semiconductors, Generation and recombination of charges, Diffusion, PN junction diode, Open-circuited p-n junction, p-n diode current, I-V characteristics using a diffusion model, Space-Charge Transition Capacitance, Diffusion Capacitance.

Unit-II: Semiconductor Diodes 12 hours

Zener diode: Operation, characteristics, equivalent circuits, and applications, Avalanche diode, Varactor diode and tuning circuits, Schottky diode, Tunnel diodes: Construction, operation, and V-I characteristics, characteristics of BJT, FET, and MOSFET, UJT: Operation, characteristics, UJT relaxation oscillator, BJT RC coupled amplifier and its frequency response.

Unit-III: Operational amplifiers 12 hours

Basics of differential amplifiers, operation and input modes of differential amplifiers, Characteristics of ideal and practical operational amplifier, Applications: inverting, non-inverting, voltage-follower, Summing, difference, integrating, differentiating amplifiers- Signal processing circuits: precision rectifiers, clipper, clamper, and peak detectors using operational amplifier.

Unit-IV: Signal generators and Active filters 12 hours

Signal generators and active filters - triangular and square wave generators, phase shift, and Wien bridge oscillator using operational amplifier - Active filters: First order low pass and high pass filters, Bandpass and band elimination filters using operational amplifier, Temperature compensated logarithmic and antilogarithmic amplifiers using operational amplifier.

Unit – V: Optoelectronics 12 hours

Radiative and nonradiative transition - Light-dependent resistor - Photodiodes, phototransistors, Photovoltaic solar cell materials - Construction and operation of the LED - Diode laser - Structure, working and factors affecting performance.

Textbooks

[1] Sze, Physics of Semiconductor Devices, Wiley.
[2] Boylsted and Nashelsky, Electronic Devices and Circuits, Pearson.
[3] Hawkes, Optoelectronics: An Introduction, PHI.
[4] Millman, Halkias and Pariksh, Integrated Electronics. McGraw Hill.

Suggested Readings

[1] Donald A. Neamen, Semiconductor Physics and Devices, McGraw Hill.
[2] Floyd, Electronic Devices, Pearson.
[3] V K Mehta and R Mehta, Principles of Electronics, S Chand.

PHYS 415 - SOLID STATE PHYSICS – I **(4 CREDITS / 1 TUTORIAL)**

UNIT – I: Crystal Structure and Symmetry **12 hours**

Classification of solids according to symmetry – Translational symmetry – Bravais lattice – Unit cell – Simple, BCC and FCC lattices – Coordination number – Wigner-Seitz primitive unit cell and conventional unit cell – Crystal structure as a lattice with basis – Diamond structure – Examples of HCP and other closed packed structures – Sodium chloride, Cesium chloride and Zinc-blende structures – Reciprocal lattice – Volume of the reciprocal lattice – First Brillouin zone – Lattice planes – Miller indices of lattice planes – Crystal directions – Classification of Bravais lattices – Point symmetries – Reflection, inversion and rotation – Crystallographic point groups and nomenclature.

UNIT – II: Crystal Binding **12 hours**

Classification of solids according to the distribution of valence electrons –Interatomic bonding – van der Waals bond – Covalent, molecular, and ionic crystals – Ionic radii – Mixed ionic and covalent solids – Examples – Metallic and hydrogen bonded solids – Cohesive energy – Lennard-Jones potential for molecular crystals Cohesion in ionic crystals – Madelung constant – Cohesion in covalent crystals and metals.

UNIT – III: Crystal Structure Analysis **12 hours**

Braggs formulation of x-ray diffraction by crystal – von Laue formulation of x-ray diffraction by crystal – Application of different radiation (X-ray, electron, and neutron) for crystal structure determination – Experimental methods – Laue method – Rotating crystal method – Powder or Debye-Scherrer method – Calculation of geometrical structure factor for simple lattices such as BCC and Diamond – Basics of atomic form factor.

UNIT – IV: Lattice Dynamics and Thermal Properties **12 hours**

Classical theory of harmonic crystal – Lattice potential energy – Harmonic approximation – Density of states of an elastic isotropic solid – Thermal energy of harmonic oscillator – Specific heat of classical crystal – Derivation of Dulong and Petit law – Normal modes of 1D monoatomic Bravais lattice – Normal modes of a 1D lattice with basis – Effects due to anharmonicity – Thermal expansion – Quantum theory of harmonic crystal – Normal modes versus Phonons – General form of lattice specific heat – High and low-temperature limits – Debye and Einstein models – Comparison of lattice and electronic specific heats.

UNIT – V: Electrical Properties of Metals **12 hours**

Drude theory of metals – Calculation of relaxation times and DC electrical resistivity using Drude model – Hall effect in metals – Derivation of Hall coefficient using Drude model – Ground state properties of electron gas – Free electron gas in infinite square well potential – Fermi gas at absolute zero of temperature – Derivation of energy of Fermi gas at absolute zero – Sommerfeld theory of metals – Derivation of density of states and Fermi temperature of electron gas using the Sommerfeld theory – Failures of the free electron model.

Textbooks

[1] Wahab, Solid State Physics, Narosa Publishing.
[2] Ashcroft and Mermin. Solid State Physics. Holt-Saunders (Indian Edition).
[3] Dekker, Solid State Physics. MacMillan India Ltd, New Delhi.
[4] Kittel, Introduction to Solid State Physics. John Wiley (Indian Edition).

Supplementary Reading

[1] Blakemore. Solid State Physics. Cambridge University Press.
[2] Ibach and Luth. Solid State Physics. Springer (Indian Edition).

PHYS 421 – STATISTICAL PHYSICS – I (4 CREDITS / 1 TUTORIAL)

Unit - I: Statistical Methods 12 hours
Probability and statistics in real life - Random walk problem in one dimension – Calculation of probability for *n*-step movement in random walk (binomial distribution) – Derivation of mean value, dispersion, and higher moments for the random walk problem – Formal definitions for discrete and continuous random variables, probability distribution function (PDF) and probability density function (pdf) for (i) uniform, (ii) binomial, (iii) Poisson, and (iv) Gaussian distributions - Calculation of (a) expected values, (b) skewness, (c) kurtosis, (d) higher moments of statistical distributions – Central limit theorem – Law of large numbers – Random number generation – Properties of random numbers – Derivation of Stirling approximation for *N!* – Problems solving.

UNIT-II: Statistical Description of Physical Systems 12 hours
Specification of state of the system - Statistical ensemble – Finding microstates for spin ½ particles as example – Postulates of statistical mechanics – Interaction between macroscopic systems – Equilibrium conditions and constraints - Ergodic hypothesis – Distribution of energy between systems in equilibrium – Derivation of relation between the number of microstates and entropy - Phase space trajectory for a free particle and other physical systems - Phase space density - Liouville theorem – Calculation of ensemble averages – Calculation of thermodynamic quantities from statistical description – Problems solving.

UNIT-III: Microcanonical Ensemble 12 hours
Microcanonical ensemble (MCE)– Postulate of equal apriori probabilities – Number of microstates and relation to thermodynamic entropy – Boltzmann *H*-theorem and hypothesis – Gibbs paradox - Correct counting – Calculation of entropy of classical and quantum harmonic oscillator - Calculation of the number of microstates in the case of (a) an ideal gas, (b) crystalline solid: Dulong-Petit's law: Einstein's theory of specific heat and (c) Paramagnetism: Curie's law, Negative temperature, and Schottky anomaly in specific heat (d) Elasticity of a rubber – Problems solving.

Unit IV: Canonical Ensemble 12 hours
Canonical ensemble (CE) – Density of phase points in CE – Canonical partition function of an ideal monoatomic gas – Calculation of thermodynamic properties from partition function for (a) classical and quantum harmonic oscillators, (b) anharmonic oscillator, (c) thermal expansion of solids – Equipartition theorem and Virial theorem – Specific heat using CE - Application of canonical partition function to (a) Ideal gas (b) Crystalline solid (c) Black body radiation and Planck's theory (d) Theory of paramagnetism: Langevin and Brillouin functions (e) Diatomic molecular gas – Problems solving.

Unit V: Grand Canonical Ensemble 12 hours
Features of grand canonical ensemble (GCE)– Comparison of three types of ensembles – Density of phase points in GCE –Calculation of thermodynamic parameters using grand partition function for (a) ideal gas, (b) linear harmonic oscillator – Fugacity – Chemical potential of (i) classical ideal gas, (ii) ideal Fermi gas, (iii) ideal Bose gas, (iv) photon gas – Fluctuations in number density and fluctuation of energy – Saha's ionization potential - Application to (a) adsorption-desorption process, and (b) chemical reactions.

Textbooks
[1] Reif, Fundamentals of Statistical and Thermal Physics, McGraw Hill.
[2] Upendranath Nandi, Statistical Mechanics, Techno World.
[3] Pathria, Statistical Mechanics, Butterworth-Heinemann.

Supplementary Readings
[1] Reichl, A Modern Course in Statistical Physics, Wiley.
[2] Huang, Statistical Mechanics, Wiley.

PHYS 422 - CLASSICAL ELECTRODYNAMICS (4 CREDITS / 1 TUTORIAL)

UNIT – I: Special techniques in Electrostatics 15 hours

Laplace equation in cartesian, cylindrical, and spherical coordinates – The need for Dirac-delta function – Green functions – Derivation of divergence and curl of the electric field from Coulomb's law - Boundary conditions and uniqueness theorems — Conductors and second uniqueness theorem - Electrostatic potential problems in cartesian, cylindrical, and spherical coordinate systems – Method of images – Physical systems with and without azimuthal symmetry – Solutions using spherical harmonics - Dielectric polarization - Boundary value problems with linear dielectrics The field of a polarized object - Multipole expansion for scalar electric potential — Origin of coordinates in multipole expansions – Boundary conditions for the electric field across the interface between two dielectric media.

UNIT – II: Magnetostatics and Electrodynamics 15 hours

Lorentz force law and Biot-Savart law — Scalar and vector potentials — Derivation of divergence and curl of the magnetic field from Biot-Savart law - Multipole expansion of magnetic vector potential — Calculation of field inside matter - Amperes law in magnetized materials and Auxiliary field H — Boundary conditions for the magnetic field across the interface between two magnetic media - Faraday's law and Lenz's law — Calculation of energy density in magnetic fields — Electrodynamics before Maxwell — Maxwell's correction of Ampere's law — Continuity equation - Derivation of Maxwell's equations in vacuum and in matter.

UNIT – III: Electromagnetic waves 15 hours

Electromagnetic waves in vacuum — Wave equation for E and B fields — Reflection, refraction of electromagnetic waves — Snell's law and Fresnel's law — Poynting theorem and its derivation — Electromagnetic waves in matter — Propagation of electromagnetic waves in linear media — Reflection and transmission at normal and oblique incidence — Absorption and dispersion of electromagnetic waves — Electromagnetic waves in conductors — Reflection at a conducting surface — Interference, diffraction, and polarization.

UNIT – IV: Potentials and Radiation 15 hours

Potential formulation — Scalar and vector potentials - Gauge transformations — Coulomb and Lorentz gauge — Retarded potentials of continuous charge distribution — Derivation of Jefimenko's Equations - Retarded potentials of point charges - Lienard- Wiechert potential — Fields of a moving point charge — Electric dipole radiation — Energy radiated by an oscillating electric dipole — Radiation from moving charges — Radiation fields — Derivation of Larmor formula – Magnetism as a relativistic phenomenon – Electromagnetic field tensor - Relativistic formulation of Maxwell's equations – Covariant formulation of electrodynamics 0 Maxwell's equations in tensor notation.

Textbooks

[1] David J Griffiths, Introduction to electrodynamics, Prentice Hall.
[2] M N O Sadiku, Elements of Electromagnetics, Oxford University Press.

Supplementary Reading

[1] John David Jackson, Classical Electrodynamics, John Wiley.

PHYS 423: ATOMIC AND MOLECULAR PHYSICS (4 CREDITS / 1 TUTORIAL)

Unit I: 10 hours

Photoelectron spectroscopy: Introduction and processes related to photoelectron spectroscopy - X-ray photoelectron spectrometer - Ultraviolet photoelectron spectrometer – Chemical information from photoelectron spectroscopy – Solid state surface studies – Surface charging and calibration – Photoelectron intensities – Valence and core-energy level studies - Auger electron spectroscopy.

Unit II: 10 hours

Microwave Spectroscopy: Rotational spectra of rigid and non-rigid diatomic molecule - Isotope effect in Rotational Spectra- Intensity of Rotational Lines- Non-rigid Rotator Vibrational Excitation Effect- Linear Polyatomic molecules- Symmetric top molecules- Asymmetric top molecules – Stark effect- Quadrupole Hyperfine interaction – Microwave spectrometer – Information from Rotational spectra.

Unit III: 10 hours

Infrared Spectroscopy: Vibrational Energy of a diatomic molecule – The diatomic vibrating rotator – Break down of Born-Oppenheimer approximation – The vibrations of polyatomic molecules – Rotation-vibration spectra of polyatomic molecules – IR spectrophotometers - Applications – Electronic spectra of molecules - Frank-Condon principle and dissociation energy.

Unit IV: 10 hours

Raman spectroscopy: Raman effect – Understanding various scattering like (i) Rayleigh, (ii) Stokes, (iii) anti-Stokes, and (iv) Raman scattering – Polarizability to understand Raman effect – Maclaurin series expansion of polarizability – Polarizability ellipsoid Raman Spectroscopy: Theories of Raman scattering – Rotational Raman Spectra – Vibrational Raman Spectra – Mutual Exclusion principle – Raman Spectrometer – Polarisation of Raman Scattered light – Structural determination from Raman and IR spectroscopy - Near IR FT-Raman spectroscopy.

Unit V: 10 hours

Nuclear magnetic resonance spectroscopy: Basic principles – magnetic resonance – relaxation processes – Pulsed (Fourier Transform) NMR – Wide line NMR spectrometers – Molecular structure – Chemical shifts – Spin-spin coupling – Integration – Applications – Electron spin resonance spectroscopy: Basic principles – ESR spectrometer – ESR spectra – Hyperfine interaction – g-factor – line widths – applications.

Unit VI: 10 hours

NQR and Mossbauer Spectroscopy: Quadrupole Hamiltonian- Nuclear Quadrupole energy level for axial and non-axial symmetry – Experimental techniques and applications – Mossbauer Spectroscopy: Principles of Mossbauer spectroscopy – Chemical shifts – Quadrupole splitting and Zeeman splitting – applications of Mossbauer spectroscopy – applications.

Textbooks

[1] Straughan and Walker, Spectroscopy, 3-volume set, Science Paperbacks.
[2] J Michael Hollas, Modern Spectroscopy, Wiley.
[3] Banwell and McCash, Fundamentals of Molecular Spectroscopy, McGraw Hill.
[4] Aruldhas, Molecular Structure, and Spectroscopy, Prentice-Hall.
[5] Gupta, Kumar, Sharma, Elements of Spectroscopy: *Atomic, Molecular and Laser Physics*, Pragati Prakashan.

Supplementary Readings

[1] H. E. White, Introduction to Atomic Spectra. McGraw Hill.
[2] G Herzberg, Atomic Spectra and Atomic Structure, Dover.
[3] D. A. Long, Raman Spectroscopy.
[4] Tores and Schawlow, Microwave Spectroscopy. McGraw Hill.
[5] Schneider and Berstin, High-Resolution NMR. McGraw Hill.
[6] Assenheim, Introduction to ESR. Plenum Press.
[7] Das and Hahn, Nuclear Quadrupole Resonance Spectroscopy. Academic Press.
[8] Goldanskil, Mossbauer effect and its application to Chemistry. Von Nostrand.

PHYS 424 –MATHEMATICAL PHYSICS – II **(4 CREDITS / 1 TUTORIAL)**

Unit-I: Linear Algebra **(15 hours)**
Introduction to abstract algebra and notation – Definition of groups, real fields, and complex fields Definition of vector space – Vector spaces over an arbitrary field - Linear vector spaces and subspaces – Null space - Span and independence of vector space – Spanning set theorem - Linear dependence and independence – Dimensionality of vector space - Basis sets for finite dimensional and infinite dimensional vector spaces – Linear transformation (mapping) - Norm and Inner product – Unit circles and spheres in inner product spaces - Cauchy-Schwarz Inequality – Orthogonal and orthonormal sets and bases - Completeness – Eigenvalues and Eigenvectors - Matrix representation - Change of orthonormal basis.

Unit-II: Hilbert Spaces and Operators **(15 hours)**
Definition of metric space and normed spaces – Definition of linear functional – Inner product spaces - Hilbert space – Families of orthogonal polynomials as basis sets in function space (Gram-Schmidt orthogonalization) – Self-adjoint and Normal operators – Linear operators – Hermitian, unitary, orthogonal, and projection operators – Trace, inverse, and rank of a linear operator - Rotation matrices in two and three dimensions – Pauli matrices.

Unit-III: Vectors and Tensors in Index Notation **(15 hours)**
Representation of vectors and matrices in index notation – Einstien summation convention - Dot product, cross product, scalar triple product, and vector triple product using index notation – Vector identities and differential operators in curvilinear coordinates and compact notation using indices – Evaluation of determinant of a matrix using Levi-Civita symbol - Fundamentals of tensors – Cartesian Tensors – Algebra of cartesian tensors – Outer product – Contraction - Quotient theorem – Symmetric and Skew-symmetric tensors – Kronecker and Levi-Civita tensors – Examples and Applications in physics.

Unit-IV: Group Theory **(15 hours)**
Introduction to Groups, fields - Definitions and examples of physically important finite groups - Point groups - Multiplication table – Subgroups - Cyclic groups, center, classes, cosets, Lagrange Theorem - Representations of finite groups - Irreducible representation – Characters - Orthogonality theorem - Schur's character table - SU(2) – SU(3) – Simple applications.

Textbooks
[1] V Balakrishnan, Mathematical Physics: Applications and Problems. Springer.
[2] Byron and Fuller. Mathematics of Classical and Quantum Physics. Dover.
[3] B R Kusse and E A Westwig. Mathematical Physics. Wiley-VCH.
[4] Kreyszig. Introductory Functional Analysis with Applications. Wiley.

Supplementary Readings
[1] Riley, Hobson, and Bence. Mathematical Methods for Physics and Engineering, Wiley.
[2] S Fujita and S V Godoy. Mathematical Physics. Wiley.
[3] Arfken et al., Mathematical Methods for Physicists. Elsevier.
[4] S Hassani. Mathematical Physics. Springer International Publishing.

PHYS 425 - SOLID STATE PHYSICS - II (4 CREDITS / 1 TUTORIAL)

UNIT – I: Band Theory of solids 12 hours

Electron levels in a periodic potential – Bloch's theorem – von Karman boundary condition – Fermi surface and density of states – Kronig-Penny model – Electrons in a weak periodic potential – Energy bands in one dimension – Formation of energy gap – General formulation for determination of band structure – Tight binding method – Experimental methods to study band structure.

UNIT – II: Semiconductors 12 hours

Band structure of a typical semiconductor – Direct and indirect band-gap semiconductors – Derivation of number of carriers in thermal equilibrium for the intrinsic semiconductor – Doping in semiconductors – Population of impurity levels in thermal equilibrium – Derivation of carrier densities in doped semiconductors – Conductivity in semiconductors – Temperature dependence – Hall effect in semiconductors – Derivation of Hall coefficient.

UNIT – III: Dielectric Properties 12 hours

Maxwell's equations for dielectrics – Local field theory for insulators – Derivation of Clausius-Mossotti relation – Theory of polarizability – Derivation of expression for atomic polarizability and displacement polarizability – Frequency dependence of dielectric polarizability – Application of ionic crystals to optical properties –Pyroelectricity and Ferroelectricity.

UNIT – IV: Magnetic Properties 12 hours

Interaction of solids with magnetic fields – Magnetization and Susceptibility – Calculation of atomic susceptibilities – Larmor diamagnetism – Derivation of diamagnetic susceptibility of insulators– Derivation of paramagnetic susceptibility of free ions – Curie law– Brillouin function – Susceptibility of metals – Derivation of Pauli paramagnetic susceptibility – Landau diamagnetism –Magnetic ordering and magnetic structure – Classification of solids into ferro, ferri and anti-ferro magnets – Curie and Neil temperatures – Domain theory for ferromagnetism – Basics of spin waves and magnons.

UNIT – V: Superconductors 12 hours

History of the discovery of superconductivity – Critical temperature – Persistent currents – Difference between perfect (ideal) conductor and superconductor – Perfect diamagnetism – Meissner effect – Destruction of superconductivity by magnetic fields – Critical field – Derivation of London equation – Isotope effect – Elementary BCS theory – Coherence length – Specific heat capacity and energy gap of superconductors Type-I and Type-II superconductors – Basics of high-temperature superconductors – Supercurrent tunneling – Qualitative treatment of DC and AC Josephson effect.

Textbooks

[1] Wahab, Solid State Physics, Narosa.
[2] Ashcroft and Mermin. Solid State Physics. Holt-Saunders (Indian Edition).
[3] Dekker, Solid State Physics. MacMillan. (Indian Edition).
[4] Kittel, Introduction to Solid State Physics. John Wiley (Indian Edition).

Supplementary Reading

[1] Blakemore. Solid State Physics. Cambridge University Press.
[2] Ibach and Luth. Solid State Physics. Springer (Indian Edition).

PHYS 426 – NONLINEAR OPTICS **(4 CREDITS / 1 TUTORIAL)**

Unit I **12 hours**

Maxwell Equations - Wave Equations in various media and its propagation (Brief Survey) - Origin of Complex Refractive Index - Classical theory of Optical Absorption (Electron Oscillator Model) and Dispersion (Lorentz Oscillator Model) - Classical theory of anharmonic oscillators.

Unit II **12 hours**

Wave equations description of nonlinear optical susceptibilities – Symmetries in Nonlinear Optical Systems - Frequency and intensity dependence of polarization and dielectric susceptibility - First-order and higher-order susceptibilities.

Unit III **12 hours**

Second-order optical nonlinearities - Second harmonic generation – Sum and difference frequency generation - Parametric processes – Simple theory and calculation of nonlinear polarization – Various phase matching techniques in SHG.

Unit IV **12 hours**

Third order optical nonlinearities - Third harmonic generation - Four-wave mixing, Kerr Nonlinearity - Intensity dependent effect - Self-Phase modulation - Cross phase modulation - Stimulated Raman Scattering (SRS) - Stimulated Brillouin scattering - Parametric gain – Parametric amplification and oscillation.

Unit V **12 hours**

Electro-Optic Effect- based on changes in Index ellipsoid -Pockel and Kerr Effect, Applications as Modulators and Phase Retarders. Optical Phase Conjugation Theory and Applications, Photorefractive effect and applications, Solitons Theory and applications – Optical bistability.

Textbooks

[1] Robert W Boyd, Nonlinear Optics.
[2] Y Guo, C K Kao, E.H.Li, K. S.Chiang, Nonlinear Photonics.
[3] Y R Shen, Principles of Nonlinear Optics.
[4] N. Bloembergen, Nonlinear Optics.

Supplementary Readings

[1] Amnon Yariv, Quantum Electronics.
[2] Saleh and Teich, Fundamentals of Photonics, Wiley.
[3] Duarte, Tunable Laser applications, CRC press.
[4] Robert R. Alfano, The Supercontinuum Laser Source, Springer.
[5] P. Hariharan, Optical Holography, Cambridge University Press.
[6] Joseph Rosen, Holography: Research and Technologies, InTech.
[7] U. Schnars and W. Jueptner, Digital Holography, Springer.
[8] Ghatak and Thyagarajan, An Introduction to fiber optics, Cambridge University Press.
[9] John Crisp and Barry Elliot, Introduction to fiber optics, Elsevier.
[10] G P Agrawal, Nonlinear Fiber optics, Elsevier.
[11] G Keiser, Optical fiber communications, Fourth edition, Tata McGraw Hill.
[12] G P Agrawal, Fiber optics communication, Wiley.
[13] H S Nalwa and S Miyata, Nonlinear Optics of Organic Molecules and Polymers.
[14] RA Fischer, Optical Phase Conjugation.
[15] R Sutherland, Handbook of Nonlinear Optics.
[16] N B Singh, Growth and Characterization of Nonlinear Optical Materials.

Detailed Syllabus of

THEORY PAPERS – 2^{nd} YEAR

(Theory Papers for Physics Department Students)

PHYS 513 – STATISTICAL PHYSICS – II **(4 Credits / 1 Tutorial)**

Unit - I **15 hours**

Quantum statistics of ideal gases: Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac statistics distributions – Identical particles and symmetry requirements for each of these distributions – Calculation of mean for these distributions – Quantum distribution functions – Photon statistics and derivation of Plank distribution – Derivation of Fermi-Dirac distribution – Derivation of Bose-Einstein statistics – Derivation of Maxwell-Boltzmann distribution – Calculation of dispersion for these distributions – Problems solving.

UNIT-II **15 hours**

Quantum state vectors - Density operator - Spin statistics connection - Density operator properties – Calculating ensemble averages using density matrix formalism –Application of density matrix to (i) electrons in a magnetic field, (ii) free particle, (iii) quantum harmonic oscillator - Strongly degenerate Bose gas: Bose-Einstein condensation – Helium as an ideal BE degenerate gas – Thermodynamic functions of a completely and strongly degenerate Fermi gas – Application to electrons in metals.

UNIT-III **15 hours**

Explanation of the following based on statistical mechanics: (i) thermal radiation, (ii) radiation pressure, (iii) Planck's spectral distribution, (iv) Stefan-Boltzmann law, (iv) Wien's displacement law, (vi) Rayleigh-Jean's law (vii) Ultraviolet catastrophe, (viii) Einstein's model of specific heat of solids (ix) Debye's model of specific heat of solids, (x) Pauli paramagnetism (xi) Landau diamagnetism –Problems solving.

Unit IV **15 hours**

Phase transitions, Order of transition, Order parameter, Critical phenomena, and critical exponents, Scaling theory and Universality class, Correlation function and fluctuation-dissipation theorem, Landau theory of phase transition, Ising model, Brag Williams theory, Random walk and diffusion equation, Brownian motion,

Textbooks

[1] Reif, Fundamentals of Statistical and Thermal Physics, McGraw Hill.
[2] Upendranath Nandi, Statistical Mechanics, Techno World.
[3] Pathria, Statistical Mechanics, Butterworth-Heinemann.

Supplementary Readings

[1] Reichl, A Modern Course in Statistical Physics, Wiley.
[2] Huang, Statistical Mechanics, Wiley.
[3] Kittel and Kroemer, Thermal Physics, W.H Freeman.
[4] Kittel, Elementary Statistical Physics, Wiley.

PHYS 514 - QUANTUM MECHANICS - II **(4 Credits / 1 Tutorial)**

Unit – I **(12 hours)**

Time independent perturbation theory – Non-degenerate and degenerate perturbation theories – Fine structure of hydrogen – Hyperfine structure – Linear stark effect – Zeeman effect in hydrogen – Variational method – Ground state of helium atom – WKB approximation – Tunneling through potential barriers.

Unit – II **12 hours**

Time-dependent perturbation theory – Transition probability – Constant perturbation – Harmonic perturbation – Fermi- Golden rule – Radiative transition in atoms – Dipole transition – Selection rules – Sudden and adiabatic approximation.

Unit – III: Identical particles **12 hours**

Schrodinger equation for many-particle systems – Interchange symmetry - Distinguishable noninteracting particles - Systems of identical particles – Exchange degeneracy – Symmetrization postulate – Symmetric and antisymmetric functions with reference to Fermi and Bose particles – Wave function of two, three, and many-particle systems – Pauli's exclusion principle – Composite-particle systems – Ensemble of identical systems and spin-statistics connection – Slater determinant.

Unit – IV **12 hours**

Scattering theory – Scattering particles – Potential scattering – Partial wave analysis – Phase shifts – Scattering lengths–Integral equations in terms of Green function – Born approximation and its validity.

Unit – V **12 hours**

Relativistic wave equations – Klein-Gordon equation – Dirac equation – Dirac matrices – Free Dirac particles – Spin magnetic moment – Spin-Orbit interaction – Central potential – Hydrogen atom – Hole theory and positrons.

Textbooks

[1] R. Shankar, Principles of Quantum Mechanics, Springer.
[2] Ghatak and Lokanathan, Quantum Mechanics, Trinity Press.
[3] V Devanathan, Quantum Mechanics, Narosa Publishing House.
[4] Zettili, Quantum Mechanics: Concepts and applications. John Wiley.
[5] Griffiths, Introduction to Quantum Mechanics, Pearson Education.
[6] Bransden and Joachai, Quantum Mechanics, Pearson India.

Supplementary Readings

[1] Sakurai and Napolitano. Modern Quantum Mechanics, Addison-Wesley.
[2] Ashok Das, Lectures on Quantum Mechanics, World Scientific.
[3] Liboff, Introductory Quantum Mechanics, Pearson Education.
[4] Schiff, Quantum Mechanics, McGraw-Hill.
[5] Schwable, Quantum Mechanics, Springer.
[6] Gasiorowicz, Quantum Physics, Wiley.

PHYS 515 - NUCLEAR PHYSICS **(4 credits / 1 Tutorial)**

Unit – I: Nuclear Properties and Nuclear Forces **12 hours**

Introductory ideas about nuclear forces and range - Deuteron problem - n-p and p-p scattering at low energy - Electric quadrupole moment of Deuteron - Introductory idea about Bartlett, Majorana, Heisenberg exchange forces – Concept of isotopic spin – Yukawa meson theory.

Unit – II: Nuclear Models **12 hours**

Nuclear models – Gas model - Liquid drop model - Semi-empirical mass formula – Magic numbers – Review of solutions to 3D problems – Infinite cartesian well, Infinite spherical well – Harmonic oscillator - Shell model potential – Energy level diagram – Spin-orbit potential – Magnetic moment and electric quadrupole moments – Valence nucleons – Collective model.

Unit – III: Nuclear Decay **12 hours**

Nuclear decay - Stability of nuclei - Radioactive decay laws - Gamow's theory of alpha decay - Beta decay - Fermi's theory - Conservation of parity - Weak interactions – Pair production – Internal conversion - Gamma decay - Selection rules.

Unit – IV: Nuclear Reactions **12 hours**

Nuclear reactions – Conservation laws - Q value - Compound nuclei and direct reactions Nuclear fission reaction - Fissionability parameter (theory of fission) - Controlled fission reactor - Nuclear fusion - Thermonuclear reactions.

Unit – V: Elementary Particles **12 hours**

Classification of elementary particles - Symmetries and symmetry violations – Quantum numbers (like charge, spin, parity, isospin, strangeness, etc.) – Gell-Mann-Nishijima formula - Properties and decay models of baryons, mesons, hadrons - Tau-Theta puzzle - Introductory concepts in quark model and GUT idea.

Textbooks

[1] Kenneth S. Krane, Introductory Nuclear Physics, Wiley.
[2] Irving Kaplan, Nuclear Physics, Narosa.
[3] Ashik Das, Introductory Nuclear and Particle Physics, Wiley.
[4] Roy and Nigam, Nuclear Physics: Theory and Experiments, New Age.
[5] Dodd and Gripaios, Idea of Particle Physics, Cambridge University Press.

Supplementary Readings

[1] L Cohen, Concepts of Nuclear Physics, Tata McGraw Hill.
[2] Palash B. Pal, An Introductory Course of Particle Physics.
[3] S L Kakani and S Kakani, Nuclear and Particle Physics, Viva.
[4] I S Hughes, Elementary Particles, Cambridge University Press.
[5] H A Bethe and D Morrison, Elementary Nuclear Theory, Dover.

PHYS 516 - LASER THEORY **(4 Credits / 1 Tutorial)**

Unit – I: Foundations **12 hours**

Maxwell's Wave equations in vacuum and media; Interaction of Electromagnetic radiation with matter, Coherence; Quantum theory of Atomic Energy levels & selection rules for single electron & multi-electron atoms. Decay of excited states, Emission broadening & line width due to radiative decay, Different broadening mechanism of emission spectra – Problems solving.

Unit – II: Einstein's Coefficients **12 hours**

Quantum Mechanical Description of Radiating atoms, Thermal Equilibrium Radiation laws- Cavity radiation Rayleigh-Jeans Formula, Planck's Law of Radiation, Relationship between Cavity and Blackbody radiation Principle of Detailed balance absorption and stimulated emission- Einstein's A and B Coefficient – Problems solving.

Unit – III: Population Inversion **12 hours**

Condition for producing a laser – Population inversion, gain and gain saturation - Saturation intensity - The threshold requirement for a laser - Laser oscillation above a threshold – Requirements for obtaining population inversion in 2, 3, and 4-level systems – Steady-state and transient population process which destroy population inversion – Problems solving.

Unit-IV: Laser Pumping **12 hours**

Laser Pumping Requirements and Techniques -Pumping threshold requirements, pumping pathway, and Specific excitation parameters associated with optical & particle pumping. Laser cavity modes-longitudinal & transverse cavity modes. Properties of laser modes –Mode characteristics & effect of modes in gain profile, Stable laser resonators & propagation of Gaussian beams using ABCD matrices – Problems solving.

UNIT-V: Laser Cavities **12 hours**

Special laser cavities and cavity effects - Unstable resonator, Q-switching, Mode locking, Different Methods, Ring laser, Cavities for producing spectral narrowing of laser output, laser cavities requiring small diameter gain region astigmatically compensated cavities – Ultrashort pulse laser - Concept of measuring brief intervals of time Pico seconds and femtosecond techniques. Method of generating pulses – Optical pulse properties – Methods of measurement of picosecond and femtosecond pulses.

Textbooks

[1] William T. Silfvast, Laser Fundamentals.
[2] Peter W Milonni and Joseph H. Eberly, Lasers.

Supplementary Reading

[1] Amnon Yariv, Quantum Electronics.
[2] Saleh and Teich, Fundamentals of Photonics, Wiley.
[3] Duarte, Tunable Laser applications, CRC press.
[4] Robert R. Alfano, The Supercontinuum Laser Source, Springer.
[5] P. Hariharan, Optical Holography, Cambridge University Press.
[6] Joseph Rosen, Holography: Research and Technologies, InTech.
[7] U. Schnars and W. Jueptner, Digital Holography, Springer.
[8] Ghatak and Thyagarajan, An Introduction to fiber optics, Cambridge University Press.
[9] John Crisp and Barry Elliot, Introduction to fiber optics, Elsevier.
[10] G.P Agrawal, Nonlinear Fiber optics, Elsevier.
[11] G. Keiser, Optical fiber communications, Fourth edition, Tata McGraw Hill.
[12] G.P Agrawal, Fiber optics communication, Wiley.

PHYS: 521 – Magnetism and Magnetotransport Phenomena (4 Credits / 1 Tutorial)

Unit I: Theories of Magnetism 12 hours

Application of Heitler-London theory of H2 molecule for spin system, Coulomb integral, Exchange integral, Bethe-Slater curve, Heisenberg exchange interactions for magnetic materials, Spin wave theory for ferromagnets, Direct exchange interactions, Indirect exchange interactions, Double exchange interactions, Anisotropic exchange interactions, Super-exchange magnetic interactions for magnetic oxides, Localized and de-localized electrons, Band theory, Stoner criterion, Magnetic impurity in nonmagnetic metal, Impurity in ferromagnet, Ferromagnetic metal.

Unit II: Thermal Relaxation and Resonance 12 hours

Zeeman splitting of a paramagnetic spin, Larmor precession of spin, Larmor frequency, Derivation of the time-dependent longitudinal and transverse spin components under external dc fields, Paramagnetic relaxation, Spin-lattice relaxation, spin-spin relaxation, Paramagnetic resonance under in-plane ac magnetic fields, Line widths, Resonance conditions, the EPR spectra of paramagnetic molecules and other systems.

Unit III: Magneto-transport phenomena 12 hours

Basic electron transport phenomena, Boltzmann transport equation, Phenomenological theory of giant magnetoresistance (GMR) and example, Colossal magnetoresistance (CMR) and example, Anisotropic magnetoresistance (AMR) and example, Magneto-transport in semiconductors, Quantum Hall effect, 1D and 2D magnetic materials, Exchange bias effect, Exchange coupling, Spin valve.

Unit IV: Advanced Magnetic properties 12 hours

The crystal field effects, Crystalline anisotropy, The s-, p-, d- electron states in transition metals under crystal fields, Landau theory for magnetic phase transitions, The magnetocaloric effect, Magnetic entropy and heat capacity from thermodynamic relations, Magnetic refrigerant materials, The deHaas-van-Alphen effect, Cyclotron frequency, Magnetoelectric and Multiferroic effects, Nanoparticle magnetism, Single domain and Multi-domain particles, Superparamagnetism, Core-shell model for ferromagnet and antiferromagnet, Spin glass, Shape memory alloys.

.

Unit V: Magnetic Measurements 12 hours

Magnetometers, Faraday balance, AC susceptometer, Vibration sample magnetometer, Experimental methods for low-temperature cooling, Spin polarization, spin injection, and spin polarization at the interface of a ferromagnet-nonmagnetic metal and between two ferromagnetic with intermediate spacer, Spintronics devices and their application in magnetic storage.

Textbooks

[1] A H Morrish, The Physical Principles of Magnetism, Krieger Publishing.
[2] A J Dekker, Solid State Physics, MacMillan.
[3] B D. Cullity, Introduction to Magnetic Materials, Wiley.
[4] D Jiles, Introduction to Magnetism and Magnetic Materials. Chapman and Hall.

Suggested Readings

[1] K H J Buschow and F R DeBoer, Physics of Magnetism and Magnetic Materials.
[2] M J Thornton, M. Ziese (Eds), Spin electronics, Springer.
[3] J M D Coey, Magnetism, and Magnetic Materials, Cambridge University Press.
[4] R C O Handley, Modern Magnetic Materials, Wiley.
[5] Stephen Blundell, Magnetism in Condensed Matter Physics, Oxford University Press.
[6] Spaldin, Magnetic Materials, Cambridge University Press.

PHYS 522 - PLASMA PHYSICS AND CONTROLLED FUSION (4 Credits / 1 Tutorial)

UNIT – 1: Collision processes 12 hours

Breakdown mechanism of gases – Gaseous discharge – Characteristic of DC glow discharge – Positive column – Cathode sheath – Negative glow and Faraday dark space – Analysis of positive column – Analysis of cathode region.

UNIT –2: Plasma Parameters 12 hours

Definition of plasma – Electron and ion temperature – Plasma potential – Sheath formation and floating substrate – Debye shielding – The contact potential – Sheath formation and Bohm criterion – Cathode sheath – Plasma oscillations – Electron oscillations – Ion oscillations – Ambipolar diffusion.

UNIT – 3: Plasma Sources 12 hours

Limitations of DC glow discharges – RF discharges – Inductive discharges – Power transfer efficiency – Matching network – Electron-cyclotron resonance – Discharges: Helicon-discharges, surface wave discharges, DBD discharges – Characteristics and application of respective discharges – Hollow cathode discharge – Planer magnetron discharge – Plasma etching – DC sputtering – RF sputtering – Thin film formation – Plasma nitriding, PECVD for nanomaterial fabrication.

UNIT – 4: Controlled Fusion 12 hours

Fission, fusion and energy needs – Lawson criterion – Magnetic confinement fusion devices (magnetic mirrors trap, tokamak) – Particle trajectories in non-uniforms magnetic and electric fields – Drift approximation – Adiabatic invariants – Plasma as a fluid – plasma heating – Current drive – Low hybrid current drive (LHCD) – Ion cyclotron resonance heating (ICRH) – Ion cyclotron resonance heating (ECRH) – Neutral beam injection (NBI) – Laser and heavy ion beams fusion, Tokomaks in India and ITER and challenges.

UNIT – 5: Experimental Demonstration 12 hours

(1) Dependence of breakdown voltage on pressure and electrode gap (Paschen Curve).
(2) Measurement of Plasma parameters by electrostatic probe (Langmuir Prob).
(3) To measure the plasma parameters by double Langmuir probe.
(4) To launch an ion-acoustic wave and demonstrate the collective behavior of the plasma.
(5) Measurement of plasma parameters of pulsed DC discharges.
(6) Characterization of DC magnetron discharges and estimation of sputtering yield.
(7) Studying the conditions for atmospheric pressure plasmas (Dielectric barrier discharges).

Textbooks

[1] Chapman, Brian, Glow discharge processes, Wiley.
[2] Lieberman and Lichtenberg, Principles of Plasma Discharges and Material Processing, Wiley.
[3] Y P Raizer, Gas Discharge Physics, Springer.

Supplementary Readings

[1] P I John, Plasma Science and the Creation of Wealth, Tata McGrow-Hill.
[2] F F Chen, Plasma Physics and Controlled Fusion, Plenum Press.

Detailed Syllabus of

ELECTIVE PAPERS

(Elective Theory Papers for Physics Department Students)

PHYS 523 - NONLINEAR DYNAMICS **(4 Credits / 1 Tutorial)**

Unit I: **15 hours**

Nonlinear waves – Nonlinear partial differential equations – physical examples – AKNS method – Applications of solitons - Introduction to synergetics – examples from Physics, Chemistry, Biology, Computer Science, Economics, Ecology, and Sociology.

Unit II: **15 hours**

Survey of first and second-order differential equations – inhomogeneous nonlinear differential equations – Linear and nonlinear dynamical systems – Solutions – Examples from physics.

Unit III: **15 hours**

Stability of solutions from nonlinear dynamics systems – Phase portrait – Trajectories – Limit cycles – Driven pendulum – van-der-Pol and Duffing oscillators – Bifurcations – Hopf bifurcation – Period doubling route to chaos – Poincare Map – Logistic Map – Strange attractors – Lorentz attractor.

Unit IV: **15 hours**

Oscillating chemical system – Lotka-Volterra equations – Brusselator model – Beluosov-Zhabotinsky reaction – Chemical chaos – Self-organization – Biology applications: Predator-prey problem, and morphogenesis.

Textbooks

[1] H Haken, Synergetics, Springer.
[2] H Haken, Advanced. Synergetics, Springer.
[3] Prigogine, Order out of chaos, Fontana.
[4] P. A. Cook, Nonlinear dynamical systems, Prentice Hall.

Suggested Readings

[1] R. Serra, Introduction to the Physics of the Complex System, Pergamon.

PHYS 524 - QUANTUM FIELD THEORY **(4 Credits / 1 Tutorial)**

Unit – I **(12 hours)**

Lorentz and Poincaré transformations — Poincaré algebra — Representations on fields — Classical field theory — Lagrangian and Hamiltonian formulations — Noether theorem — Real and complex scalar fields — Spinor fields — Electromagnetic field.

Unit – II **(12 hours)**

Quantization of Klein-Gordon field — Quantization of Dirac field — Quantization of pure Electromagnetic field.

Unit – III **(12 hours)**

Interaction picture — Feynman propagator — Wick's theorem — Feynman diagrams — Cross sections and S-matrix — One loop diagrams — Introduction to regularization and renormalization.

Unit – IV **(12 hours)**

Quantum electrodynamics: QED Lagrangian — CPT symmetry — Feynman rules — One loop Divergences — Cross section for $e^+e^- \rightarrow \mu^+\mu^-$ process.

Unit – V **(12 hours)**

Non-abelian gauge transformations - Yang-Mills theory — Introduction to quantum chromodynamics — Spontaneous symmetry breaking — Global and Goldstone-Boson symmetry — Local symmetry and Higgs mechanism.

Textbooks

[1] Michele Maggiore, A Modern Introduction to Quantum Field Theory.
[2] M E Peskin and D V Schroeder, An Introduction to Quantum Field Theory.
[3] Amitabha Lahiri and Palash B. Pal, A First Book of Quantum Field Theory.
[4] F Mandl and G Shaw, Quantum Field Theory.
[5] Ashok Das, Lectures on Quantum Field Theory.

Supplementary Readings

[1] Lowell S. Brown, Quantum Field Theory.
[2] C Itzykson and J B Zuber, Quantum Field Theory.
[3] Lewis H Ryder, Quantum Field Theory.
[4] J D Bjorken and S D Drell, Relativistic Quantum Fields.
[5] W Greiner and J Reinhardt, Field Quantization.

PHYS 525 – PARTICLE PHYSICS **(4 Credits / 1 Tutorial)**

UNIT – I **12 hours**

Special theory of relativity and relativistic kinematics, four-vector formalism, covariant form of Dirac equation, Covariance of Dirac equation, properties of gamma matrices – Review of properties of elementary particles – Interaction strengths and ranges – Field-quantum properties.

UNIT – II **12 hours**

Summary of interactions and conserved quantities – Yukawa's proposal on meson exchange – Spin and parity determination of Pions – Properties of quarks and their classifications – Baryon, and meson multiplets – Basic ideas of SU(2), U(1), and SU(3) symmetry groups - Hadron classification.

UNIT – III **12 hours**

Symmetries and Conservation laws - Noether's theorem in classical mechanics, Continuous space-time symmetries and associated conservation laws of momentum, energy, angular momentum, Lorentz invariance - Symmetries in quantum mechanics - Discrete Symmetries, Parity, Charge conjugation and time reversal, CPT theorem, C, P, T properties of bilinear covariants, Examples of determination of intrinsic quantum numbers, mass and spin.

UNIT – IV **12 hours**

More elementary particles. Composite particles based on isospin and Strangeness. Application of isospin invariance to pion nucleon scattering, Strangeness, charm, and other additive quantum numbers, Resonance, and their quantum numbers with special reference to pion nucleon scattering. Gell-Mann-Nishijima formula.

UNIT – V **12 hours**

Violation of symmetries - Parity non-conservation in weak interactions, CP violations in neutral Kaons. Main ideas behind Standard Model, Electro-weak interactions, W & Z bosons - Experimental techniques: Cyclotron, synchrotron, linear accelerators, colliding beam experiments, intersecting storage rings and stochastic cooling. Detectors for photons, leptons, and hadrons.

Textbooks

[1] Perkins, Introduction to High Energy Physics, Cambridge University Press.
[2] Griffiths, Introduction to Particle Physics, Wiley.
[3] Ferbel and Ashok Das, Introduction to Particle and Nuclear Physics, World Scientific.

Suggested Readings

[1] Francis Halzen, Alan D. Martin, Quarks and Leptons, Wiley.
[2] Sakurai, Invariance Principles and Elementary Particles, Princeton University Press.

PHYS 526 - GRAVITATION AND COSMOLOGY **(4 Credits / 1 Tutorial)**

Unit – I **(12 hours)**

Flat spacetime - Lorentz transformations – Tensors in special relativity – Energy-momentum or stress-energy tensor for perfect fluids – Conservation of energy - Momentum of perfect fluids.

Unit – II **(12 hours)**

Curved spacetime - Curvilinear coordinates – Curved spaces – Metric tensor – Contravariant and covariant tensors – Christoffel symbols and covariant differentiation – Parallel transport and geodesics – Curvature tensor – Ricci tensor – Curvature scalar – Bianchi identities – Einstein tensor.

Unit – III **(12 hours)**

Gravitational field equations - Principle of equivalence – Newtonian motion as geodesic equation – Gravity as spacetime curvature – Field equation in Newtonian gravity – Sources of curvature and energy-momentum tensor – Einstein's field equations – Linearized field equations.

Unit – IV **(12 hours)**

Solutions and applications - Schwarzschild solution – Geodesic in the schwarzschild metric – Precession of perihelion of mercury – Bending of light – Gravitational red shift – Introduction to black holes and gravitational waves.

Unit – V **(12 hours)**

Cosmology fundamentals - History of the universe – Hubble's law – FLRW metric – Friedmann equations – Matter, radiation, and vacuum dominated universes – Equation of state – Cosmological red shift – Introduction to modern trends in cosmology.

Textbooks

R Hentschke and C Hölbling, A Short Course in General Relativity and Cosmology.
S Carroll, Spacetime and Geometry, Addison Wesley.
T. Padmanabhan, Gravitation: Foundations and Frontiers.
S Weinberg, Gravitation and Cosmology, Wiley.
J Foster and J D Nightingale, A Short Course in General Relativity.

Supplementary Readings

J B Hartle, Gravity: An Introduction to Einstein's General Relativity.
B F Schutz, A First Course in General Relativity.
W Rindler, Relativity – Special, General, and Cosmological.
J V Narlikar, An Introduction to Cosmology.

PHYS 527 – NUMERICAL METHODS **(4 Credits with Practicals)**

UNIT – I: Introductory Concepts **15 hours**

Overview of scientific programming languages like Matlab, Fortran, and Python - Representing numbers in a computer – Floating point arithmetic – Overflow and underflow – Absolute and relative errors - Machine precision (epsilon) – Loss of significance - Robustness of numerical method - Errors in mathematical approximations – Error propagation – Lagrange polynomial interpolation – Orthogonal polynomials – Splines and B-spline interpolation – Chebyshev polynomials – Hermite interpolation - Linear versus Polynomial least squares approximation - Matrices and linear system of equations – Elementary row operations – Tridiagonal and band matrices - Symmetric positive definite matrices – Norm and condition numbers of matrices.

UNIT – II: Linear Systems **15 hours**

Linear systems – Gauss elimination and pivoting - Gauss method to compute the Inverse – LU decomposition – Cholesky decomposition – QR factorization – The Gram-Schmidt algorithm – Givens rotations method – Relaxation methods – Jacobi and Gauss-Seidel iterative methods – Steepest descent method – Conjugate gradient method - Eigenvalues and eigenvectors of a real symmetric matrix by Jacobi's method – Determination of largest eigenvalue by Power method – Convergence of the above numerical methods.

UNIT – III: Differential Equations **15 hours**

Taylor series and finite differences – Forward and backward difference tables for first and higher-order derivatives – Center-difference and three-point difference formulae - Euler's method for the solution of the ordinary differential equation – Convergence, stability, and error propagation in Euler's method – Runge-Kutta methods with Runge's coefficients – Solving Laplace equation and Poisson equation using the finite difference method – Numerical solution of the one-dimensional heat equation.

UNIT – IV: Programming Lab **30 hours lab (Ten 3-hour Lab session)**

The laboratory exercise involves writing programs in any scientific language such as Fortran / Matlab / Python to solve problems of numerical techniques for the topics learned in this course.

Textbooks

[1] K Atkinson, and W Han. Elementary Numerical Analysis. Wiley, 2003.
[2] E Süli, and D F Mayers. An Introduction to Numerical Analysis. CUP, 2003.
[3] A C Faul. A Concise Introduction to Numerical Analysis. Chapman, 2016.
[4] Iyengar and Jain. Numerical Methods. New Age International, 2009.

Supplementary Readings

[1] I H Hutchinson, A Student's Guide to Numerical Methods. CUP, 2016.
[2] T Sauer, Numerical Analysis, Pearson, 2011.
[3] T Heister, L G Rebholz, and F Xue, Numerical Analysis: An Introduction, De Gruyter, 2019.
[4] R L Burden, J D Faires, Numerical Analysis, Brooks Cole, 2010.

PHYS 531 – Materials Synthesis and Characterization **(4 Credits / 1 Tutorial)**

Unit I: Synthesis **15 hours**

Preparation methods – Direct heating of solids (ceramic method) – Solid state reaction – Reducing particle size using spray drying and ball milling – Co-precipitation methods – Precursors – Wet chemical methods: Sol-Gel method – Examples like the synthesis of BaTiO3 – Vapor deposition methods like CVD, PVD - Intercalation compounds like graphene intercalation - Thin film techniques – Evaporation rate and vapor pressure - Thermal evaporation methods – Deposition thickness monitors – Methods of thickness measurement - RF and magnetron sputtering - Pulsed laser deposition – Application of thin films – Vacuum requirements.

Unit II: Characterization – I **15 hours**

Structure characterization – X-ray tubes for X-ray diffraction experiments – Background noise in x-ray data - Systematic absences due to symmetry elements – Practical methods to find lattice parameter from XRD data – Phase purity using XRD data – Finding crystallite size from sharpness of x-ray data – Soving crystal structures using Rietveld method – Difference between single crystal XRD, polycrystal XRD and glancing XRD methods – Distinction between X-ray neutron diffraction – Advantages of using neutron diffraction for analysis of magnetic materials - Structural modeling of amorphous materials - Dense random packing – Continuous random packing.

Unit III: Characterization – II **15 hours**

Thermal analysis like thermogravimetry – Differential thermal analysis – Differential scanning calorimetry – Characterization of materials using infra-red spectrum and Raman spectrum – Optical microscopy for morphology studies – Practical methods like SEM – Distinction between optical microscope and electron microscope – Resolving power of SEM versus TEM – Gaining additional information using EDAX – Quantum tunneling – Scanning tunneling microscopy – Atomic force microscopy: Contact mode and non-contact modes of operation – Magnetic force microscopy – Application of AFM, MFM to study magnetic nanoparticles – Characterization of magnetic nanoparticles using dynamic light scattering.

Unit IV: Crystal Growth and Alloys **15 hours**

Crystal growth - Thermodynamics of point defects, Schottky and Frenkel defects, color centers, polarons and excitons, Dislocations, Strength of crystals, crystal growth, Melt methods – Czochralski process – Bridgman and float-zone processes - stacking faults, and Grain boundaries – Distinction between alloys and solid solutions – Hume–Rothery rules - Order-disorder transformation - Transition metal alloys - Kondo effect - Microscopic aspects of diffusion – Measurement of diffusion coefficients - Measurement of conductivity – Determination of transference numbers – Inter relation among diffusion coefficient, mobility, and ionic conductivity.

Textbooks

[1] L L Hench and J. K. West, Principles of Electronic Ceramics, Wiley.
[2] T Kudo and K Fueki, Solid State Ionics, Wiley.
[3] A R West, Solid State Chemistry, Wiley.
[4] S Chandra, Superionic Solids, North-Holland.

Suggested Readings

[1] H P Myers. Introductory Solid State Physics, Viva Publishers.
[2] B V R Chowdari *et al*., Solid State Ionics. World Scientific.
[3] T Minami, *et al*., Solid State Ionics for Batteries, Springer.

PHYS 532 – MATERIALS MODELLING AND SIMULATIONS (4 Credits / with Lab)

UNIT – I: 12 hours

Thomas-Fermi-Dirac approximations, Kohn-Sham theorems, Solution of the Self-Consistent Coupled Kohn-Sham equations, Self-consistency, Exchange-correlation energy, Meaning of Eigen Values, Local Density approximation and beyond, semi-empirical corrections, Pseudopotentials-Scattering amplitudes, Orthogonal Plane waves, Norm-Conserving, Ultrasoft and PAW potentials, Localized orbitals, Augmented Functions, LAPW, and LMTO methods.

UNIT – II: 12 hours

Electronic total energies and forces on atoms, minimizations, Cohesive and Binding energies, bonding and charge densities, Electronic band structure for 1D-, 2D- and 3D- structures, Electronic temperature, Smearing methods to metals, Dispersion Curves, symmetries, and energy bands, Effective masses and real-space orbitals, Fermi Surfaces, Density of States, Phase transitions: Pressure-volume curves, Birch-Muruaghan equations and more, Bulk modulus, Mechanical properties, Limitations of Density Functional Theory and Tight-binding Model, Molecular dynamics.

UNIT – III: 12 hours

Interacting Green's functions, Linear response theory, RPA dielectric functions, Interband optical transitions in semiconductors & insulators, Electron-hole interactions & exciton effects, Density Functional Perturbation Theory, Phonons, Lattice dynamics, electron-phonon matrix elements for metals, Superconductivity within BCS theory, Magnetism in metals, semiconductors, and insulators. Topological insulators in two & three dimensions. Polarizations, Localization, and Berry Phases Surfaces.

UNIT–IV: Hands-on-Training 24 hours (8 Lab sessions)

Hands-on exercises using the software Quantum espresso/VASP/SIESTA to execute the topics learned in this course.

Textbooks

[1] Richard M. Martin, Electronic Structure: Basic Theory and Practical Methods.
[2] Marvin L. Cohen and Steven and G. Louie, Fundamentals of Condensed Matter Physics.

Supplementary reading

[1] Harrison. Electronic Structure and the properties of solids.

PHYS 533 - MEASUREMENT SYSTEMS **(4 Credits / 1 Tutorial)**

UNIT – I: **15 hours**

Significance of measurement – Role of instruments in industrial processes – Block representation of measurement systems – Need for calibration and standards – Instrument parameters: sensitivity, accuracy, resolution, span, range – Classification of instruments – Generalized system configuration – Functions and characteristics of instruments and measurement systems – Measurement errors – Analysis, sources of errors and techniques for error-minimizing – Classification of instrument transducers – Input and output characteristics – Static and dynamic response – Linearity and hysteresis.

UNIT – II: **15 hours**

Fundamentals of transducers - Examples of (i) resistive, (ii) inductive, (iii) capacitive, (iv) thermoelectric, (v) photo-electric, (vi) piezo-electric, (vii) ionization and (viii) Hall-effect based transducers – Displacement measurement – Force and torque measurement – Pressure and sound measurement – Relationship between absolute, atmospheric and gauge pressures – Fluid flow measurement – Temperature measurement – Measurement of light – Measurement of magnetic field.

UNIT – III: **15 hours**

The need for signal conditioning – Requirements and characteristics of signal conditioners – DC and AC bridge circuits – Operational amplifiers in instrumentation – Unity gain buffer – Instrumentation amplifier – Log and antilog amplifiers – Constant current source – Voltage and current conversion – Passive and active filters.

UNIT – IV: **15 hours**

Measurement of fundamental constants: *e, h, c* – Measurement of high and low resistances, inductance, and capacitance – Detection of x-rays, Gamma rays, charged particles, neutrons – Solid State detectors – Vacuum Pumps: Rotary and diffusion pump – Measurement of vacuum: Pirani and Penning gauges – Hot Cathode gauge – Low-temperature systems – Methods of cooling a sample down to 4K – Low-temperature measurement systems and low-temperature sensors – High-temperature measurements – Different types of thermocouples like J, K, T, R and its use with PID controllers.

Textbooks

[1] Doebelin, Measurement Systems, Tata McGraw Hill.
[2] Holman, Experimental Methods for Engineers. McGraw Hill.
[3] Helfrick and Cooper, Modern Electronic Instrumentation and Measurement Techniques, PHI.

Supplementary reading

[1] Lafferty, Foundations of Vacuum Science and Technology, Wiley.
[2] Kent, Experimental Low-Temperature Physics, Macmillan.
[3] Montgomery, Design, and Analysis of Experiments, Wiley.
[4] Beckwith, Marangoni, Lienhard, Mechanical Measurements, Prentice Hall.
[5] Blackburn, Modern Instrumentation for Scientists and Engineers, Springer.
[6] Neubert, Instrument Transducers, Oxford University Press.

PHYS 541 - LASER SPECTROSCOPY **(4 Credits / 1 Tutorial)**

UNIT-I: Laser as Spectroscopic Light Sources **12 hours**

Fundamental of Lasers - Laser resonators - Spectral characteristics of laser emission - Experimental realization of single mode lasers- Controlled wavelength tuning of single mode lasers - Linewidths of single-mode lasers.

UNIT-II: Nonlinear Optical Mixing Techniques & Spectroscopy **12 hours**

Physical background - Phase matching - Second harmonic generation - Quasi phase matching - Sum frequency and higher-harmonic generation - Difference frequency spectrometer.

UNIT-III: Absorption and Fluorescence Spectroscopy with Lasers **12 hours**

Advantages of lasers in spectroscopy – Direct determination of absorbed photons – Ionization spectroscopy – Opto-galvanic spectroscopy- Laser-induced fluorescence - Comparison between the different methods.

UNIT-IV: Nonlinear Spectroscopy **12 hours**

Linear and nonlinear Absorption - Saturation of inhomogeneous line profiles – Saturation spectroscopy - Polarization spectroscopy - Multiphoton spectroscopy - Special techniques of nonlinear spectroscopy.

UNIT-V: Time-Resolved Spectroscopy **12 hours**

Lifetime measurements with ultrafast laser pulses – Pump and probe techniques.

Textbook

[1] Demtroder, Laser Spectroscopy: Basic Concepts and Instrumentation, Springer.

PHYS 542 – QUANTUM ENTANGLEMENT **(4 Credits / 1 Tutorial)**

Unit I **15 hours**

Postulates of quantum mechanics – Dirac formalism - EPR paradox - Hidden variable and Bell's theorem – Quantum calculation of the correlation in Bell's theorem – Bell's theorem without inequalities (GHZ equality).

Unit II **15 hours**

Entanglement as a physical resource – Quantum circuits – Quantum search algorithm – Quantum computers – Physical realization – Condition for quantum computation – Different implementation schemes for quantum computation.

Unit III **15 hours**

Quantum information theory: Distinguishing quantum states, data compression, classical and quantum information, noisy quantum channels – Quantum cryptography – Bennett-Brossard protocol.

Unit IV **15 hours**

Quantum non-demolition measurement – Quantum key distribution and security of quantum key distribution.

Textbooks

[1] Nielsen and Chuang, Quantum Computation and Quantum Information, CUP.
[2] Mikio Nakahara and Ohmi, Quantum Computing, CRC Press.

PHYS 551 – ASTROPHYSICS - I **(4 Credits / 1 Tutorial)**

Unit – I: Celestial coordinates **12 hours**

Co-ordinate system, Time System-Solar and Sidereal times, Spherical trigonometry, Magnitude scale - Apparent and Absolute magnitudes, Trigonometric Parallax.

Unit – II: Astronomy in different bands **12 hours**

Resolving power of a telescope, atmospheric effects at different wavelengths, Optical astronomy, radio astronomy, X-ray astronomy, telescopes and their characteristics, Modern Optical telescopes, Neutrino Astronomy, and Gravitational wave astronomy.

Unit – III: Astronomical Instruments – Part A **12 hours**

Atmospheric extinction, Photometer, Spectrographs, Charge Coupled Detector, Space astronomy, sensitivity, noise, quantum efficiency, Johnson noise, signal to noise ratio.

Unit-IV: Astronomical Instruments – Part B **12 hours**

Astronomical imaging, spectroscopy, polarimetry, calibration, adaptive optics, interferometry, speckle interferometry, aperture synthesis, and analysis of spectral lines.

Unit-V: Radiative Transfer **12 hours**

Black-body radiation, formation of spectral lines, Radiation field, Radiative transfer equation, Optical depth, thermodynamic equilibrium, radiative transfer through the stellar interior, Bremsstrahlung, Compton scattering, Thomson scattering, cyclotron and synchrotron radiation, opacity.

Textbooks

[1] Zeilik and Gregory, Introductory Astronomy and Astrophysics, Saunders.
[2] Bowers and Deeming, Astrophysics vols-I and II, Jones and Bartlett.
[3] Roy and Clarke, Astronomy Principles and Practice, Institute of Physics.
[4] Kitchin, Astrophysical Techniques, Institute of Physics.
[5] Rybicki and Lightman, Radiative Processes in Astrophysics, Wiley.

Supplementary Readings

[1] Smart, Spherical Astronomy, Cambridge University Press.
[2] Saha, Diffraction-limited imaging with large and moderate telescopes, World Scientific.
[3] Saha, Aperture synthesis: Methods and Applications to Optical Astronomy, Springer.
[4] Frank Shu, The Physical Universe, University Science Books.

PHYS 552 - ASTROPHYSICS–II **(4 Credits / 1 Tutorial)**

Unit–I: Stellar properties **12 hours**
Observational properties of stars – spectral and luminosity classification of stars - H-R Diagram, Saha equation, Star formation - Jean's mass, Jeans Length, and Free fall timescale, Main Sequence Evolution, Mass- luminosity relation, White Dwarfs – Chandrasekhar's Limit, Neutron Stars, Pulsars, Supernovae, Stellar Black holes.

Unit–II: Solar atmosphere and active regions **12 hours**
Overview of Sun, Location of Sun, Sun's spectrum, Solar interior structure - Energy Generation, Radiative zone, Convection Zone, Observing the Sun, Solar Telescopes, Satellite Missions, Solar Polarimetry, Solar Radio Astronomy. Solar Atmosphere – Photosphere - active Regions, Sunspots – solar cycle, active and quiet Sun, Granulation, Faculae, Chromosphere -Diagnostics, Radiative Transfer, Heating, Supergranulation, Solar Flares-Properties, Classification, Occurrence, Prominences, Corona-Basic Facts, Observational Features, CME, Radio bursts, Solar Wind and Interplanetary Magnetic field.

Unit–III: Stellar structure **12 hours**
Hydrostatic Equilibrium, Mass conservation, Luminosity gradient equation, Temperature gradient Equations, Lane – Emden equation for polytrophic stars and its physical solution, estimates of central pressure and temperature, Radiation pressure, equation of temperature gradient for radiative and convective equilibrium, Schwarzschild criterion, gas pressure and radiation pressure, Linear Model and its properties, Volt – Russell theorem, Zero age main sequence, Mass – Luminosity relation.

Unit–IV: Interstellar Medium **12 hours**
Overview of the ISM, Types of interstellar media, Physical description of the ISM (various equilibria), Models of the ISM, Heating & cooling mechanisms, Thermal stability & equilibrium (2-phase models). Neutral atomic gas (HI regions): Interstellar UV & Visible absorption line observations, Radiative transfer in Lines & Line formation, line broadening mechanisms, Equivalent width, Interstellar HI Lyman absorption lines, Gas-phase abundance of metals, 21cm hydrogen line, 21cm line formation in absorption & emission. Strongmen sphere, Ionized gas (HII regions) & the physical processes.

Unit-V: Extra-Galactic Astronomy **12 hours**
Galactic structure: local and large-scale distribution of stars and interstellar matter, the spiral structure, and the galactic center. Galactic dynamics, stellar relaxation, dynamical friction, star clusters, density wave theory of galactic spiral structure, stellar populations, dark matter, redshift, neutrinos.

Textbooks

[1] Hanslmeier, The Sun and Space Weather, Springer.
[2] Schwarzschild: Structure and Evolution of Stars, Dover.
[3] Arnett, Supernovae and Nucleosynthesis, Princeton University Press.
[4] Erika Bohm Vitense, Introduction to Stellar Astrophysics, vol. 3, Cambridge University Press.
[5] Smart and Greene, Textbook on Spherical Astronomy, Cambridge University Press.

Supplementary Readings

[1] Kippenhahn and Weigert, Stellar Structure and Evolution, Springer.
[2] Clayton, Principles of Stellar Evolution, University of Chicago Press.
[3] Berry, Principles of Cosmology and Gravitation, Cambridge University Press.
[4] Peacock, Cosmological Physics, Cambridge University Press.
[5] Kitchin, Stars, Nebulae and the Interstellar Medium, Taylor and Francis.
[6] Herwitt, Astrophysical Concepts, Springer.

PHYS 553 - ASTROPHYSICS – III **(4 Credits / 1 Tutorial)**

Unit-I: Large Scale Structure of the Universe **12 hours**

Expansion of the Universe, Hubble's Law, Evolution of the Universe, Dark matter, formation of galaxies, morphological classification of galaxies, Evolution of galaxies, Cluster of galaxies, large-scale distribution of galaxies, chemical evolution in the galaxy, interactions of galaxies, theory of Gravitational lensing.

Unit-II: The Milky Way Galaxy **12 hours**

Counting of stars in the sky, Star clusters – Globular open association, historical models, Morphology of the galaxy, different populations, Mass distribution, estimate of the total mass of the galaxy, Kinematics of the Milky Way, Differential rotation of the Galaxy, Rotational curves, Oort's constants, Galactic center, Supermassive black hole, and jets.

Unit-III: Compact Objects **12 hours**

Radio galaxies, Active-galactic nuclei, Quasars – superluminal motion, Features of AGNs – luminosity and Taxonomy, formation of accretion disks, Unification scheme, neutron stars – density, degeneracy pressure, structure, pulsar, magnetic field of the pulsar, black holes, observational evidence of black holes.

Unit-IV: General Relativity and Cosmology **12 hours**

Foundations of general relativity, elements of tensor analysis, Schwarzschild and Kerr spacetimes, black hole physics, gravitational radiation, gravitational lensing, the redshift, distance measures, Pseudo- Newtonian cosmology, Dynamical evolution, cosmological solutions, age of the universe, matter content, dark matter, Cosmological constant, CMBR, observational tests. Theories of the universe, Big Bang, expansion of the universe, CMB radiation, Olber's paradox.

Unit - V: History of Universe **12 hours**

Very early Universe, Primordial nucleosynthesis, Baryogenesis, Cosmic neutrino background, Cosmic microwave background, anisotropies in CMBR, galaxies at high redshift, intergalactic medium, structure formation, matter-antimatter asymmetry in the Universe.

Textbooks

[1] Binney and Merrifield: Galactic Astronomy, Princeton University Press.
[2] Lyne and Smith: Pulsar Astronomy, Cambridge University Press.
[3] Binney and Tremaine: Galactic Dynamics, Princeton University Press.
[4] Bahcall, Neutrino Astrophysics, Cambridge University Press.
[5] Spitzer, Physical Processes in the Interstellar Medium, Wiley.

Suggested Readings

[1] Luminet: Black Holes, Cambridge University Press.
[2] Narlikar, Introduction to Cosmology, Cambridge University Press
[3] Shapiro and Teukolsky, Black Holes, White Dwarfs and Neutron Stars, Wiley.
[4] Padmanabhan. Theoretical Astrophysics: 3-volume set, Cambridge University Press.
[5] Narlikar, General relativity and Cosmology, Macmillan Press.

* * * THE END * * *