BANKURA UNIVERSITY

বাঁকুড়া বিশ্ববিদ্যালয়

SYLLABUS FOR M. Sc. IN PHYSICS
EFFECTIVE FROM 2023 – 2025 SESSION

Course Structure in Physics

Semester	Paper	Core Subjects	Marks	Credit
SEMESTER I	**PHYS101C**	Mathematical Methods I & Classical Mechanics	50	4
	PHYS102C	Quantum Mechanics I & Classical Electrodynamics I	50	4
	PHYS103C	Solid State Physics I & Electronics I	50	4
	PHYS104C	Atomic Spectroscopy & Nuclear Physics I	50	4
	PHYS105 PR	General Practical	50	4
	106CF	Communicative English and Personality Development	50	0
	PHYS107 IA	IA	50	4
		TOTAL (SEM-I)	**300**	**24**
SEMESTER II	**Paper**	**Core Subjects**	**Marks**	**Credit**
	PHYS201C	Mathematical Methods II & Advanced Optics	50	4
	PHYS202C	Quantum Mechanics II & Classical Electrodynamics II	50	4
	PHYS203C	Solid State Physics II & Electronics II	50	4
	PHYS204C	Statistical Mechanics I & Nuclear Physics II	50	4
	PHYS205PR	General Practical	50	4
	206E F	1. Yoga and Life Skill 2. Education Value Education and Human Rights	50	0
	PHYS207IA	IA	50	4
		TOTAL(SEM-II)	**300**	**24**
SEMESTER -	**Paper**	**Core Subjects**	**Marks**	**Credit**
	PHYS301C	Statistical Mechanics II & Molecular Spectroscopy-I	50	4
	PHYS302C	Computer Applications in Physics & Advanced Quantum Mechanics	50	4
		Major Elective Subjects		
	PHYS303ME	**A.** Advanced Electronics-I **B.** Laser Physics and Nonlinear Optics -I **C.** Nano Science and Nano-technology -I **D.** Advance Nuclear Physics-I **E.** Quantum Information Processing-I	50	4

III	PHYS304ME	**A.** Advanced Electronics-II **B.** Laser Physics and Nonlinear Optics -II **C.** Nano Science and Nano-technology -II **D.** Advance Nuclear Physics-II **E.** Quantum Information Processing–II	50	4

	Students have to choose either **PHYS303ME A** & **PHYS304ME A OR PHYS303ME B** & **PHYS304ME B OR PHYS303ME C** & **PHYS304ME C.**			
	Minor Elective Subjects			
	PHYS305EID	Biophysics	50	4
	PHYS306PR	Advanced General Practical	50	4
	TOTAL(SEM-III)		**300**	**24**
SEMESTER-IV	**Paper**	**Core Subjects**	**Marks**	**Credit**
	PHYS401C	Molecular Spectroscopy-II & Nonlinear Dynamics	50	4
	PHYS402C	Relativity & Astrophysics	50	4
	PHYS403PR	Computer Practical & Social Out Reach	50	4
	PHYS404PJ	Project	50	4
	Major Elective Subjects			
	PHYS405ME	**A.** Advanced Electronics-III **B.** Laser Physics and Nonlinear Optics -III **C.** Nano Science and Nano-technology -III **D.** Advance Nuclear Physics-III **E.** Quantum Information Processing –III	50	4
	The following are the options for students for major electives in Semester-IV as per their choice in Semester-III:			
	PHYS406PR	Advanced General Practical	50	4
	TOTAL(SEM-IV)		**300**	**24**

EACH LECTURE IS OF ONE HOUR DURATION

Department will decide major Elective papers to be offered to the students in each session through DC meeting.

IN THE CORE PAPERS 80% OF THE MARKS WILL BE DETERMINED BY THE END SEMESTER AND 20% OF THE MARKS WILL BE DETERMINED THROUGH MID-SEMESTER.

Programme Outcome

The postgraduate (PG) programme of Physics is constructed. The syllabus is based on the CBCS system which covers almost all the fields of Physics in basic as well as advance levels. The students will be enriched with plenty of knowledge after the completion of the course. The complete syllabus is compatible with the competitive examination (such as NET, GATE, JEST, etc) for higher studies and research. The program provides the candidate with knowledge, general competence, and analytical skills on an advanced level, needed in industry, consultancy, education, and research. The choice of major and minor elective courses offers a glimpse in the frontier areas of research and allows students to work on research projects. The program also provide adequate exposure to the students for pursuing higher education in the field of technology (M. Tech.), Physics (Ph.D.) and other job opportunities in academia and industry. The lab experiments allow students to understand the fundamental aspects of the subject. On completion of program,

- The students will apply the knowledge in different fields of physics; become professionally trained in the area of electronics, quantum information processing, nuclear physics, computer programming, etc.
- The students will understand the basic concepts of physics particularly concepts in classical mechanics, quantum mechanics, electrodynamics and electronics to appreciate how diverse phenomena observed in nature follow from a small set of fundamental laws.
- A research oriented learning that develops analytical and integrative problem-solving approaches.
- The students will learn to carry out experiments in basic as well as certain advanced areas of physics such as nuclear physics, electronics and lasers.
- The students can increase their skill from the course of project work, computer programming, graph plotting, etc.

SEMESTER – I **(TOTAL MARKS 300)** **(CREDIT 24)**

Paper: PHYS101C **[Marks 50]** **[Credit 4]**

Unit - I
Mathematical Methods – I

Complex variable: Functions. Brief review of the areas included in the honours syllabus: analytic functions, Cauchy-Riemann equations, integration in the Complex plane, Cauichy's theorem & integral formula. Liouville's & Moretra's theorem.

Taylor and Laurent series, Singular Points and their classification. Branch Point & branch Cut. Riemann sheets. Residue theorem & its application. Integrals involving branch point singularity.

Linear vector spaces, subspaces, Bases & dimension, Linear dependence and independence, Orthogonality of vectors, Gram-Schmidt Orthogonalisation procedure. Linear operators. Matrix representation. Matrix algebra. Special matrices. Rank of a matrix. Elementary transformations. Elementary and Equivalent matrices. Solution of linear equations. Linear transformations. Change of Basis. Matrix: Eigenvalues and eigenvectors. The Cayley-Hamilton theorem. Diagonalisation of matrices. Bilinear and Quadratic forms. Principal axis transformation. Functions of matrices. Powers, Roots, Exponential and Logarithm of a matrix.

Books Recommended:

1. M. R. Spiegel (Schaum's outline series) – Theory and Problems of Complex Variables.
2. George B. Arfken and Hans J. Weber (Academic Press) – Mathematical Methods for Physicists.
3. J. Mathews and R. I. Walker (Benjamin) – Mathematical Methods of Physics.
4. P. Dennery and A. Krzywicki (Harper and Row) – Mathematics for Physicists.
5. K.F. Riley, M.P. Hobson, S.J. Bence: Mathematical Methods for Physics and Engineering (Cambridge)

Learning outcome

• The knowledge gathered (viz. complex analysis, differential equations) during this course would have direct applications in other branches of physics, especially in quantum mechanics, electrodynamics, solid state physics.

• The students will be able to learn different mathematical tools to deal with the different problems of natural phenomena

Unit -II
Classical Mechanics

Review of Lagrangian and Hamiltonian formalisms in different systems. Legendre transformation. Hamilton's canonical equations and their applications. Lagrangian and Hamiltonian for relativistic particles. Principle of least action.

Canonical Transformation: Equations of point, generating functions, example. Lagrange and Poisson brackets and their applications. Invariance of Poisson bracket under canonical transformation; Equations of motion in Poisson Bracket; infinitesimal canonical transformation;

constants of motion and symmetry principles; generators of infinitesimal symmetry transformation; Noether's theorem; integral invariant of Poincare. Conservation theorems and angular momentum relation in Poisson brackets. Liouville's theorem.

Hamilton-Jacobi equation: Hamilton-Jacobi equation for Hamilton's principle and characteristics functions; Physical significance of these functions; Application of Hamilton-Jacobi equation in linear harmonic oscillator, particle falling under gravity etc.; action and angle variables and its importance & applications; Path from classical to quantum mechanics. Rigid body motion. Heavy symmetrical top with one point fixed on the axis. Fast and sleeping top.

Books Recommended:

1. Classical mechanics-Goldstein
2. Introduction to advances dynamics-McCuskey
3. Mechanics- Landau and Liftshitz.
4. Classical Mechanics- K.C. Gupta
5. Classical Mechanics- Rana and Jog

Learning outcome

• Apart from describing the system classically, the Lagrangian and Hamiltonian approaches will be useful in describing a microscopic system too.
• The concept of Hamilton- Jacobi theory will raise the idea of transition of a system from classical to quantum mechanics.
• The students will be able to describe a wide variety of physical phenomena (i.e. Small oscillation, rigid body motion, continuous media and non-linear motion etc) by the Lagrangian and the Hamiltonian formalism, non-linear dynamics to generalize the laws of physics in higher dimensions.

Paper: PHYS102C **[Marks 50]** **[Credit 4]**

Unit – I (Quantum Mechanics-I)

Operator Algebra: Vector space, concept of state vectors , principle of superposition of states, basis functions, change of basis, Bra and Ket vector and its characteristics, orthonormality, completeness condition and closure property, Hilbert space.
Operators, Hermitian, Inverse and Unitary operator and its characteristics, Functions of Operators, projection operator, theorems of commutations of two operators, Uncertainty principle. Angular momentum Operators.

Representation Theory: Closure property for continuously varying Kets, relation between wave function (Ψ) and state vector IΨ>, operator representation of position and momentum, relation between Ψ(x) and Ψ(p).

Fundamental postulates of Quantum mechanics: Eigenvalue equation, Eigenvalues of Hermitian operators, orthogonality of eigenkets for non-degenerate eigenvalues for Hermitian operators, expectation value. The State of a System, Time Evolution of the System's State, Conservation of probability, Connecting Quantum to Classical Mechanics.

Equations of motion: Time dependence of expectation values, Schrodinger, Heisenberg and Interaction pictures, equation of motion in Schrodinger picture, time translation operator, transition to Heisenberg picture, equation of motion in Heisenberg and interaction pictures, stationary states.

Stationary states problem: (a) One dimensional problem, (b) delta function potentials and barriers, (c) three dimensional problems- Free Particle, Box Potential, S.H.O., Hydrogen problem.

Harmonic oscillator with operator algebra: Creation and annihilation operators, Harmonic oscillator: Dirac's approach, Dipole selection rule, solution of wave functions. Coherent state: photon number distribution, orthogonality and completeness properties of coherent state, displacement operator.

Books Recommended:

1. 'Quantum Physics' by Robert Eisberg and Robert Resnick (John Wiley and sons).
2. 'Quantum Theory' by D. Bohm (Prentice-Hall).
3. 'Quantum Mechanics: Theory and Applications' by A. K. Ghatak and S. Lokanathan (Macmillan India Ltd.).
4. 'Quantum Mechanics' by L. I. Schiff (McGraw-Hill Book, New York).
5. 'Quantum Mechanics' by Cohen and Tanandji.
6. Prabir Ghosh, Quantum mechanics, Narosa Publication
7. N. Zettili: Quantum Mechanics (Wiley)
8. J.J. Sakurai: Modern Quantum Mechanics (Pearson)
9. Introduction to Quantum Mechanics by David J. Griffiths
10. J.J. Sakurai: Advanced Quantum Mechanics.
11. 2. T.L. Floyd: Electronic Devices (Prentice Hall)
12. F. Schwabl: Advanced Quantum Mechanics.

LEARNING OUTCOMES

Upon completing this course, students will:

- Understand key quantum mechanics concepts, including vector spaces, operators, and Eigenvalues.
- Apply operator algebra to solve quantum problems.
- Understand the representation theory and its relevance to wave functions.
- Comprehend fundamental postulates of quantum mechanics and their practical applications.
- Solve equations of motion in different pictures.
- Analyze complex problems, including the Harmonic Oscillator, coherent states, and more.

Unit – II (Classical Electrodynamics- I)

Delta and Green function, Inhomogeneous wave equation: it's solution.

Liénard–Wiechert potential, Fields of a uniformly moving charge, Fields of an accelerated charge: Fields, radiation (power) and angular distribution from a charge at low velocity (non-relativistic), radiation (power) from a charge at linear motion and circular motion or orbit, angular distribution of power for linearly accelerated charges, relativistic correction,

Bremsstrahlung-Cerenkov radiation. Radiation from a localised oscillating charges, near and far zone field, multipole expansion, dipole and quadrupole radiation, centre-fed linear antenna, classical theory of electron: radiation reaction from energy conversation: Lorentz theory, self-force.

Books Recommended:

1. Marion- Classical Electrodynamics
2. Jackson- Classical Electrodynamics
3. Panofsky & Phillips- Classical Electrodynamics
4. Chen- Plasma Physics
5. Griffith-Electrodynamics
6. Electricity and magnetism: e. M. Purcell, d. J. Morin

LEARNING OUTCOMES

At the end of the course

- Students will learn to solve inhomogeneous wave equation.
- The course enable students to solve moving charge particle problem.
- Students will learn the theory of radiation from a localized oscillating charges.
- The students will learn the classical theory of radiation.

Paper: PHYS103C **[Marks 50]** **[Credit 4]**

Unit – I (Solid State Physics- I)

Crystal structure and X-ray diffraction: Lattices and Unit cells, Symmetry, Reciprocal lattice, Brillouin Zone, Simple crystal structures: FCC, BCC, HCP, NaCl, ZnS and diamond, Waves in crystals, X-ray diffraction, Laue and Bragg condition, Ewald construction, derivation of amplitude of scattered wave, atomic form factor, crystal structure factor, geometrical structure factor, X-ray, electron and neutron diffraction.

Imperfection in solids: Different types of defects and dislocation, point defects and line defects, defect concentration, disorder.

Crystal binding: General considerations about bonding: ionic bonds, covalent bond, van der Walls-Fluctuating dipole forces-or molecular bonding, metallic bonding, hydrogen bonds.

Lattice vibrations: Lattice dynamics, harmonic approximation, vibration of monatomic and diatomic linear lattices, dispersion relations and normal modes, quantization of lattice vibration and phonons, anharmonic crystal interactions and thermal expansion (qualitative discussion only)

Magnetic properties of solids: Diamagnetism, paramagnetism – semi-classical treatment-paramagnetism for J=1/2, Brillouin function-van Vleck paramagnetism; ground state of an ion and Hund's rules, crystal field-quenching of orbital momentum, ferromagnetism-Weiss model, magnetic susceptibility, effect of a magnetic field, origin of the molecular field, anti-ferromagnetism-Weiss model, magnetic susceptibility, types of antiferromagnetic order, ferrimagnetism, ferromagnetic domains and domain walls, exchange interactions.

Books recommended:

1. F.C.Phillips: An introduction to crystallography (wiley)(3rd edition)
2. Charles A Wert and Robb M Thonson: Physics of Solids
3. J. P. Srivastava: Elements of solid state physics (Prentice Hall India; 2nd edition).
4. Christmaan-solid state physics (academic press)
5. A R Verma & O N Srivastava, Crystalolgraphic application to solid state physics
6. F.C.Phillips: An Introduction to Crystallography

LEARNING OUTCOMES

At the end of the course, students will

- Understand crystal structures, lattices, and unit cells.

- Explain symmetry and reciprocal lattices.
- Analyze X-ray diffraction and its conditions.
- Recognize imperfections in solids and types of defects.
- Comprehend various bonding types in crystals.
- Explore lattice vibrations and phonons.
- Explain magnetic properties of solids, including paramagnetism and ferromagnetism.

Unit - II (Electronics- I)

Semiconductor Devices:

p-n junction physics- Fabrication steps; thermal equilibrium condition; depletion capacitance; current-voltage characteristics; charge storage and transient behavior; junction breakdown; heterojunction.

Characteristics of semiconductor devices- BJT, JFET, MOSFETS, LED, LASER, Solar cell, Tunnel diode, Gunn diode and IMPATT.

Active Circuits:

Transistor amplifiers- Basic design consideration; low and high frequency effects; video and pulse amplifier; resonance amplifier; feedback in amplifiers.

Harmonic self-oscillators - Condition of oscillations, Steady state operation of self-oscillator; nonlinear equation of self- oscillator; examples.

Op-Amp Circuits:

Characteristics of ideal and practical op-amp; Derivation of CMRR, Applications of opamp: inverting, non-inverting, buffer, adder, subtractor, difference, differentiator, integrator Nonlinear amplifiers using op-amps- log amplifier, anti-log amplifier, regenerative comparators; Precession rectifiers, Active filters; precision rectifiers; ADC and DAC circuits; Op-amp based self-oscillators: sinusoidal and relaxation oscillators; Voltage regulator.

Books Recommended:

1. J D Ryder, Electronics Fundamental and application, PHI
2. Gaykwad, Operational Amplifier.
3. Zee, Physics of semiconductor devices.
4. Milman and Grable, Microelectronics. Tata MacGraw Hill.
5. Chattopadhyay and Jain, Analog integrated circuits
6. Chattopadhyay and rakshit, Electronic Circuit analysis

LEARNING OUTCOMES

At the end of the course

- Students will recognize the underlying physics of semiconductor devices.
- The course enable students to solve voltage current equations in transistor and operational amplifier circuits.
- The students will be able to design the transistor amplifiers, different response of them in different frequency zones
- The condition of oscillation and different oscillator design will be done by students
- The students will learn the opamp based circuits in details.

Paper: PHYS104C **[Marks 50]** **[Credit 4]**

Unit – I (Atomic Spectroscopy)

General discussion in Hydrogen spectra, Hydrogen-like systems, Spectra of monovalent atoms, quantum defect, penetrating and non-penetrating orbits, introduction to electron spin, spin-orbit interaction and fine structure, relativistic correction to spectra of hydrogen atom, Lamb shift, effect of magnetic field on the above spectra, Zeeman and Paschen-Back effect.

Spectra of divalent atoms: Singlet and triplet states of divalent atoms, L-S and j-j coupling, branching rule, magnetic field effects, Breit's scheme, complex spectra, equivalent electrons and Pauli Exclusion Principle.

Hyperfine structure in spectra of monovalent atoms, origin of X-rays spectra, screening constants, fine structure of X-ray levels, spin-relativity and screening doublet-laws, non-diagram lines, Auger effect.

Laser in Spectroscopy: Basic elements of a laser, Einstein A B Coefficients, Population inversion, Different energy level lase system, Broadening of spectral lines, absorption spectroscopy, excitation spectroscopy, ionization spectroscopy, saturation absorption spectroscopy, photo acoustic spectroscopy, opto-galvanic spectroscopy, Tera Hertz spectroscopy.

Recommended books:

1. Introduction of atomic spectroscopy: H E White
2. Laser Spectroscopy: A Corney
3. Laser in Chemistry: D L Andrew
4. Physics of Atoms and Molecules: Bransden and Joachain

LEARNING OUTCOMES

At the end of the course students will:

- Understand the hydrogen spectrum and how it applies to other monovalent atoms.
- Explore concepts like quantum defects, electron spin, and how magnetic fields affect atomic spectra.
- Learn about the spectra of divalent atoms and the rules governing them.
- Examine hyperfine structure in atomic spectra and its origin.
- Discover X-ray spectra and the principles of screening constants.
- Gain insight into the operation of lasers in spectroscopy, including population inversion and various spectroscopic techniques like absorption, excitation, ionization, and more.

Unit – II (Nuclear Physics- I)

Properties of nuclei: static and dynamic, parity and isospin of nuclei, Determination of nuclear size: mirror nuclei, muonic atoms and electron scattering methods, charge and mass distribution, charge form factor. Magnetic dipole moment and electric quadrupole moment; Experimental determination. [4 lectures]

Two-nucleon problem and nuclear forces: Deuteron problem; ground state and excited states, spin dependence of nuclear force, charge symmetry and charge independence of nuclear forces, electromagnetic moment and magnetic dipole moment of deuteron and the necessity of tensor forces. Form of nucleon-nucleon, nucleon-nucleus, nucleus-nucleus potential; Exchange nature of nuclear forces, elementary discussion on Yukawa's theory. [6 lectures]

Alpha, Beta and Gamma decay: Basics alpha decay process, alpha decay systematics, theory of alpha decay. Fermi's theory of beta decay, allowed and forbidden transitions, selection rules, non-conservation of parity in beta decay, Wu's experiment; direct evidence for the neutrino, gamma–decay and selection rules. [8 lecture hours]

Nuclear structure: Liquid drop model, Bethe-Weizsacker binding energy/mass formula, Fermi gas model, Shell model, Extreme single particle model, Spin orbit interactions and reproduction of magic numbers; Predictions of shell model: Ground state spin parity; Magnetic dipole moment and electric quadrupole moment; Single particle model; Introduction to Collective model. [10 lectures]

Books Recommended:

1. Nuclear Physics- S. N. Ghoshal (S. Chand Publications)
2. Nuclear Physics- D. C. Tayal (Himalaya Publications)
3. Introductory Nuclear Physics- K. S. Krane (Wiley India)
4. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)
5. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)
6. S.S.M. Wong: Introductory Nuclear Physics (PHI)

LEARNING OUTCOMES

At the end of the course students will:

- Learn comprehend nuclear properties, static and dynamic, including parity and isospin.
- Familiarize themselves with methods to determine nuclear size and charge/mass distribution.
- Understand magnetic and electric moments, and how they are experimentally determined.
- Understand the Deuteron problem, spin-dependent nuclear forces, charge symmetry, and charge independence.
- Explore nuclear force potentials, exchange forces, and elementary discussions on Yukawa's theory.
- Gain knowledge of various nuclear models, their predictions, and the role of spin-orbit interactions.
- Explain alpha, beta, and gamma decay processes, selection rules, and experimental evidence.

Paper: PHYS105PR **[Marks 50]** **[Credit 4]**

General Practical

List of experiments

Group A:

1. Determination of wavelength of light from He-Ne laser by Michelson interferometer
2. Determination of e/m by magnetron valve/magnetic focusing method
3. Determination of (i) Rydberg constant, (ii) ionization potential and (iii) quantum defect of an alkali atom.
4. Determination of Stefan's constant and hence computation of the Planck's constant
5. Determination of Hall voltage and carrier concentration of a given semiconductor
6. Determination of speed of ultrasonic waves in an aqueous medium
7. Study of optical characteristics of a LED and determination of band gap of the material of LED.

8. Study of dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibrations.
9. To draw the plateau curve of a GM counter and hence to determine the statistical variation of counts of the GM Counter.
10. Determination of wavelength of sodium light using Lloyd's mirror.

Group B:

1. Study the current mirror biasing and V_{BE} multiplier based voltage reference.
2. Study the transistor amplifier in common emitter (CE) mode.
3. To draw the LDR characteristics at different intensities and to find out the value & the dark resistance of the LDR.
4. To study the transfer characteristics of different networks and to study the phase transfer characteristics of a given two-port network (RC) by using CRO.
5. To design a three bit parallel adder.
6. Study on op-amp based linear and nonlinear amplifier.
7. To design RC-phase shifter oscillator.
8. Study the input and output voltage characteristics of Schmitt trigger circuit.
9. To Construct and test the operation Pre-emphasis & de-emphasis circuits by plotting frequency response using Op-amp.
10. To Study the amplitude modulation technique and determine the modulation index.

Learning outcome:

• This course aims at performing Nuclear, optics, electronics and solid state physics experiments by the students. Hands on experiments in the concerned equipment will give the students the ability of the theoretical understanding.

All the students will be divided into two groups i.e. Group A & Group B and that will be Decided by the Department

Paper: 106CF **[Marks 50]** **[Credit 0]**

Communicative English and Personality Development

Note: The foundation courses are to be conducted by the University. The course shall have internal assessment only. However, the candidates are required to obtain Satisfactory to become eligible for the final semester examination/ award of the PG Degree.

Paper: PHYS107IA **[Marks 50]** **[Credit 4]**

To be decided by the ***DC**

(END OF SEMESTER-I)

SEMESTER-II

SEMESTER – II **(TOTAL MARKS 300)** **(CREDIT 24)**

Paper: PHYS201C **[Marks 50]** **[Credit 4]**

Unit – I

Mathematical Methods- II

Special functions: Hermite, Bessel, Laguerre and Legendre functions.

Integral transforms. Fourier & Inverse Fourier transforms. Fourier transform of derivatives. Convolution theorem. Momentum representation. Laplace & Inverse Laplace transforms. Laplace transform of derivatives. Integration of transforms. Laplace convolution theorem. Solution of ordinary and partial differential equations by Fourier and Laplace transform methods.

Green's functions for ordinary and partial differential equations of mathematical physics. Integral equations. fredholm and volterra equations of the first and second kinds. Solution of integral equations using Integral transforms, Generating functions, Neumann series, separable (degenerate) kernels, Hilbert – Schmidt theory.

Tensor analysis, Coordinate transformations, scalars, Covariant and Contravariant tensors. Addition, Subtraction, Outer product, Inner product and Contraction. Symmetric and anti-symmetric tensors.

Books Recommended

1. George B. Arfken and Hans J. Weber (Academic Press) – Mathematical Methods for Physicists.
2. J. Mathews and R. I. Walker (Benjamin) – Mathematical Methods of Physics.
3. P. Dennery and A. Krzywicki (Harper and Row) – Mathematics for Physicists.
4. W. Joshi (Wiley Esstern) – Matrices and Tensors
5. K.F. Riley, M.P. Hobson, S.J. Bence: Mathematical Methods for Physics and Engineering (Cambridge)

Learning outcome:

• The knowledge gathered (viz. differential equations, integral trans form, linear algebra) during this course would have direct applications in other branches of physics, especially in quantum mechanics, electrodynamics, solid state physics.

• Introduction of Tensor analysis will be effectively helpful while studying general theory of relativity, advanced quantum mechanics as well as advanced electrodynamics.

Unit - II (Advanced Optics)

Historical background of laser, Einstein coefficients and stimulated light amplification: population inversion, creation of population inversion in three level & four level lasers.

Gas Laser: CO_2 laser, Solid State Laser: Host material, Nd:YAG laser, Liquid laser: Dye laser, Semiconductor laser.

Laser beam propagation, properties of Gaussian beam, resonator, stability, various types of resonators, resonator for high gain and high energy lasers, Gaussian beam focusing.

Origin of nonlinearity, susceptibility tensor, phase matching, second harmonic generation.

Importance of coherence, Principle of holography and characteristics, applications.

Principle of Q-switching, Pockel and Kerr Effect.

Detection of optical radiation: Human eye, thermal detector (bolometer, pyro-electric), photon detector (photoconductive detector, photovoltaic detector and photo-emissive detector), p-i-n photodiode, Avalanche Photo Diode.

Books recommended:

1. Principles of lasers: O Svelto
2. Solid State Laser Engineering: W Koechner
3. Laser: B A Labgyel
4. Gas laser: A J Boom
5. Methods of Experimental Physics Vol. 15B ed.: C L Tang
6. Industrial Application of Lasers: J F Ready
7. Handbook of Nonlinear Optics: R L Sutherland
8. Laser and electro optics: C C Davis

LEARNING OUTCOMES

At the end of the course students will:

- Learn laser history, Einstein coefficients, and population inversion.
- Identify various types of lasers, their materials, and laser beam properties.
- Learn concepts related to nonlinear optics, coherence, holography, and Q-switching.
- Learn about human and technical optical detection methods, including photodiodes and avalanche photodiodes.

Paper: PHYS202C **[Marks 50]** **[Credit 4]**

Unit - I (Quantum Mechanics- II)

Time independent perturbation theory (first and Second order corrections) and its application (anharmonic oscillator, Stark effect in hydrogen atom, Ground state energy of Helium atom). Variational method and its application for finding the ground state of Helium atom. WKB method and its application. Time-dependent perturbation theory and its applications (Harmonic perturbation, Fermi's golden rule), Adiabatic and Sudden approximation.

Infinitesimal rotation, Generator of rotation, Commutation rules, angular momentum and spin, Matrix representation of angular momentum operators and spin operator, Pauli spin matrices, Rotation of spin states, Coupling of two angular momentum operators, Clebsch-Gordan co-efficients.

Symmetries, Invariance principle and Conservation laws, Space and Time translation, Space rotation, Irreducible spherical tensor operators, Wigner-Eckert theorem and its applications, Space inversion, Time reversal.

Identical Particles, many-particle systems, Systems of Identical Particles, The Pauli exclusion principle, the periodic-table.

Scattering of a particle by a fixed center of force, scattering amplitude, differential and total cross sections. Scattering by a hard sphere and potential well. Integral equation for potential scattering. Green's function. Born approximation. Method of partial waves, phase shifts, optical theorem. Scattering of Identical Particles. Yukawa and Coulomb potential.

Books Recommended:

1. 'Quantum Physics' by Robert Eisberg and Robert Resnick (John Wiley and sons).
2. 'Quantum Theory' by D. Bohm (Prentice-Hall).
3. 'Quantum Mechanics: Theory and Applications' by A. K. Ghatak and S. Lokanathan (Macmillan India Ltd.).
4. 'Quantum Mechanics' by L. I. Schiff (McGraw-Hill Book, New York).
5. 'Quantum Mechanics' by Cohen and Tanandji.
6. Prabir Ghosh, Quantum mechanics, Narosa Publication
7. N. Zettili: Quantum Mechanics (Wiley)
8. J.J. Sakurai: Modern Quantum Mechanics (Pearson)
9. Introduction to Quantum Mechanics by David J. Griffiths
10. J.J. Sakurai: Advanced Quantum Mechanics.
11. 2. T.L. Floyd: Electronic Devices (Prentice Hall)
12. F. Schwabl: Advanced Quantum Mechanics.

LEARNING OUTCOMES

At the end of the course students will:

- Understand time-independent and time-dependent perturbation theory, including practical applications.
- Apply perturbation theory to solve problems in atomic and molecular physics.
- Utilize the variational method and the WKB method.
- Learn the principles of scattering theory and identify cross-sections and scattering amplitudes.
- Understand angular momentum, matrices, and spin states.
- Learn about symmetries and their connection to conservation laws.
- Discuss space and time translations, space rotations, spherical tensor operators, and space inversion.
- Analyze systems of identical particles, considering the Pauli Exclusion Principle.
- Explore particle scattering by fixed centers of force, integral equations, and the Born approximation.
- Students will acquire advanced knowledge in quantum mechanics, symmetries, and particle behavior in various contexts.

Unit – II (Classical Electrodynamics- II)

Dispersion and absorption: Lorentz electromagnetic theory. Kramers-Kronig relation.

Magneto-hydrodynamic (MHD) equations, magnetic, viscosity, pressure, Reynolds number, etc. MHD waves. Alfven waves and velocity, Hartmann flow and Hartmann number

Orbit theory of drift motions in a plasma. Pinch effect. Instability in pinched plasma column. Plasma oscillations, short wavelength of plasma oscillation and Debye screening length

Propagation of EM waves through plasma. Effect of external magnetic field on wave propagations:

ordinary and extraordinary rays.

Wave guides and resonant cavities: Basic concept of wave guides, TE & TM modes, Rectangular waveguide, circular waveguide, resonant cavities, rectangular cavity resonator-TE, TM modes. Power loss in a cavity-Q of a cavity.

Books Recommended:

1. Marion- Classical Electrodynamics
2. Jackson- Classical Electrodynamics
3. Panofsky & Phillips- Classical Electrodynamics
4. Chen- Plasma Physics
5. Griffith-Electrodynamics

LEARNING OUTCOMES

At the end of the course students will be able to:

- Understand dispersion and absorption, applying the Kramers-Kronig relation.
- Learn MHD equations and analyze MHD waves, including Alfven waves.
- Explore plasma drift motions and recognize instabilities in plasma columns.
- Understand plasma oscillations and their Debye screening length.
- Analyze the impact of external magnetic fields on wave propagation.
- Comprehend waveguides, their modes, and resonant cavities.
- These skills will empower students to comprehend and analyze phenomena in electromagnetism, plasma physics, and waveguides.

Paper: PHYS203C **[Marks 50]** **[Credit 4]**

Unit – I (Solid State Physics-II)

Free electron theory. Fermi energy, wave vector, velocity and temperature, density of states. Electronic specific heats. Pauli spin paramagnetism. Sommerfeld's model for metallic conduction. AC conductivity and optical properties, plasma oscillations. Hall effects.

Energy bands in solids. The Bloch theorem. Bloch functions. Review of the Kroning-penney model. Brillouin zones. Number of states in the band. Nearly free electron model. The tight binding model. The Fermi surface. Electron dynamics in an electric field. The effective mass. Concept of hole. (Elementary treatment)

Superconductivity. Critical temperature high-Tc superconductors. Meissner effect. Type I and type II superconductors. Thermodynamics of superconducting transition. London equation. London penetration depth. Energy gap. Basic ideas of BCS theory. Josephson junction and some applications;.

Dielectric and optical properties of solids: Dielectric constant and polarizability, sources of polarizability, dipolar polarization in solids, ionic polarizability, electronic polarizability, piezoelectricity, ferroelectricity.

Books recommended:

1. John Singleton: Band theory and Electronic properties of Solids (Oxford University Press; Oxford Master Series in Condensed Matter Physics).

2. Ibach & Luth: Solid State Physics
3. M. Ali Omar: Elementary solid state physics (Addison-wesley)
4. C. Kittel: Solid-state physics (Wiley eastern) (5th edition).
5. Superconductivity: M. Tinkham
6. F.C.Phillips: An Introduction to Crystallography

LEARNING OUTCOMES

At the end of the course, students will:

- Learn free electron theory, structure of solid and energy band theory.
- Apply knowledge of core concepts on the theory of super conductivity.
- Understand the dielectric and optical properties of solid.
- Demonstrate knowledge of frontier of the discipline, for example, in the experimental research work.

Unit - II (Electronics-II)

Passive Network: Four-terminal two-port network – parameters for symmetrical and unsymmetrical networks; image, iterative and characteristic impedances; propagation function; lattice network; Bisection theorem and its application.
L-C filters-LPF, HPF, BPF and BRF type constant-k prototype filters; m-derived filters (principle only, no detailed analysis is required), Attenuators,

High Frequency Transmission Line: Distributed parameters; primary and secondary line constants; Telegraphers' equation; Reflection co-efficient and VSWR; Input impedance of loss-less line; Distortion of em wave in a practical line.

Elements of Communication Electronics: Principles of analog modulation- linear and exponential types; comparison among different techniques; power, bandwidth and noise immunity consideration; Generation of transmitted carrier and suppressed carrier type AM signals; principles of FM and PM signal generation. Principles of detection of different types of modulated signals (TC and SC types). Modulation techniques in some practical communication systems: AM and FM radio, VSB AM and QAM technique in TV broadcasting.

Digital Circuits: Logic functions; Logic simplification using K-maps; SOP and POS design of logic circuits; MUX as universal building block. RCA, CLA and BCD adder circuits; ADD-SHIFT and array multiplier circuits. RS, JK and MS-JK flip-flops; registers and counters.

Books Recommended:

1. R P Jain, Modern digital electronics, Tata mac'Hill.
2. J.D.Ryder, Networks line and fields.
3. Frazier, Telecommunications
4. Roddy and Coolen, Electronic Communication systems. PHI.
5. S.M. Sze, Physics of semiconductor devices
6. Milman and Grable, Microelectronics. Tata MacGraw Hill.
7. B. C. Sarkar and S. Sarkar, Analog Electronics, DamodarPrakashani
8. B. C. Sarkar and S. Sarkar, Digital Electronics.
9. D. Roy Chowdhuri and Jain, Analog integrated circuits, New age Publishers
10. Chattopadhyay and Rakshit, Electronic Circuit analysis
11. Roddy and Coolen, Electronic Communication systems. PHI.

LEARNING OUTCOMES

At the end of the course

1. Students will recognize the underlying physics of semiconductor devices.
2. The course enable students to solve voltage current equations in transistor and operational amplifier circuits.
3. Students will be able to understand and solve problems from digital electronics.
4. The course will develop skill to apply their knowledge in engineering fields and industry

Paper: PHYS204C **[Marks 50]** **[Credit 4]**

Unit – I (Statistical Mechanics- I)

Scope and aim of statistical mechanics. Transition from thermodynamics to statistical mechanics. Review of the ideas of phase space, phase points, Ensemble, Density of phase points. Liouville's equation and theorem.

Stationary ensembles- physical significance, Classical equipartition theorem, Gibb's paradox, Microcanonical, canonical and grand canonical ensembles. Partition function formulation. Fluctuation in energy and particle. Virial theorem, Equilibrium properties of ideal systems: ideal gas, Harmonic oscillators, rigid rotators. Paramagnetism, concept of negative temperature.

Density matrix: Idea of quantum mechanical ensemble. Statistical and quantum mechanical approaches, Properties. Pure and Mixed states.

Density matrix for stationary ensembles. Application to a free particle in a box, an electron in a magnetic field. Density matrix for a beam of spin ½ particles. Construction of the density matrix for different states (pure and mixture) and calculation of the polarization vector.

Distribution functions. Bose-Einstein and Fermi-Dirac statistics. General equations of state for ideal quantum systems.

Books Recommended:

1. R. K. Pathria, Statistical Mechanics
2. K. Huang, Introduction to Statistical Mechanics
3. Silvio R. A. Salinas, Introduction to Statistical Mechanics.
4. F. Reif, Fundamentals of Statistical and Thermal Physics.
5. Kadanoff, Statistical Mechanics. World Scientific.
6. R. Kubo, Statistical Mechanics. (Collection of problems)

LEARNING OUTCOMES:

- Give an account of the relevant quantities used to describe macroscopic systems, thermodynamic potentials and ensembles.
- Give an account of the macroscopic and microscopic description of temperature, entropy and free energy and their descriptions in terms of probabilities.
- Give an account of the theory of statistical mechanics and the approximations making a statistical description possible.
- Explain statistical physics and thermodynamics as logical consequences of the postulates of statistical mechanics.
- Apply the theory to understand gases and crystals and, in addition, be able to construct microscopic models, and from these derive thermodynamic observables.

- Understand the strengths and limitations of the models used and be able to compare different microscopic model

Unit – II (Nuclear Physics- II)

Two-body scattering Experimental n-p scattering data, Partial wave analysis and phase shifts, scattering length, magnitude of scattering length and strength of scattering, Significance of the sign of scattering length; Scattering from molecular hydrogen and determination of singlet and triplet scattering lengths, effective range theory, low energy p-p scattering. [6 lecture hours]

Nuclear reaction: Different types of reactions, Quantum mechanical theory, Resonance scattering and reactions — Breit-Wigner dispersion relation; Compound nucleus formation and break-up, Statistical theory of nuclear reactions and evaporation probability, Optical model; Principle of detailed balance, Transfer reactions. [6 lectures]

Nuclear fission and fusion: Basics of fission and fusion, Experimental features, spontaneous fission, liquid drop model theory of fission, barrier penetration, statistical model, Basics of fusion reaction, characteristics of fusion, solar fusion. Elementary ideas about astrophysical reactions, Nucleosynthesis and abundance of elements. [4 lecture hours]

Reactor Physics: Basics components of a fission and fusion reactor. Slowing down of neutrons in a moderator, average log decrement of energy; slowing down power and moderating ratio, slowing down density; Fermi age equations, Four- factor formula; buckling and critical size of reactors. Radioactive fission products, concept of prompt and beta delayed neutrons. [6 lectures]

High energy physics : Types of interaction in nature-typical strengths and time-scales, conservation laws, charge-conjugation, Parity and Time reversal, CPT theorem, Gell-Mann-Nishijima formula, intrinsic parity of pions, resonances, Relativistic kinematics; Symmetry classification of elementary particles, quark hypothesis, charm, beauty and truth, gluons, quark-confinement, asymptotic freedom. [10 lectures]

Books Recommended:

1. Nuclear Physics- S. N. Ghoshal (S. Chand Publications)
2. Nuclear Physics- D. C. Tayal (Himalaya Publications)
3. Introductory Nuclear Physics- K. S .Krane (Wiley India)
4. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)
5. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)
6. S.S.M. Wong: Introductory Nuclear Physics (PHI)

LEARNING OUTCOMES

At the end of the course students will be able to:

- Interpret n-p scattering data and perform partial wave analysis, including phase shifts and scattering length.
- Analyze the significance of the sign of scattering length and apply it to molecular hydrogen scattering.
- Utilize effective range theory and study low-energy p-p scattering.
- Apply quantum mechanics to understand different types of nuclear reactions, resonance scattering, compound nucleus formation, and statistical theory.

- Understand the basics of nuclear fission and fusion, experimental features, barrier penetration, and their implications in astrophysics and element abundance.
- Understand reactor physics components, neutron slowing down, and critical reactor size.
- Analyze high-energy physics concepts, including elementary particle classification and properties, quark theory, and interaction strengths.

Paper: PHYS205PR **[Marks 50] [Credit 4]**
General Practical
LIST OF EXPERIMENTS:

Group A:

1. Determination of wavelength of light from He-Ne laser by Michaelson interferometer
2. Determination of e/m by magnetron valve/magnetic focusing method
3. Determination of (i) Rydberg constant, (ii) ionisation potential and (iii) quantum defect of an alkali atom.
4. Determination of Stefan's constant and hence computation of the Planck's constant
5. Determination of Hall voltage and carrier concentration of a given semiconductor
6. Determination of speed of ultrasonic waves in an aqueous medium
7. Study of optical characteristics of a LED and determination of band gap of the material of LED.
8. Study of dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibrations.
9. To draw the plateau curve of a GM counter and hence to determine the statistical variation of counts of the GM Counter.
10. Determination of wavelength of sodium light using Lloyd's mirror.

Group B

1. Study the current mirror biasing and VBE multiplier based voltage reference.
2. Study the transistor amplifier in common emitter (CE) mode.
3. To draw the LDR characteristics at different intensities and to find out the value & the dark resistance of the LDR.
4. To study the transfer characteristics of different networks and to study the phase transfer characteristics of a given two-port network (RC) by using CRO.
5. To design a three bit parallel adder
6. Study on op-amp based linear and nonlinear amplifier
7. To design RC-phase shifter oscillator
8. Study the input and output voltage characteristics of Schmitt trigger circuit
9. To Construct and test the operation Pre-emphasis & de-emphasis circuits by plotting frequency response using Op-amp.
10. To Study the amplitude modulation technique and determine the modulation index

All the students will be divided into two groups i.e. Group A & Group B. Those students who have done Group A experiments in Semester-I will have to opt Group B experiments in Semester-II and vice versa.

Learning Outcome:

- This course aims at performing Nuclear, optics, electronics and solid state physics experiments by the students. Hands on experiments in the concerned equipment will give the students the ability of the theoretical understanding.

Paper: 206EF **[Marks 50]** **[Credit 0]**

1. Yoga and Life Skill

2. Education Value Education and Human Rights

Note: The foundation courses are to be conducted by the University. The course shall have internal assessment only. However, the candidates are required to obtain Satisfactory to become eligible for the final semester examination/ award of the PG Degree.

Paper: PHYS207IA **[Marks 50]** **[Credit 4]**

To be decided by the Departmental Committee

(END OF SEMESTER-II)

SEMESTER – III

SEMESTER – III (TOTAL MARKS 300) (CREDIT 24)

Paper: PHYS301C **[Marks 50]** **[Credit 4]**

Unit – I (Statistical Mechanics- II)

Properties of ideal Bose gas: Bose-Einstein condensation: Transition in liquid He^4, Superfluidity in He^4. Photon gas: Planck's radiation law. Phonon gas: Debye's theory of specific heat of solids.

Properties of ideal Fermi gas: Review of the thermal and electrical properties of an ideal electron gas. Fermi energy, equation of state of an ideal Fermi gas, Sommerfeld Expansion, evaluation of chemical potential and specific heat of an ideal Fermi gas, Landau levels, Landau diamagnetism, Pauli Paramagnetism.

Exact solution of one-dimensional Ising system (Matrix methods). Bragg-William's approximation (Mean field theory) and the Bethe-Peierls approximation.

Phase transitions: Landau theory of phase transitions: First and Second order phase transitions, Spontaneous and Explicit Symmetry Breaking in Landau Theory. Onset of hysteresis in first order phase transitions. Critical phenomena and critical indices.

Thermodynamic fluctuations. Spatial correlations in a fluid. Brownian motion: Einstein-Smoluchowski's theory.

Books Recommended

1. Sanchez Bowley, Introductory Statistical Mechanics, Oxford University Press
2. R. K. Pathria, Statistical Mechanics
3. K. Huang, Introduction to Statistical Mechanics
4. Silvio R. A. Salinas, Introduction to Statistical Mechanics.
5. F. Reif, Fundamentals of Statistical and Thermal Physics.
6. Kadanoff, Statistical Mechanics. World Scientific.
7. R. Kubo, Statistical Mechanics. (Collection of problems)
8. L.E. Reichl, A Modern course in statistical physics, Wiley-VCH, 4th Ed.
9. S.K. Ma, Modern Theory of Critical Phenomena, Westview Press, 1st Ed

LEARNING OUTCOMES:

- Give an account of the relevant quantities used to describe macroscopic systems, thermodynamic potentials and ensembles.
- Give an account of the macroscopic and microscopic description of temperature, entropy and free energy and their descriptions in terms of probabilities.
- Give an account of the theory of statistical mechanics and the approximations making a statistical description possible.
- Explain statistical physics and thermodynamics as logical consequences of the postulates of statistical mechanics.
- Apply the theory to understand gases and crystals and, in addition, be able to construct microscopic models, and from these derive thermodynamic observables.
- Describe the importance and consequences of quantum mechanics for macroscopic particle systems, both for ideal gases and strongly interacting systems.
- Understand the role of cooperative physics in emergent phenomena such as quantum magnetism and

phase transitions.

- Understand and appreciate the role of symmetry in facilitating universality during phase transitions in many-particle systems, as well as give an account of critical phenomena and corresponding scaling laws.
- Understand the strengths and limitations of the models used and be able to compare different microscopic model

Unit –II (Molecular Spectroscopy – I)

Born-Oppenheimer approximation and separation of electronic and nuclear motions in molecules. Band structures of molecular spectra. Breakdown of the Born-Oppenheimer approximation.

Introduction of quantization of energy. Regions of the spectrum. The intensities of spectral lines.

Microwave spectroscopy: Energy levels of diatomic molecules under rigid rotator and non-rigid rotator models. Selection rules. Spectral structure. Structure determination. Isotope effect. Rotational spectra of polyatomic molecules. Microwave Oven.

Infrared spectra: Energy levels of diatomic molecules under simple harmonic and anharmonic (no deduction necessary for this one) models. Selection rules and spectral structures. Morse potential energy curves. Dissociation energies. Isotope effect. Rotational – vibrational coupling. Parallel and perpendicular modes. Symmetry properties of molecular wave functions and nuclear spins. Raman spectroscopy. Rotational, Vibrational, Rotational-Vibrational Raman spectra. Stokes and anti-stokes Raman lines. Selection Rules. Spectral structures. Nuclear spin and its effect on Raman spectra.

Vibrational spectra of poly atomic molecules. Normal modes. Selection rules for Raman and infrared spectra. Complementarity of Raman and infrared spectra. Normal modes of CO_2 molecule. Normal modes of other simple triatomic molecules.

Electronic spectra of diatomic molecules: Vibrational band structure. Progressions and sequences. Isotope shifts. Deslandres tables. Molecular constants in the ground and excited electronic states and crude idea of molecular bonding.

Rotational structure of electronic spectra. P-, Q- and R- branches. Band head formation and shading of bands.

Intensity distribution in the vibrational structure of electronic spectra and Franck-Condon principle. Hund's coupling. Experimental determination of dissociation energy.

Books Recommended:

1. G. Herzberg. 'Molecular Spectroscopy (Diatomic Molecules)' Van-Nostrand.
2. G. M. Barrow. 'Molecular Spectroscopy'. McGraw-Hill.
3. J.Michael Hollas. 'Modern spectroscopy'. John-Wiley & sons.
4. C. L. Banwell and E. M. McCash. 'Fundamentals of Molecular Spectroscopy' Tata- McGraw-Hill..
5. G.Aruldhas 'Molecular Spectroscopy'.
6. Bransden and Joachin. 'Atoms and Molecules'
7. F.A.Cotton. 'Chemical application to Group theory'.
8. M. Hammermesh. 'Group Theory'. Addison-Wesley

9. M. Tinkham. ‘Group Theory and Quantum Mechanics;. McGraw-Hill.
10. G. G. Hall. ‘Applied Group Theory’. Longmans, Green.
11. A. W. Joshi. ‘Group Theory’. Wiley Eastern Ltd..
12. N. Deo : Group Theory (Tata McGraw Hill)

Learning outcome:

- The student should be able to achieve advanced knowledge about the interactions of electromagnetic radiation and matter and their applications in spectroscopy.
- This course would also motivate students to pursue research careers especially in material sciences and associated fields.

Paper: PHYS302C **[Marks 50]** **[Credit 4]**

Unit-I (Computer Applications in Physics)

Computer fundamentals:

Functional units-CPU, Memory, I/O units; Information representation- integral and real number representation; Character representation: Alphanumeric codes; BCD, Gray, ASCII codes; Error detection and error correcting codes; Hamming codes; CRC codes.

CPU- programmers model; instruction set and addressing modes of a generic CPU; RISC and SISC; Storage System- primary and secondary memory; semiconductor, magnetic and optical memory; cache memory; virtual memory; memory management; IO Units – keyboard, mouse, VDU, printers; (principle of operation only). Computer Networks- motivation, classification, topology, technology (qualitative description); Internet- structure, TCP/IP protocol, internet services; Introduction to WWW.

Computer Software and Operating Systems: System software and application software; Translator programs; Loaders and linkers; Operating systems- classification; Elements of DOS, Windows, and Linux- basic commands.

Elements of C Programming Language: Algorithms and flowchart; Structure of a high level language program; Features of C language; constants and variables; expressions; Input and output statements; conditional statements and loop statements; arrays; functions; character strings; structures; pointer data type; list and trees.

Introduction to Python programming: The Python Interpreter, Python console, Jupyter and python IDEs; Setting up and using python on GNU/Linux, Windows and Android operating systems; Simple Input and Output; Variables; Mathematical Operators; list, string, tuple, set, dictionary; Control flow and decision control: logical loop structure; Functions and lambdas; Object and class; Files: reading and writing. Python namespaces, installation, design and import of modules in python.

Scientific Computing in Python: Introduction to the Numerical Python (numpy), Scientific Python (scipy), and matplotlib modules.Numpy arrays; Initialization and basic operations; resizing; slicing of arrays; array as a matrix; 2D plotting with matplotlib; plot with external data. Fast Fourier Transform (FFT) and the Danielson-Lanczos/Cooley-Tukey algorithms. Implementation of FFT using numpy/scipy. Sparse matrices in scipy, types of sparse matrices. Linear algebra operations withnumpy arrays using numpy-BLAS. Determination of eigenvalues and eigenfunctions of simple Fermionic and Bosonic systems.

Numerical Methods in Scientific Computing with Python: Representation of real and complex numbers, statistical calculations, factorial, infinite series, iterative methods: logistic map; binary search. Imprecisions in integer and floating point arithmetic. Interpolation of datasets using the Lagrange polynomial. Numerical root finding: Bisection method, False position method, Newton-Raphson method.Solution of system of simultaneous linear equations: Gauss elimination, Gauss-Seidel method, LUdecomposition algorithm. Numerical integration using Newton-Cotes quadratures: Trapezoidal and Simpson‟s 1/3rd methods.

Numerical solutions of Differential Equations: Ordinary Differential Equations: Simple Euler and Runge-Kutta methods. Application in physics problems: damped harmonic oscillator, forcing and resonance; self sustained oscillation (van der Pol oscillator, Lorenz and Roessler oscillator); Henon-Heiles potential problem; visualization in phase space and Poincare sections. Partial Differential Equations: Laplace and Wave equations. Schrodinger equation and solutions to the eigenvalue problem for simple systems.

(1. Instructor should demonstrate the installation of Python, Matplotlib, NumPy, and Scipy in Windows and Linux. 2. Emphasis will be given to solve physical problems and their visualizations. 3. Assignments should be given to the students at a regular interval.)

Introduction to software packages: Computational package: Scilab, Sage math, plotting software: Matplotlib, gnuplot. Document processing software: Latex, Lyx, Open office.

Books Recommended:

1. Sastry, Introductory Methods of Numerical Analysis. PHI
2. Kyayszig, Advance Engineering Mathematics. John Willey, 9th Ed.
3. Tanenbaum, Computer Network, Prentice Hall.
4. B. A. Ferourzan, Data Communication and Networking, McGraw Hill.
5. Tanenbaum, Operating system. Prentice Hall.
6. Gottfried, Programming with C. Schaum series.
7. Balaguruswamy, ANSI C. TMH.
8. Kanetkar, Let Us C, BPB Publications

LEARNING OUTCOMES

On completion of the course, the student should be able to:

- Translate a theoretical or algorithmic model into code that enables computation, logically subdivide a computational model into a set of manageable computational tasks, and organize their code accordingly, choose among computational algorithms and computational tools to produce a solution, debug, test, and validate computational models, and extract physical insight from a computation.
- Use the Python programming language to numerically solve physics problems, focussing on the use of Python‟s numeric modules SciPy (Scientific Python), Numpy (Numerical Python), and graphics module Matplotlib (MATLAB-like Plotting Library).
- Apply Monte Carlo simulations, curve-fitting and interpolation of datasets, numerically solve systems of nonlinear equations, ordinary differential equations, multiple integrals, perform computational linear algebra, solve optimization problems, perform signal analysis using Fast Fourier Transforms etc
- Formulate and computationally solve any tractable problem in physics

Unit – II (Advanced Quantum Mechanics)

The Klein Gordon (KG) equation. Covariant notations. Free particle energy, negative energy and negative probability density, KG equation in e-m field.
The Dirac equation. Properties of the Dirac matrices. The Dirac particle in an external electromagnetic field. The non-relativistic limit of the Dirac equation and the magnetic moment of the electron.

Covariant form of the Dirac equation. Lorentz covariance of the Dirac equation. Boost as hyper rotation, boost, rotation, parity and time reversal operation on the Dirac wave function.

Conjugate Dirac spinor and its Lorentz transformation. The γ^5 matrix and its properties. Bilinear covariants and their properties.

Boosting the wave function from the rest frame. Plane wave solutions of the Dirac equation and their properties. Energy and spin projection operators.

Dirac's hole theory and charge conjugation. Feynman-Stuckelberg interpretation of antiparticles.

Field Quantization: Introduction of Classical and quantum field theory, Lagrangian and Hamiltonian formalism of a particle in an electromagnetic field, Second quantization, Concepts and illustrations with Schrödinger field.

Relativistic Quantum Field Theory: Quantization of a real scalar field and its application to one meson exchange potential. Quantization of a complex scalar field, Dirac field and e.m. field, Commutation relations.

Books Recommended:

1. Relativistic Quantum Mechanics – J.D.Bjorken and S.D.Drell, McGraw-Hill, New York (1964).
2. Relativistic Quantum Mechanics- Walter Greiner, Springer-Verlag (1990)
3. Advanced Quantum Mechanics – J.J.Sakurai, Addison-Wesley Publishing Company, Inc. (1967).
4. Relativistic Quantum Mechanics and Quantum Fields – T-Y Wu and W-Y Pauchy Hwang, Allied Publishers Limited (2001).

LEARNING OUTCOMES

On completion of the course, the student should be able to:

- Understand Klein-Gordon and Dirac equations, including their application in electromagnetic fields.
- Analyze the non-relativistic limit and magnetic properties of particles.
- Explore Dirac spinors, γ5 matrix, and bilinear covariants..
- Learn about Dirac's hole theory, charge conjugation, and antiparticles.
- Gain insights into classical and quantum field theory, including Lagrangian and Hamiltonian formalism, field quantization, and commutation relations.

Major Electives

Paper: PHYS303ME **[Marks 50]** **[Credit 4]**

A. Advanced Electronics-I

Microwave Devices: Problems of microwave generation in conventional oscillators.
Vacuum tube devices: Klystron and Reflex Klystron, Magnetrons, Slow wave structure and Travelling wave tubes,
Solid state devices: Gunn diode, Impatt, Trapatt, transistors, GaAs-InP FET, HEMT.
Optical Devices: Laser and Laser resonator, LEDs, Photodiodes, Photo conductor.

Microwave measurements (Frequency, power, impedance).

Optical modulator: Electro optics modulation (amplitude and phase).

Optical coupler: Coupling of light from one fiber to other with the use of evanescent wave.

Analysis of networks and systems: Sample data system. Z-transform, Fourier and Laplace transforms.

Microwave Transmission lines and Waveguides: Standing wave ratio, Quarter wave transformer, Smith Chart, Stub matching. Wave guides coaxial, rectangular and cylindrical; Waveguide attenuation, Resonators.
Antenna theory: Antennas-dipole, Antenna arrays, reflectors, steering strip, microstrip and coplanar structure.
Feed back control systems: Feed back system, stability, performance criteria, servo systems, automatic control principle

Books Recommended

1. P. Bhattacharya - Semiconductor opto electronics devices.
2. R E Collin - Foundations of Microwave engineering.
3. S.Y.Liao – Microwave Devices on circuits.
4. J. Ryder – Networks, Lines and Field.
5. A. Papoulis – Signal Analysis
6. Electronic and Radio Engineering – F. E Terman.
7. Microwaves – K. C. Gupta.
8. Optoelectronics and Fibre Optic Communication –C. Sarkar.
9. Photonics – A. Yariv and P. Yeh.

LEARNING OUTCOMES:

In Electronic Communication Microwave is a very important signal used for various long distance and reliable communications. After going through this paper Students can know various types of developing of Microwave sources (like Klystron, Reflex Klystron, Magnetron, Gunn diode, Advanced Bipolar transistors etc.) as well as Microwave Detectors. They can also get knowledge on the advantages of Optical communications in modern days and hence they will get ideas of developing different Optical/Optoelectronic sources and high-speed detectors in optical regime. Again they can get the concepts of high s[peed Electro-optic switching operations. At the same time the Students will gather knowledge on working principle of Transmission lines and wave guides, Antenna etc.

Paper: PHYS304ME **[Marks 50]** **[Credit 4]**

A. Advanced Electronics -II

IC Technology: Hybrid and monolithic IC; Semiconductor processing diffusion, implantation, oxidation, epitaxy, lithography; Si IC technology-MOS and Bipolar; Packaging and testing.

Analog Integrated Circuits. Differential amplifier, OP-AMP based comparator; opamp based Schmitt trigger, opamp based continuous time filters, switched capacitance implementation of sample data filters; analog multiplexers, PLL and frequency synthesizer.

Digital Integrated Circuits: Logic families – TTL, ECL, MOS, MESFET; design of combinational and sequential circuits – MUX, decoder/ encoder, registers, counters, gate arrays; programmable logic devices – PAL, GAL, PLA, Programmable gate arrays.

Application specific ICs: ICs for analog communication; Digital signal processing ICs; Speech and image processing.

Memories: Sequential and Random access memories; RAM bipolar and MOS static and dynamic memories; programmable memories PROM, EPROM, EEPROM.

Microprocessor and their applications: Architecture of 8 bit (8085) and 16 bit (8086) microprocessors; addressing modes and assembly language programming of 8085 and 8086. 8086 machine cycles and their timing diagrams; Interfacing concepts memory and I/O interfacing; Interrupts and interrupt controllers; microprocessor based system design; comparison of different microprocessors.

Books Recommended:

1. Geiger, Allen and Strader – *VLSI – Design Techniques for Analog and Digital Circuits*.
2. Gray and Meyer – *Analysis and Design of Analog Integrated Circuits*.
3. A P Mathur – *Microprocessors.*
4. R S Gaonkar – *Microprocessor Architecture, Programming and Applications with 8085/ 8085A* (2nd Ed.).
5. D V Hall – *Microprocessor and Interfacing*.
6. Lin and Gibson – *Microprocessor*.
7. S Soelof – *Applications of Analog Integrated Circuits*.

LEARNING OUTCOMES

1. Students will learn the internal circuit and design of digital integrated circuit.
2. It will enable students to develop skills digital circuits for electronics and communications applications.
3. The holistic approach of the course will contribute towards the skill development of the students such that they can apply the acquired knowledge in research and development sector.

Paper: PHYS303ME **[Marks 50]** **[Credit 4]**

B. Laser Physics and Nonlinear Optics -I

Basic Laser Principle: Summary of black body radiation, Quantum theory for evaluation of the transition rates and Einstein coefficients-allowed and forbidden levels-metastable state; population inversion; rate equations for three level and four level lasers, threshold of power calculation, various broadening mechanism, homogeneous and inhomogeneous broadening

Basic Laser System: Basic concept of construction of laser system, various pumping system, pumping cavities for solid state laser system, characteristics of host materials and doped ions.

Optical beam propagation: Paraxial ray analysis, wave analysis of beams and resonators, propagation and properties of Gaussian beam, Gaussian beam in lens like medium, ABCD law-Gaussian beam focusing.

Resonators: Stability of resonators-'g' parameter, various types of resonators, evaluation of beam waist of such combination, design aspect of resonator for various types of lasers, unstable resonator and their application. Rabi oscillation and frequency

Q-switching: Giant pulse theory, different Q-switching techniques: mechanical Q-switching, electrooptic Q-switching Pockel and Kerr effect), acoustooptic Q-switching, dye Q-switching, Raman-Nath effect.

Ultrafast Phenomenon: Principle of generation of ultrafast pulses, basic concepts for measurement of fast processes, Streak techbique, Stroboscopy, sampling technique, nonlinear optical methods for measuring ultrashort pulses

Different laser systems:

Gas Laser: (i) molecular gas lasers- CO_2 laser & N_2 laser; (ii) ionic gas laser – Ar^+ laser
(iii) gas dynamic laser; (iv) high pressure pulsed gas laser

Solid State Laser: (i) Nd:YAG laser, (ii) Nd:Glass laser, comparison of performances
(iii) Tunable solid state laser: Ti:sapphire laser; Alexandrite laser

Chemical Laser: HF laser, HCl laser

Excimer laser; Fibre laser**,** Free electron laser; semiconductor laser

Laser speckle and Laser safety:

Spatial frequency filtering- principle and its application. Various hazards due to laser radiation-eye, skin, chemical etc., safety measures and standard

Books Recommended:

1. Solid State Laser Engineering- W Koechner
2. Quantum Electronics- A Yariv
3. The Physics and Technology of Laser Resonator- D R Hall & P E Jackson
4. Introduction to optical electronics- K A Jones
5. Laser- B A Langyel
6. Gas laser- A J Boom
7. Principles of lasers- O Svelto

LEARNING OUTCOMES

On completion of the course, the student should be able to:

- Learn the fundamental principles of lasers, including population inversion and rate equations.

- Understand laser construction and pumping mechanisms.
- Comprehend optical beam propagation and Gaussian beams.
- Learn about different laser resonators and their design.
- Study Q-switching techniques and ultrafast pulse generation.
- Explore various types of lasers, including gas, solid-state, chemical, and semiconductor lasers.
- Understand laser safety and hazards, along with safety measures and standards.

Paper: PHYS304ME **[Marks 50]** **[Credit 4]**

B. Laser Physics and Nonlinear Optics -II

Nonlinear Optics:
Introduction, nonlinear polarization, generation of second harmonic, D.C., sum- and difference-frequency generation, anharmonic oscillator model, Miller's rule, crystal symmetry, coupled amplitude equation, Manley-Rowe relation

Phase Matching:
Basic idea of phase matching, quasi-phase matching method, various methods of phase matching (angle, temperature, birefringence etc.) critical and noncritical phase matching, collinear and non-collinear phase matching, expression of angle band-width ($\Delta\theta$) and wavelength band-width ($\Delta\lambda$) in phase matched second harmonic generation, idea of tangential and dispersion phase matching

Second Harmonic Generation:
Basic equation, conversion efficiency and parameters affecting doubling efficiency, various methods of enhancing conversion efficiency, second harmonic generation with Gaussian beam, intra-cavity second harmonic generation

Higher Order Nonlinear Processes:
Four wave mixing processes-third harmonic generation, resonance enhancement of nonlinear susceptibilities, different phase matching techniques, generation of tunable deep UV and IR radiation, stimulated Raman scattering, inverse Raman scattering, anti-stokes coherent Raman scattering, application in spectroscopy

Chemical Application:
Selective excitation reaction, different separation processes, principle of isotope separation, uranium enrichment, Ultrashort pulses in chemical reaction.

Laser in medical science:
Laser tissue interaction, physical effects on human skin of laser beam reflection, absorption, scattering, different interaction mechanism, different surgical treatment. Effects of ultrashort pulses

Books Recommended:

1. Methods of Experimental Physics Vol. 15B ed. By C L Tang
2. Industrial Application of Lasers – J F Ready
3. Solid State Laser Engineering- W Koechner
4. The Principle of Nonlinear Optics- Y R Shen
5. Handbook of Nonlinear Optics- R L Sautherland

6. Laser and electrooptics- C C Davis

LEARNING OUTCOMES

On completion of the course, the student will be able to:

- Learn the fundamentals of nonlinear optics, covering topics such as nonlinear polarization and second harmonic generation.
- Understand phase matching, including methods like angle, temperature, and birefringence-based phase matching.
- Analyze higher-order nonlinear processes like third harmonic generation and resonance enhancement.
- Explore chemical applications and separation processes, including isotope enrichment.
- Comprehend laser-tissue interaction and its effects on human skin.
- Apply laser technology in medical science, including surgical treatments and ultrashort pulse effects on chemical reactions.
- These skills enable students to work with nonlinear optics in a wide range of applications, from chemistry to medical science.

Paper: PHYS303ME **[Marks 50]** **[Credit 4]**

C. Nano Science and Nano-technology -I

Applied crystallography in Nano science and nano materials

Noncrystalline and semicrystalline states, Lattice. Crystal systems, unit cells. Indices of lattice directions and planes. Coordinates of position in the unit cell, Zones and zone axes. Crystal geometry. Symmetry classes and point groups, space groups. Glide planes and screw axes, space group notations, Equivalent points. Systematic absences, Determination of crystal symmetry from systematic absences. Stereographic projections. Standard projection of crystals.

Section II: Introduction to materials, Classification of materials:

Crystalline & amorphous materials, high Tc superconductors, alloys & composites, semiconductors, solar energy materials, luminescent and optoelectronic materials, Polymer, Liquid crystals and quasi crystals, Ceramics.

Synthesis and preparation of Nanomaterials:

Synthesis of bulk nanostructured materials - Sol Gel processing- bulk and nano composite materials - Grinding - high energy ball milling – injection moulding - extrusion - melt quenching and annealing.

Synthetic Technique (Physical and Chemical): Self assembly-Self Assembled Monolayers (SAM) - Vapour Liquid Solid (VLS) approach - Chemical Vapour Deposition (CVD) - Langmuir-Blodgett (LB) films - Spin coating - Templated self assembly Electrochemical approaches: Thin films - Epitaxy -Lithography.

One dimensional and Two dimensional nanostructures: Nanowires and Nanotubes: Evaporation-condensation - Vapor- liquid - solid (VLS) - surface and bulk diffusion – kinetics – growth of various nanowires –control of size –precursors and catalysts - single- and multiwall CNT - Si nanowires – density and diameter – doping in nanowire.

Phase transition in materials

Solid solutions, Phases, Thermodynamics of solutions, Phase rule, Binary phase diagrams, Binary isomorphous systems, Binary eutectic systems, ternary phase diagrams, kinetics of solid reactions. Order disorder phenomenon in binary alloys, long range order, super lattice, short range order. (10 lectures)

Books Recommended:

1. Materials science and Engineering by *V. Raghavan*, Prentice-Hall Pvt. Ltd.
2. Thin Solid Films by *K. L Chopra*
3. Elements of X-ray diffraction by *B. D. Cullity*, Addison-Wesley Publishing Co.
4. Elements of crystallography by *M. A. Azaroff*
5. Engineering Materials by *Kenneth G. Budinski*, Prentice-Hall of India Pvt. Ltd.
6. W. Gaddand, D.Brenner, S.Lysherski and G.J.Infrate (Eds), Handbook of nanoscience, Engg and Technology, CRC Press,2002.
7. G.Cao, Naostructures and Nanomaterials: Synthesis, properties and applications, Imperical College Press, 2004.
8. J.George, Preparation of thin films, Marcel Dekker, InC., New York, 2005.
9. C.N.R.Rao, A.Muller, A.K.Cheetham (Eds), The chemistry of nanomaterials: Synthesis, properties and applications, Wiley VCH Verlag Gmbh&Co, Weinheim, 2004.

Paper: PHYS304ME **[Marks 50]** **[Credit 4]**

C. Nano Science and Nano-technology -II

Nanomaterials and their applications

Background to Nanoscience: Defination of Nano, Scientific revolution-Atomic Structure and atomic size, emergence and challengs of nanoscience and nanotechnology, carbon age-new form of carbon (CNT to Graphene), influence of nano over micro/macro, size effects and crystals, large surface to volume ration, surface effects on the properties.

Types of nanostructure and properties of nanomaterials: One dimensional, Two dimensional and Three dimensional nanostructured materials, Quantum Dots shell structures, metal oxides, semiconductors, composites, mechanical-physical-chemical properties.

Application of Nanomaterial: Ferroelectric materials, coating, molecular electronics and nanoelectronics, biological and environmental, membrane based application, polymer based application.

Lattice Imperfections

Point defect, line defect, plane defect, volume defect, dislocation, stacking faults, application, Burger vectors.

Structure of metals, semiconductors and ceramics

Difference between structures of metals and ceramics, close-packed structures: BCC, FCC & HCP metals. Structure of semiconductors: Si, Ge, ZnS, pyrites, chalcopyrite's, ZnO etc.; structure of ceramics: metal oxides, nitrides, carbides, borides, ferrites, perovskites, etc.

Microstructure characterization by direct & indirect methods

Diffraction techniques: interpretation of x-ray powder diffraction patterns, Identification & quantitative estimation of unknown samples by X-ray powder diffraction technique and fluorescent analysis. Theory and method of particle size analysis. Integral breadth method, Warren-Averbach's Fourier method, profile fitting method, Rietveld Method.

Characterization techniques related to nanomaterials

Electron Microscopy techniques: TEM, SEM & STEM. AFM, XPS, EDX. Electron and neutron diffraction.

Books Recommended:

1. X-ray diffraction by *B. E. Warren*, Addison-Wesley Publishing Co.
2. An Introduction to Metallurgy by *Sir Alan Cottrell*, University Press
3. The Structure & Properties of Materials (Volume II) by *J. H. Brophy, R. M. Rose and J. Wulff*, Wiley Eastern Ltd.
4. Structure of Metals, *C. S. Barrett & T. B. Massalski*, McGraw-Hill Book Company.
5. The Optical principles of the Diffraction of X-rays by R. W. James, G. Bell & Sons Ltd.

Paper: PHYS303ME **[Marks50] [Credit 4]**

D. Advanced Nuclear Physics-I

Basic ingredients for nuclear physics experiment: Ion sources, Making beams of projectile - Accelerators; Target systems; Detection system, Nuclear electronics and pulse processing, vacuum systems, Beam dump and its shielding, A schematic diagram of nuclear physics experiment [3 lectures]

Ion sources: Basic components of ion sources, dynamics of ion sources, different types of ion source-PIG and ECR ion source. [3 lectures]

Particle accelerators: Van de Graaff accelerator, Linear accelerator, Pelletron and tandem accelerator, Cyclotron, Synchrotron and synchrocyclotron, colliding beams. Accelerator facilities in India. [8 lectures]

Detection systems:

Radiation sources- source of gamma, charge particle and neutron radiations. Interaction of radiation (gamma, charge particle and neutron) with matter, Photo electric effect, Compton scattering, pair production, ionization, excitation, absorbtion, elastic and inelastic scattering. Energy loss Mechanism, Bohr's Ionization formula, stopping power, Braggs curve, energy straggling, Range of charge particle. [6 lectures]

General properties of detectors, energy and time resolution, detection efficiency, dead time of the detector. Types of detectors- inorganic and organic scintillator, gas detectors, semiconductor detector, plastic scintillators. Photomultiplier tube and photo diodes. [4 lectures]

Gamma detector: Inorganic scintillators detector and its working principle; Semiconductor detector and its working principle. Example of gamma detector- BaF2, NaI, HpGe, etc. [6 lectures]

Charge particle detector: Semiconductor and inorganic scintillator detector and their working principle. Gas detectors and its working principle. Example of charge particle detectors-

Proportional counter, MWPC, GM counter, Si detector, CsI detector, surface barrier detector, P.I.N diode, etc [6 lectures]

Neutron detector: Organic scintillators detector and its working principle; Plastic scintillator, Example of neutron detectors- ^{3}He gas filled detector, BF_3 proportional counter, ^{6}LiF converter, organic scintillator (BC501A, NE213, etc), CLYC detector. [6 lectures]

Vacuum systems: Necessity of vacuum in nuclear physics experiment, Basic principle of vacuum. Gueges: Penning, Pirani, etc. Different types of pumps- rotary pump, diffusion pump, roots pump, turbo molecular pump, etc. [4 lectures]

Beam dump and its shielding: Necessity of shielding, sources of backgrounds, background in gamma ray spectra, background in other detectors, shielding materials, shielding of different radiations, Nuclear safety, Nuclear waste management. [2 lectures]

Books Recommended:

7. Introductory Nuclear Physics- K. S .Krane (Wiley India)
8. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)
9. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)
10. C Iliadis: Nuclear Physics of Stars
11. J.L. Basdevant, J Rich and M. Spiro: Fundamentals in Nuclear Physics
12. G.F. Knoll: Radiation Detection Measurement
13. B.E.J. Pagel: Nucleosynthesis and Chemical Evolution of Galaxies
14. Techniques for Nuclear and Particle Physics Experiments: A How-to Approach Book by William R. Leo

LEARNING OUTCOMES

On completion of the course, the students will:

- Understand the essential elements required for a nuclear physics experiment, including ion sources, accelerators, target systems, detection systems, nuclear electronics, vacuum systems, and shielding.
- Explore various particle accelerators, such as Van de Graaff, linear accelerator, Pelletron, cyclotron, synchrotron, and synchrocyclotron, and discover accelerator facilities in India.
- Examine general detector properties, including energy and time resolution, detection efficiency, and detector dead time.
- Focus on gamma detectors, charge particle detector and neutron detectors.
- Discover the importance of vacuum in nuclear experiments, grasp the basic vacuum principles, and become familiar with various vacuum pumps like rotary pumps, diffusion pumps, roots pumps, and turbo molecular pumps.
- Recognize the necessity of shielding and address sources of background radiation.

Paper: PHYS304ME **[Marks50] [Credit 4]**

D. Advanced Nuclear Physics-II

Nuclear electronics and pulse processing:
Pulse Signal Terminology, Analog and Digital Signals, Fast and Slow Signals, The Frequency Domain. Bandwidth. Signal transmission, impedance matching. [2 lectures]

Electronics for pulse processing- Preamplifier, shaping and fast amplifier, CR-RC pulse shaping, pole zero cancellation and base line restoration, biased amplifier, linear transmission gate, discriminator, leading edge and constant fraction discriminator (LED, CFD), FAN-IN-FAN-OUT (liner and logic), delay module, single channel and multi-channel analyzers (SCA, MCA), digital to analog converter (DAC), Analog to Digital converter (ADC), Time to amplitude converter (TAC), Charge to Digital converter (QDC), Scalers, Gate and delay generator (GDG), Coincidence unit, pulse splitting. [12 lectures]

Pulse height analysis- a simple counting system, pulse height selection, SCA calibration and energy measurement, pulse height spectroscopy with MCA, Basics coincidence technique, timing measurement. Combining the pulse height selection and coincidence determination, pulse shape discrimination. Measurement using a coincidence unit. Measurement of absolute source activity using coincidence techniques. Modular instruments for timing measurements [8 lectures]

A schematic set up for energy and timing measurement with MCA and TAC. A schematic set up for energy and timing measurement with QDC and TDC. Typical gamma rays spectrum in gamma detector and spectrum with the thickness of detector. Typical charge particle spectrum in charge particle detector. Typical neutron spectrum in charge particle detector. [4 lectures]

Introduction of digital pulse processing: ADC, different types of ADC, different type of digitizer, pulse shape analysis with digitizer. Measurement of energy and timing properties with digitizer. [6 lectures]

Nuclear electronic module: The NIM standard modules, NIM logic signal, TTL and ECL logic signals. Introduction of Computer controlled electronics – CAMAC, VME; Dead time of the electronics module. [3 lectures]

Experimental Set-up: A schematic diagram of nuclear physics experiment. A typical gamma, charge particle and neutron spectra in the corresponding detectors. [1 lectures]

Statistics and the Treatment of Experimental Data:
Characteristics of Probability Distributions- Cumulative distributions, Expectation Values Distribution Moments, The Mean and Variance, The Covariance.
Some Common Probability Distributions- The Binomial Distribution, The Poisson Distribution, The Gaussian or Normal Distribution, The Chi-Square Distribution.
Measurement Errors and the Measurement Process- Systematic Errors and Random Errors.
Examples of Applications- Mean and Error from a Series of Measurements, Combining Data with Different Errors, Determination of Count Rates and Their Errors, Propagation of Error, Examples- Curve Fitting, The Least Squares Method, Linear Fits-The Straight Line, Linear Fits-When Both

Variables Have Errors, Nonlinear Fits; Some General Rules for Rounding-off Numbers for Final Presentation. **[8 lectures]**

Statistical Theory of Nuclear Reaction: Statistical theory of compound nuclear decay, Hauser-Feshbach Thoery, Decay probabilities, Transmission coefficient, Nuclear level density, Particle and gamma emission probabilities, Evaporated particle spectra, Gamma ray spectrum. [4 lectures]

Simulation in nuclear physics: Introduction of detector simulation like GEANT4. Introduction of PACE4 calculation. [Only introduction] [2 lectures]

Books Recommended:

15. Introductory Nuclear Physics- K. S .Krane (Wiley India)
16. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)
17. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)
18. C Iliadis: Nuclear Physics of Stars
19. J.L. Basdevant, J Rich and M. Spiro: Fundamentals in Nuclear Physics
20. G.F. Knoll: Radiation Detection Measurement
21. B.E.J. Pagel: Nucleosynthesis and Chemical Evolution of Galaxies
22. Techniques for Nuclear and Particle Physics Experiments: A How-to Approach Book by William R. Leo

LEARNING OUTCOMES

On completion of the course, the students will:

- Understand Nuclear Electronics and Pulse Processing, covering topics like pulse signal terminology, analog and digital signals, signal transmission, and pulse shaping.
- Learn about Nuclear Electronic Modules, the NIM standard modules, and computer-controlled electronics.
- Dive into Digital Pulse Processing, focusing on analog-to-digital converters, digitizers, and pulse shape analysis.
- Study Statistics and the Treatment of Experimental Data, covering probability distributions, measurement errors, parameter estimation, and error propagation.
- Gain insights into the Statistical Theory of Nuclear Reactions, encompassing compound nuclear decay, Hauser-Feshbach theory, nuclear level density, and particle/gamma emission probabilities.
- Get introduced to Simulation in Nuclear Physics, specifically detector simulation using tools like GEANT4 and PACE4.
- These outcomes provide a comprehensive understanding of nuclear electronics, data processing, and statistical analysis in the context of nuclear physics experiments.

Paper: PHYS303ME **[Marks 50]** **[Credit 4]**

E. Quantum Information Processing –I

1. Introduction and overview:
Definition of information, Quantitative measure of information, Shannon’s first coding theorem, History of quantum computation and quantum communication, the concept of qubits.

[4 Lectures]

2. Basic ideas of classical and quantum computational models and complexity classes:
Elementary idea of complexity of an algorithm, Turing machine, Deterministic Turing machine, Probabilistic Turing, Reversible Turing machine, Circuit model of computation, Computational complexity and related issues. [4 Lectures]

3. Mathematical tools and simple quantum mechanics required for quantum computing:
Vector space, The *Cn* vector space, Inner product space and Hilbert space, Bases and linear independence, *C*2 space, The space spanned by a single Qubit, Outer product, Relation between bases, Subspace (basis for a vector space adapted to a subspace, Direct sum and sum, Linear operators, Null space, range and rank of a linear operator, Inevitability (invert sub space of a linear operator).

Pauli matrices, Gram-Schmidt procedure, Eigenvalues and eigenvectors, Hermitian operators, Normal, unitary and positive operators, Diagonalizable operator and spectral decomposition, Tensor products, Trace, Postulates of quantum mechanics (Postulate 1: The State of a System, Postulate 2: Observable Quantities Represented by Operators, Postulate 3: Measurements, Postulate 4: Time Evolution of the System),

Density operator and density matrix, Density operator of pure and mixed states, Positive maps (Completely and noncompletely), More general evolution by Kraus Operator (trace out the environment and the study the principle system)

4. Bloch sphere and Qubit:
State space of a qubit, Density operator and bloch vector. (locate any given state on a bloch sphere), plots of maximally mixed , mixed and pure state on bloch sphere, Quantum measurement and find probability corresponding bloch sphere state.

Books Recommended:

1. Quantum Computation and Quantum Information, Michael A. Nielsen, Isaac L. Chuang
2. Quantum Computing Explained, David McMahon. WILEY-INTERSCIENCE. A John Wiley & Sons,
3. Vector Spaces and Matrices in Physics ; M. C. Jain, CRC Press, 2001
4. Elements of Quantum Computation and Quantum Communication, Anirban Pathak.
5. Computational Physics , Problem solving with python, Rubin H. Landau, Manuel J. Paez, Cristian C. Bordeianu
6. Quantum Information theory. M. Wilde, Cambridge University Press, 2013.
7. An Introduction to Quantum Computing. P. Kaye, R. Laflamme and M. Mosca. Oxford University Press, New York, 2007.
8. Quantum Optics-An introduction; Mark Fox.

LEARNING OUTCOMES

On completion of the course, the students will:

- Learn the definition of information and understand quantitative measures of information, including Shannon's first coding theorem. Gain knowledge about the history of quantum computation and communication, along with the concept of qubits.
- Explore the basics of classical and quantum computational models and complexity classes, covering concepts like Turing machines, circuit models of computation, and computational complexity.
- Acquire mathematical tools and fundamental quantum mechanics concepts necessary for quantum computing, including vector spaces, Hilbert spaces, Pauli matrices, and density operators. Understand the Bloch sphere and qubit state representation, along with quantum measurements.
- These skills prepare students for more advanced topics in quantum computing and quantum information theory.

Paper: PHYS303ME [Marks 50] [Credit 4]

E. Quantum Information Processing –II

1. Entanglenglement:
The meaning of entanglement, EPR paradox, Bell's inequality and nonlocality, Basic algebra for quantum computing, Bell measurement and entanglement, Partial trace, Quantum bit commitment and quantum coin tossing, Schmidt decomposition, Partial transpose and test of entanglement, Entanglement witness, State discrimination, Trace distance and, Measures of entanglement, Schmidt measure, Peres-Horodecki Criterion and its limitations, Von Neumann entropy of the, Negativity, Concurrence and entanglement of formation, State purification, Holevo bound, Bloch sphere, Nocloning theorem, No-go theorems. [12 Lectures]

2. Quantum gates and quantum circuits:
Single qubit gates, Two qubit gates, Three qubit gates, Quantum circuits, Entangled circuits(Bell, GHZ, W, Cluster N-qubit), Quantitative measures of quality of a circuit, Gate count or circuit cost, Garbage bit, Quantum, Depth and width of a circuit, Total cost, Circuit optimization rules, Moving rule, Template matching.

[6 Lectures]

3. Quantum algorithms:
Deutsch's algorithm, Deutsch Jozsa (DJ) algorithm, Grover's algorithm, Simon's algorithm, Classical approach, Quantum approach, Complexity analysis, Shor's algorithm, Basic ideas of number theory, Euclid's algorithm, Period of the modular exponential function, Continued fraction representation, The strategy, Quantum Fourier transformation, Main (quantum) part of the algorithm, Solution of Pell's equation and the principal ideal problem. [16 Lectures]

4. Quantum error correction:
Quantum error correction, Basic idea of an error model, How to correct classical errors, Difference between classical error and quantum error, Correction of quantum bit flip error: A 3-qubit code, Correction of phase flip error: A 3-qubit code, Fault-tolerant quantum computation, Threshold theorem for quantum computation, Decoherence and decoherence free subspace, Decoherence free subspace. [6 Lectures]

4. Experiments/Simulations: Group A [10 Lectures]

Basic necessary codes (python 3)
[for loop and range function, random number, the math function, if else statement,, elif satement, Flag Variable, string, List, Array, user define function, use of numpy, scipy, matplotlib]

(i) Different matrix operations (without using module)
(a) Addition of matrix (b) Subtraction of matrix (c) Transpose of a matrix (d) Exponent of a matrix (Cayley Hamilton theorem)
(ii) Find eigen value eigen vector of a given matrix (Hermitian/Non Hermitian) [for non hermitian case plot real part vs imaginary part of eigen value for the given system. (hamitonian or matrix)
(iii) State (you can assume any basis state) evolution of a given hamiltonian (matrix). Find the probability vs time graph for a given range of time (you can use module).
(iv) Code for Partial Transpose and partial trace of a given system or matrix.
(v) States and operator using python
(a) Density matrices (b) Pauli sigma properties (c) Harmonic Oscillator operators(creation and annihilation) (d) Quantum communication relation using python (e) Cat vs coherent states in a Kerr resonator and the role of measurement.
(vi) Python coding for Fourier transform [(a) Continuous Fourier transform, (b) Discrete Fourier Transform]
(vii) Code for logic gate (NOT, AND, OR, XOR, XNOR, NAND)

Recommended Books:

1. Quantum Computation and Quantum Information, Michael A. Nielsen, Isaac L. Chuang
2. Quantum Computing Explained, David McMahon. WILEY-INTERSCIENCE. A John Wiley & Sons,
3. Vector Spaces and Matrices in Physics ; M. C. Jain, CRC Press, 2001
4. Elements of Quantum Computation and Quantum Communication, Anirban Pathak.
5. Computational Physics , Problem solving with python, Rubin H. Landau, Manuel J. Paez, Cristian C.
Bordeianu
6. Quantum Information theory. M. Wilde, Cambridge University Press, 2013.
7. An Introduction to Quantum Computing. P. Kaye, R. Laflamme and M. Mosca. Oxford University Press, New York, 2007.
8. Quantum Optics-An introduction; Mark Fox.

LEARNING OUTCOMES

On completion of the course, the students will:

- Understand the concept of entanglement, the EPR paradox, Bell's inequality, and nonlocality in quantum mechanics. Gain proficiency in the algebra and mathematics used in quantum computing. Learn about various aspects of entanglement, including Bell measurements, partial trace, quantum bit commitment, Schmidt decomposition, and measures of entanglement such as Von Neumann entropy, negativity, concurrence, and entanglement of formation.
- Explore quantum gates and circuits, including single qubit gates, two qubit gates, and quantum circuit optimization. Develop skills in analyzing and optimizing quantum circuits, considering gate count, depth, width, and total cost.
- Dive into quantum algorithms, including Deutsch's algorithm, Deutsch-Jozsa algorithm, Grover's algorithm, Simon's algorithm, and Shor's algorithm. Understand the quantum approaches to solving computational problems and analyze their complexity.
- Gain insights into quantum error correction, including error models, classical vs. quantum errors, and quantum error correction codes. Learn about fault-tolerant quantum computation, the threshold theorem, and decoherence-free subspaces.
- Develop programming skills in Python, including matrix operations, eigenvalue and eigenvector calculations, state evolution, partial transpose and trace calculations, density matrices, Pauli sigma properties, harmonic oscillator operators, Fourier transforms, and logic gate implementations. These skills prepare students to work with quantum systems and quantum computation, both in theory and through practical programming and simulations.

Minor Electives:
Paper: PHYS305EID **[Marks 50]** **[Credit 4]**
Biophysics

Basic concepts and laws of thermodynamics: Isolated system, closed system, Open system; Thermodynamic variables, Thermodynamic equilibrium, Reversible process, Irreversible process; First law of thermodynamics, second law of thermodynamics. Meaning of entropy, Entropy production and the stationary state as the basic principle of life.
Diffusion: Fick's law, equation of continuity; basics of elasticity, viscosity, and surface tension.
Biophysics of neuron: Structure of neoronal cells, Ion channels and ion pumps, Action membrane potenial and its propagation, Synaptic transfer of action potentials, Hodgkins-Huxley model of neuron (qualitative description).
Biophysics of hearing: Sound as a mechanical oscillations of an elastic medium, Quantities used to measure sound, Biophysical function of outer, middle and inner ear; sound pollution.

Non-ionizing electromagnetic radiation and its biological effects, spectrum of electromagnetic radiation, Biophysical effects of ionizing radiation, linear energy transfer.
Physical Methods in Biology and Medicine: Types of radioactive decay, laws of radioactive decay, Basic of x-rays, X-Ray diffraction; Isotope labelling; Photodynamic therapy, ECG, EEG, MRI, Tomography.

Books:
1. Elementary Biophysics: An Introduction, by P. K. Srivastava
2. Physics for the Biological Sciences, by Hallett et al.

LEARNING OUTCOMES

The students are expected to learn the thermodynamics and fluid mechanics associated with biological system, physics of neurons and physics of nuclear fission and nuclear reactor, nuclear fusion and tokomak, nuclear radiation hazard and radiation dosimetry.

Paper: PHYS306PR **[Marks 50]** **[Credit 4]**

Advanced General Practical

List of Experiments

Group A:

1. Determination of temporal coherency of a laser light source and compare it with an incoherent source
2. Determination of spatial coherency of a laser light source and compare it with an incoherent source
3. Study of magneto-optic effect (Faraday effect)
4. Study of electro-optic effect (Pockels effect)
5. Study of Zeeman effect
6. Design of active band-pass filters and to verify the Barkhausen criteria
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Design of astable multivibrator using 555 Timer
9. Determination of particle size of an unknown specimen
10. Band-gap determination from thermal variation of resistivity

Group B:

1. Measurement of magnetic susceptibility using Quincks method
2. Study of ESR
3. Phase identification of an unknown sample from its X-ray diffraction pattern
4. Studies on Gunn oscillator in the microwave frequency region (Microwave workbench)
5. Studies on antenna theory
6. Studies on van der Pol oscillator: Sinusoidal and relaxation oscillations
7. Studies on laser diodes and its application in optical communication
8. Finding Speed of light in air using laser.
9. To study and characterize a quantum dot structure.
10. To verify Raman Effect.
11. Determination of efficiency of GM counter.

All the students will be divided into two groups i.e. Group A & Group B and that will be decided by the Department

Learning outcome:

• Selected experiments of physics will enhance knowledge, and assist in learning and clarification and consolidation of theory.

(END OF SEMESTER-III)

SEMESTER IV

SEMESTER IV (Total 300 Marks) (CREDIT 24)

Paper: PHYS401C **[Marks 25]** **[Credit 2]**
Unit – I (Molecular Spectroscopy –II)

Hydrogen molecule ion and molecular orbitals. Valence Bond approach in hydrogen molecule. Coulomb and exchange integrals. Electronic structures of simple molecules. Chemical bonding. Hybridizations.

Basic aspects of photo physical processes: radiative and non-radiative transitions; fluorescence and phosphorescence; Kasha's rules. Nuclear Magnetic resonance spectroscopy. Electron spin resonance spectroscopy. Fourier transform spectroscopy. Photo acoustic spectroscopy. Photo electron spectroscopy. Mossbauer spectroscopy.

Group Theory: Definition, postulates, Representation of Groups, Finite and infinite groups, order of a group, Rearrangement theorem. Group multiplication table. Subgroups and Cosets. Lagrange's theorem. Order of an element. Conjugate elements and classes. Cyclic and other distinct groups. Permutation groups. Invariant subgroups, factor groups. Generators. Isomorphism and homomorphism. Illustrations with point symmetry groups.

Books Recommended:

1. G. Herzberg. 'Molecular Spectroscopy (Diatomic Molecules)' Van-Nostrand.
2. G. M. Barrow. 'Molecular Spectroscopy'. McGraw-Hill.
3. J.Michael Hollas. ' Modern spectroscopy'. John-Wiley & sons.
4. C. L. Banwell and E. M. McCash. 'Fundamentals of Molecular Spectroscopy' Tata- McGraw-Hill..
5. G.Aruldhas 'Molecular Spectroscopy'.
6. Bransden and Joachin. 'Atoms and Molecules'
7. F.A.Cotton. 'Chemical application to Group theory'.
8. M. Hammermesh. 'Group Theory'. Addison-Wesley
9. M. Tinkham. 'Group Theory and Quantum Mechanics;. McGraw-Hill.
10. G. G. Hall. 'Applied Group Theory'. Longmans, Green.
11. A. W. Joshi. 'Group Theory'. Wiley Eastern Ltd..
12. N. Deo : Group Theory (Tata McGraw Hill)

Learning outcome:

The concept of Group Theory will be of immense use in studying various symmetry properties in high energy physics, quantum mechanics as well as condensed matter physics.

Unit – II (Nonlinear Dynamics)

Dynamical System, motion in 1D and 2D spaces, constants of motion, phase space, fixed points. Nonlinear dynamical systems in Physics, biology, engineering, etc. Dynamical equations and Stability for linear systems. Flow defined by nonlinear systems of ODEs, linearization and stable manifold theorem. Hartman- Grobman theorem. Stability and Lyapunov functions. Poincare-Bendixon theorem. Planar flows: saddle point, nodes, foci, centers and nonhyperbolic critical points.
Bifurcation theory: saddle-node, pitch-fork, Hopf, period doubling, homoclinic, codimension-2 bifurcations. Applications in: Laser model, population dynamics.

Limit cycle oscillations and Chaos: Concept of limit cycle, Poincare-Bendixon theorem; role of nonlinearity: From harmonic oscillator to Van der Pol oscillator, Chaos, Lorenz equation and Rossler equation. Applications in: Chaos in electronic oscillators, chaos in Laser system.

Discrete time nonlinear systems: logistic map, sine circle map, linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; universality and the Feigenbaum numbers; bifurcation and chaos, intermittency, crises; Applications in: population dynamics, discrete phase-locked loop system, power electronics.

Dispersion, Dissipation and nonlinearity, Korteweg–de Vries (KdV) equation, solitory waves and soliton interaction, Application of KdV equations, nonlinear Schoedinger equation.

Pattern formation: Reaction-diffusion equation, Turing instability: linear stability analysis. Numerical realizations.

Books Recommended:

1. Stephen Wiggins, "Introduction to Applied Nonlinear Dynamical Systems and Chaos", Springer-Verlag, Second Edition.
2. Steven Strogatz. "Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering", Levant Publishers, 1994.
3. Edward Ott**,** Chaos in Dynamical Systems**,** Cambridge University Press.
4. Dominic Jordan, Peter Smith, "Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers" (Oxford Texts in Applied and Engineering Mathematics)
5. J K Bhattacharyya, Nonlinear Dynamics
6. Ajoy Ghatak & K Thyaragrajan, Introduction to Fiber Optics (Cambridge University Press).
7. G P Agrawal, Application to Non Linear Fiber Optics (Academic Press).

LEARNING OUTCOMES:
At the end of the course
1. Students will recognize the impact of nonlinearity on the natural phenomena.
2. Students will be able to solve paradigmatic problems in physics that can not be solved using the conventional linear approach.
3. Students can apply the knowledge to understand the problems from biology, chemistry, and engineering.
4. Since this course is inherently interdisciplinary, therefore, it will help students for developing skills to pursue research in the multidisciplinary fields.

Paper: PHYS402C **[Marks 25]** **[Credit 2]**

Unit – I (Relativity)

Brief review of Minkowski's Four Dimensional Space-time.

Vectors and Tensors, Idea of parallel transport and covariant derivatives, covariant derivative of $g_{\mu\nu}$, Geodesics, Curvature tensor and its properties, Bianchi Identities, Ricci tensor, Einstein tensor.

Principles of equivalence, Principle of general covariance, Metric tensors and Newtonian Gravitational potential, Logical steps leading to Einstein's equations of gravitation, Linearised equation for weak fields.

Schwarzschild's exterior solution, singularity, event horizon and concept of black holes, Birkhoff's theorem, Observational tests of Einstein's theory – Precession of Perihelion of the planet Mercury, Bending of light rays in a gravitation field, Gravitational Red shift.

Books Recommended:

1**.** General Relativity and Cosmology (MacMillion, 1978).- J. V. Narlikar
2.Theory of Relativity (Wiley, 1972). - S. Weinberg
Introduction to Theory of Relativity (Prentice-Hall, 1969). - P. G. Bergmann
3. Introduction to Special Theory of Relativity.- R. Resnick
4. The Special Theory of Relativity (Prentice Hall of India, 2002) S. Banerji and A. Banerjee
5. Introduction to the Theory of Relativity. - W.G.V. Rosser

Unit-II (Astrophysics)

Star formation, Stellar Magnitudes, Classification of stars, H-D classification, Hertzsprung-Russell (H-R) diagram, Virial theorem (derivation is not required), Equations of stellar structure.

Pre-main sequence evolution, Jeans criteria for star formation, Post main sequence stage.

Thermonuclear reactions in stars, pp chains and CNO cycle, Helium burning and subsequent thermonuclear reactions, nucleosynthesis beyond iron, r- and s- processes.

Introduction, Newtonian theory of stellar equilibrium, White Dwarfs, Chandrasekhar Mass Limit (no derivation), Neutron Stars, Tolman-Oppenheimer-Volkoff (TOV) equation (derivation is not required) and its consequences,. Pulsars.
Black holes, Schwarzschild and Kerr black hole (no derivation), event horizon, Penrose process of energy extraction, No Hair Theorem.
Qualitative discussions on: Quasars, Brown dwarfs, Red Giant Stars, Nova, Supernova

Galaxy-elliptic and spiral. Classification of Galaxies. Density wave theory of galactic structure. Galactic rotation curve and Dark matter.

Cosmological Principles, Weyl postulate, Hubble's law. Robertson-Walker metric, Cosmological parameters, Standard model of Cosmology, Success and Limitations of Standard model of Cosmology, Inflation, Late time acceleration, Dark Energy models (ΛCDM Model, Scalar field

Models, F(R) theory of Gravity.)

Introduction, plane waves, radiation of gravitational waves, detection of waves. Theory of gravitational lensing, magnification and amplification of images.

Astronomical Instruments: Optical telescopes, Optical photometric instruments and Techniques, Optical spectroscopy and Radio telescopes.

Space Astronomies: Infrared Astronomy, Ultraviolet Astronomy, X-ray astronomy, Gamma ray astronomy and The Hubble space telescope.

Books Recommended:

1. Textbook of astronomy and astrophysics with elements of cosmology, V.B.Bhatia, Narosa publishing house, 2001.
2. Theoritical Astrophysics (Vols.I,II,III) – T. Padmanavan (CUP)
3. Introduction to Cosmology – J.V.Narlikar (Cambridge University Poress)
4. General Relativity, Astrophysics and Cosmology – A.K.Raychaudhuri, S.Banerji and A.Banerjee (Springer-Verla, 1992)
5. General Relativity and Cosmology – S. Banerji and A. Banerjee (Elsevier, 2007)
6. The Structure of the Universe – J.V.Narlikar (OUP, 1978)

Learning Outcomes:
On completion of this course, the student will be able to:
Explain the nature of galaxies, their formation and their evolution, and the cosmological nature of the Universe
Apply knowledge of core concepts in physics to derive astrophysical properties of galaxies and the Universe
Formulate solutions to astrophysical problems related to galaxies and cosmology, involving new concepts, with limited guidance
Demonstrate knowledge of the frontiers of the discipline, for example, through cases where current theories fail to explain a set of observational data
Demonstrate a high degree of independence in learning and retrieving information on galaxies and cosmology from the primary research literature, books and other sources.

Paper: PHYS403PR **[Marks 50]** **[Credit 4]**

Computer Practical

* Initially preliminary programs using decision making statements and loop structures to be executed in C and Python.

1. Numerically solve the Rossler's equations

$$\frac{dx}{dt} = -y - z,$$

$$\frac{dy}{dt} = x + ay,$$

$$\frac{dz}{dt} = b + z(x - c),$$

Draw the periodic and chaotic time series and phase plane plots for different values of a, b, and c.

2. Numerically solve the Lorenz's equations

$$\frac{dx}{dt} = \sigma(y - x),$$

$$\frac{dy}{dt} = x(\rho - z) - y,$$

$$\frac{dz}{dt} = xy - \beta z.,$$

Draw the periodic and chaotic time series and phase plane plots for different values of σ, ρ , and β.

3. Write the C programming code to solve the van der Pol equation with suitable parameter values.

$$\frac{d^2x}{dt^2} - \mu(1 - x^2) + x = 0.$$

4. Write the C programming code to solve the Linear Harmonic Oscillator problem.

$$\frac{d^2x}{dt^2} + \omega^2 x = 0.$$

5. Write the C programming code to solve the wave equation in free space with specific boundary conditions.

$$\frac{d^2U}{dt^2} = c^2 \frac{d^2U}{dx^2}.$$

6. Draw the phase plane plot of

$$\frac{dx}{dt} = x + y,$$

$$\frac{dy}{dt} = 4x - 2y,$$

for a range of initial conditions.

7. Consider a particle of mass m=1 is moving in a double well potential $V(x) = -\frac{1}{2}x^2 + \frac{1}{4}x^4$. Plot the phase portrait.

8. Draw the phase plane plot of

$$\frac{dx}{dt} = x - y,$$

$$\frac{dy}{dt} = 1 - e^x,$$

for a range of initial conditions.

9. Draw the bifurcation diagram of (i) $\dot{x} = r + x^2$, (ii)$\dot{x} = rx - x^2$, (iii) $\dot{x} = rx - x^3$, and (iv) $\dot{x} = rx + x^3 - x^5$,

10. Write the C programming code for the solution of simultaneous equations by Gauss-Jordon method.

11. Write the C programming code to simulate the random-walk problem.

12. Write the C programming code to solve the polynomial equation with Newton-Raphson method.

$$2x^3 - 2.5x - 5 = 0$$

13. Using Planck's formula write the C programming code to plot the intensity distribution of blackbody radiation at different absolute temperatures.

13. Write the C programming code for multiplication of two matrices.

14. Write the C programming code to solve the 1D heat equation with suitable values of parameters and boundary conditions.

$$\frac{dU}{dt} = \frac{k}{s\rho}\frac{d^2U}{dx^2}.$$

15. Write the C programming code to solve the Laplace equation of electrostatics with boundary conditions.

$$\nabla^2\varphi = 0$$

- All the above programs also to be executed in Python language.

Unit – II (Social out-reach activity)

To be decided by the Departmental Committee

Paper: PHYS404PJ **[Marks 50]** **[Credit 4]**

Project

To be decided by the Departmental Committee

Major Elective

Paper: PHYS405ME **[Marks 50]** **[Credit 4]**

A. Advanced Electronics-III

Review of CW Modulation Technique:
Linear modulation DSB, SSB, VSB, QAM techniques, Exponential modulation FM and PM; AM and FM modulators and demodulators.

Pulse Modulation and Demodulation Techniques:
Sampling the rein PAM, PWM, PPM, Pulse code modulation – coding technique modulation and demodulation.

Digital Modulation Techniques: ASK, FSK, PSK, DPSK, QPSK, MSK, Principle, modulators and demodulators.

Effect of Noise on Communication System:
Characteristics of additive noise; Performance of AM, FM and PCM receivers in the face of noise; Multi-path effect.

Elements of Information Theory:
Information, average information, information rate, Effect of coding on average information per bit; Shanon's theorem; Channel capacity, an optimum modulation system.

RADAR System: Basic pulsed radar system – modulators, duplexer indicators, radar antenna CW radar; MTI radar FM radar; chirped pulse radar.

Optical Communication: Fibre optic communication systems; Power budget equation; Multiplexing; Quantum limit; Incoherent reception; signal-to-noise ratio calculation; Basics of coherent techniques in FOC.

Satellite Communication:
Orbits, Station keeping; Satellite attitude; Path loss calculation; Link calculation; Multiple access techniques; Transponders; Effects of nonlinearity of transponders.

Specialized Communication Systems:
Mobile Communication – Concepts of cell and frequency reuse description of cellular communication standards; Pagers. Computer communication – Types of networks; Circuit message and packet switched networks; Features of network, design and examples of ARPANET, LAN, ISDN, Medium access techniques – TDMA, FDMA, ALOHA, Slotted ALOHA, CSMA/CD; Basics of protocol.

Introduction to Microcontrollers. Basic Structure, Application, Coding, Examples to control different external devices.

Books Recommended

1. A B Carlson – *Communication Systems.*
2. D Roddy and J Coolen – *Electronic Communications.*
3. Franz and Jain – *Optical Communication Systems.*
4. A M Dhake – *Television and Video Engineering*.
5. Gulati – *Monochrome and Color TV*.
6. Kennedy and Davis – *Electronic Communication Systems*.
7. Taub and Schilling – *Principle of Communication Systems*.

LEARNING OUTCOMES:

High speed and secured communication are very important parts in modern civilization. Reading this course / paper the Students can understand the theory working behind the meaningful and reliable communications. They can get the concepts/ ideas on various types of analog, pulse, and digital communications. The ideas/concepts of modulation as well as de-modulation circuits in the above three branches of communication processes will be possible to be gathered by them. The Students will get knowledge on information theory working behind any digital communication process. They will get also ideas on Different issues of fiber-optic communications, Satellite Communications,, Radar systems for long range detection, Some aspects of specialized communications like cellular network, LAN, ISDN, Packet Switches etc. The microcontroller will enable students to control different hardware.

Paper: PHYS405ME **[Marks 50] [Credit 4]**

B. Laser Physics and Nonlinear Optics-III

Optical fibre waveguide, modes in optical fibre, pulse distortion and information rate in optical fibres, distortion in single mpde fibre, fibre losses, coupling of source with fibre, modulation, PCM, multiplexing, WDM, TDM, solitons.
UV-VIS-NIR crystals, assessment of nonlinear crystals (Kurtz powder method, Maker fringe method), chalcopyrites, derivation and characteristics.
Outline of crystal growth method, liquid phase epitaxy, vapour phase epitaxy, metal organic chemical vapour deposition, chemical beam epitaxy, molecular beam epitaxy.
Principle of measurement with laser beam, distance measurement, rotation, fluid velocity measurement, laser range finder.
Advantages of remote monitoring of the atmosphere by laser, principles of remote monitoring, different lidar systems, sources of noise and its remedial measures, Raman back scattered lidar.

Laser in drilling, cutting, welding, marking, annealing.

Principle of optical bistability, different optical logic gates, optical phase conjugation, production of phase conjugated beam, self focusing, optical computing.
Principle of laser cooling & trapping, optical molasses, cooling below doppler limit, magnetic trapping, applications

Books Recommended:

1. Methods of Experimental Physics Vol. 15B ed. By C L Tang
2. Industrial Application of Lasers – J F Ready
3. Laser remote Sensing:- R M Measures
4. Optical bistability- H M Gibbs
5. Handbook of Nonlinear Optics- R L Sautherland
6. Laser and electrooptics- C C Davis

LEARNING OUTCOMES

On completion of the course, the student should be able to:

- Understand optical fiber waveguides, modes, and information transmission in optical fibers.
- Learn crystal growth processes and their applications.
- Learn about laser-based measurements, ranging from distance and rotation to fluid velocity.
- Explore the advantages and principles of remote atmospheric monitoring using lasers.
- Understand the application of lasers in various fields, including drilling, cutting, welding, marking, and annealing.
- Comprehend optical bistability, optical logic gates, and phase conjugation.
- Explore laser cooling and trapping methods and their practical uses.
- These skills prepare students for a diverse range of applications involving lasers and optical technologies.

Paper: PHYS405ME **[Marks 50]** **[Credit 4]**

C. Nano Science and Nano-technology -III

Optical and dielectric properties of materials

Theory of electronic polarization and optical absorption, ionic polarization, orientational polarization. Optical phonon model in an ionic crystal; Interaction of electromagnetic waves with optical modes, polariton, Dispersion curves of transverse optical (TO) phonon and optical photon in a diatomic ionic crystal, LST relation; Metal-insulator transition. UV-VIS, IR, FTIR and Raman spectroscopy. Optical properties of metals & nonmetals, Luminescence,photoconductivity.

Electrical properties of crystalline, nanocrystalline and polymeric materials Resistivity variation in metals, alloys, semiconductors and nanocrystalline materials, electrical conduction in ionic ceramics, clay materials and conducting polymers. Two-probe and four probe techniques, DC and AC conductivity measurements.

Mechanical Properties of metals and ceramics:

Concepts of stress & strain, stress-strain behavior, anelasticity, Plastic deformation, Hardness-Knoop & Vicker's hardness test.

Thermal properties of metals & alloys:

Temperature effects on the intensities of Bragg reflections. Influence of temperature on diffraction of X-rays, DTA, TGA, DSC (Outline only). Annealing processes, mechanism of hardening. Quenching, thermal stresses.

Thermoelectric Materials: Concept of phonon, Thermal conductivity specific heat, exothermic and endothermic processes, Different types of thermoelectric materials, Bulk properties, One dimensional and composite thermoelectric materials, Applications.

Nanostructured Magnetism: Nanostructure magnetism, Effect Bulk nanostructuring of magnetic property, Giant and colossal magnetic resistance, Nanomagnetic materials, Paramagnetism in metallic nanoparticles, Semiconduction quantum dots.

Section V: Structure - Property correlation, application aspects of material
Correlation of structure with physical properties of materials, application prospects of materials in different areas.

BOOKS RECOMMENDED

1. Introduction to Ceramics by *W. D. Kingery, H. K. Bowen and D. R. Uhlmann*, John Wiley & Sons
2. Diffraction analysis of the microstructure of materials by *E. J. Mittemeijere and P. Scardi*, Springer
3. Materials Science & Engineering by *William D. Callister*, John Wiley & Sons, Inc.
4. Modern techniques of surface science by *D. P. Woodruff & T. A. Delchar*, Cambridge University Press
5. X-ray spectroscopy by *B. K. Agarwal*, Springer-Verlag.
6. Poole and Owners: Introduction to Nanotechnology.
7. M. Wilson, K. Kannangara, G Smith, M. Simmons, B. Raguse, Nanotechnology: Basic.
8. H S Nalwa (Editor): Handbook of Nanostructured Materials and Nanotechnology.
9. S K Kulkarni : Nano Technology/ Principles and Practices. 6. Silvana Fiorito : Carbon Nanotubes.
10. R Booker and El Boysen: Nanotechlongy

Paper: PHYS405ME **[Marks50] [Credit 4]**

D. Advance Nuclear Physics-III

Nuclear Astrophysics:
Thermonuclear reactions in stars, pp chain, CNO cycle, Reaction rates. Low energy behaviour and astrophysical S-factors, Forward and reverse reactions, Non-resonant and resonant reactions, Maxwell-Boltzmann distribution of velocities, Gamow peak. [6 lecture hours]

Big Bang nucleosynthesis: He production, Be bottleneck, Abundance of light elements. Stellar structure: Classical stars, Degenerate stars [6 lecture hours]

Nuclear burning in stars: H burning, He burning, Advanced nuclear burning, Core collapse. [4 lecture hours]

Stellar nucleosynthesis: Abundance of elements, Production of nuclei beyond iron, r-, s- and γ-processes. [4 lecture hours]

Different Experimental techniques:
Experimental signature of different nuclear reactions- compound nucleus and direct reaction measurement. Measurement of angular distribution of elastically and inelastically scattered

products. Measurement of fusion cross-section. [4 lecture hours]

Charged particle measurement- detection and identification using particle telescope and time of flight measurement. [4 lecture hours]

Neutron detection using pulse shape discrimination and time of flight technique. Measurement of nuclear level density and thermodynamic properties of atomic nuclei. Study of pairing correlation [4 lecture hours]

Measurement of low energy gamma ray measurement, evaluation of level structure, lifetime measurement, polarization measurement. [4 lecture hours]

Measurement of the high energy gamma rays and giant resonance. Study of nuclear shape transition. [4 lecture hours]
Neutron induced reaction and measurement. Proton induced spallation reactions [4 lecture hours]

Neutrino physics:
Theory of neutrino oscillation (Theoretical calculations are not required). Solar and atmospheric neutrino anomalies. Neutrino experiments detection of solar neutrino. Davies experiment, SNO experiment, Kamiokande and super-kamiokande experiment, The India-based Neutrino Observatory. [4 lecture hours]

High Energy Physics (HEP) experiments: A Short Introduction of high energy phsyics experiment- Large hadron Collider experiment. [1 lecture hours]

Experimental facility in India: Nuclear physics experiment facility in India such as (a) VECC, Kolkata, (b) TIFR, Mumbai (c) BARC, Mumbai (d) SINP, Kolkata (e) IUAC, Delhi. [1 lecture hours]

Books Recommended:
1. Introductory Nuclear Physics- K. S .Krane (Wiley India)
2. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)
3. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)
4. C Iliadis: Nuclear Physics of Stars
5. J.L. Basdevant, J Rich and M. Spiro: Fundamentals in Nuclear Physics
6. G.F. Knoll: Radiation Detection Measurement
7. B.E.J. Pagel: Nucleosynthesis and Chemical Evolution of Galaxies

LEARNING OUTCOMES

Throughout this course, students will:

- Explore Nuclear Astrophysics, covering thermonuclear reactions in stars, Big Bang nucleosynthesis, stellar structure, nuclear burning in stars, and stellar nucleosynthesis processes.
- Gain knowledge of various experimental techniques, including charged particle and neutron measurements, gamma-ray analysis, neutron-induced reactions, proton-induced spallation reactions, and nuclear level density studies.
- Dive into the field of Neutrino Physics, understanding neutrino oscillation theory and experiments to detect solar neutrinos.

- Get an introductory overview of High Energy Physics (HEP) experiments, with a focus on the Large Hadron Collider (LHC).
- Familiarize themselves with nuclear physics experimental facilities in India, such as VECC, TIFR, BARC, SINP, and IUAC.
- These outcomes provide a well-rounded understanding of nuclear astrophysics and the related experimental techniques and facilities.

Paper: PHYS405ME **[Marks 50]** **[Credit 4]**

E. Quantum Information Processing –III

1. Quantum teleportation and super dense coding:
Different types of teleportation schemes, Perfect and probabilistic teleportation, quantum information splitting, Hierarchical quantum information splitting Modified teleportation schemes, Remote state preparation, Modified remote state preparation schemes, Superdense coding. [8 Lectures]

2. Quantum cryptography:
History of cryptography, Jargon related to cryptography, some interesting classical ciphers,
RSA and its limitations, Different aspects of quantum cryptography, Development of QKD protocols, BB84 protocol, Elementary idea of decoy state, B92 protocol, GV protocol: QKD with orthogonal state, Ping-pong protocols, CL protocol, LM05 protocol, PPGV protocol, DLL and modified DLL(DLLGV), DSQC protocol and its modifications , The DSQC protocol with arbitrary, A QSDC protocol from Protocol, Protocols of quantum dialogue, Ba An protocol, Generalized protocol of quantum dialogue, Applications of quantum dialogue protocols in the socialist millionaire problem, Various attacks in the protocols, efficiency. [18 Lectures]

3. Quantum Noisy Channel
The Depolarization Channel, The Bit Flip and Phase Flip Channels, Amplitude Damping, phase damping, Distance measures for classical information, Trace distance, Fidelity, Relationships between distance measures, preservation of information in quantum channel. [10 Lectures]

4. Experiments/Simulations: [14 Lectures]

Basic Quantum Computing with Qiskit (python 3)
Hands on coding in IBM Q lab (qiskit)

(i) Perform different gate operation (taught in the course) by using qiskit and locate on bloch sphere and for phase information use Q-sphere.
(ii) Establish Bell state, GHZ state and W state in IBM Q lab (Qiskit) or Jupyter notebook (a) Draw the circuit and then measure it. (b) Plot probability Histogram and explain the circuit is entangled or not. (c) Run above circuits on real quantum computer and show the noise in quantum computer by using histogram plot (probability).
(iii) For a given Quantum circuit, write the code and draw the circuit by using qiskit.
(iv) Contract Teleportation circuit (a) Draw it (b) Measure and simulate it, execute for given number of shots (like 2000) (c) plot histogram

(v) Bernstien – Vazirani Algorithm implement by using qiskit, and show that classical computer need more tries but quantum computer do that by one try.

(vi) Establish the Grover Search algorithm on qiskit.

(vii) Vii) Implement Shor’s Algorithm (you can use in build qiskit modules), Deutsch-Jozsa Algorithm, Simon’s Algorithm, Superdense coding, Quantum Key Distribution, Quantum Fourier Transform and Quantum Phase Estimation, Quantum Counting.

Recommended Books:

1. Quantum Computation and Quantum Information, Michael A. Nielsen, Isaac L. Chuang
2. Quantum Computing Explained, David McMahon. WILEY-INTERSCIENCE. A John Wiley & Sons,
3. Vector Spaces and Matrices in Physics; M. C. Jain, CRC Press, 2001
4. Elements of Quantum Computation and Quantum Communication, Anirban Pathak.
5. Computational Physics , Problem solving with python, Rubin H. Landau, Manuel J. Paez, Cristian C. Bordeianu
6. Quantum Information theory. M. Wilde, Cambridge University Press, 2013.
7. An Introduction to Quantum Computing. P. Kaye, R. Laflamme and M. Mosca. Oxford University Press, New York, 2007.
8. Quantum Optics-An introduction; Mark Fox.

LEARNING OUTCOMES

On completion of the course, the students will:

- Understand different quantum teleportation schemes, including perfect and probabilistic teleportation, quantum information splitting, and superdense coding.
- Explore the history and jargon related to cryptography, classical ciphers, and the limitations of RSA.
- Learn about various aspects of quantum cryptography, including the development of quantum key distribution (QKD) protocols like BB84, B92, and GV, as well as protocols for quantum dialogue, socialist millionaire problems, and potential attacks on these protocols.
- Gain knowledge of quantum noisy channels, including depolarization, bit flip, phase flip, amplitude damping, and phase damping channels, along with distance measures for classical and quantum information.
- Engage in experiments and simulations, including hands-on coding with IBM Qiskit to perform gate operations, establish entangled states, and implement various quantum algorithms like Grover's search and Shor's algorithm.
- These skills prepare students for advanced concepts in quantum information and computing, enabling them to work with quantum systems and cryptography protocols.

Paper: PHYS406PR **[Marks 50]** **[Credit 4]**

Advanced General Practical

List of Experiments

Group A:

1. Determination of temporal coherency of a laser light source and compare it with an incoherent source
2. Determination of spatial coherency of a laser light source and compare it with an incoherent source
3. Study of magneto-optic effect (Faraday effect)
4. Study of electro-optic effect (Pockels effect)
5. Study of Zeeman effect
6. Design of active band-pass filters and to verify the Barkhausen criteria
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Design of astable multivibrator using 555 Timer
9. Determination of particle size of an unknown specimen
10. Band-gap determination from thermal variation of resistivity

Group B:

1. Measurement of magnetic susceptibility using Quincks method
2. Study of ESR
3. Phase identification of an unknown sample from its X-ray diffraction pattern
4. Studies on Gunn oscillator in the microwave frequency region (Microwave workbench)
5. Studies on antenna theory
6. Studies on van der Pol oscillator: Sinusoidal and relaxation oscillations
7. Studies on laser diodes and its application in optical communication
8. Finding Speed of light in air using laser.
9. To study and characterize a quantum dot structure.
10. To verify Raman Effect.
11. Determination of efficiency of GM counter.

All the students will be divided into two groups i.e. Group A & Group B. Those students who have done Group A experiments in Semester-III will have to opt Group B experiments in Semester-IV and vice versa.

***DC** : Departmental Committee.

(END OF SEMESTER-IV)

Swapan Mandal. Balaram Dey

Kaushik Sarkar Sourangshu Mukhopadhyay 15.10.2023