2-Year M. Sc. in Physics

SEMESTER- I

MAJOR COURSE

Course Name: Computational Physics

Course Code: MSCPHSMC701

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Computational Physics	MAJOR	MSCPHSMC101	3-0-4	5	30	15	20	35	100

Course Objectives

In this course the students will be introduced to high level programming language like C. They will also be introduced to numerical methods like solution of polynomial and non-polynomial equations, numerical interpolation, numerical integration, ordinary differential equations. These are widely used in diverse areas of physics, materials science and allied fields. Introduction to finite element methods will help students to learn about various discretization methods and solution of partial differential equations on discrete space-time grid. The hands on numerical projects will introduce the students to code development.

Course Outcomes

Upon completion of this course the students will learn about

- High level programming language C.
- Real root finding for polynomial and non-polynomial/ transcendental equations.
- Numerical interpolation of a given data set and integrate functions of single variable.
- Simple solution of ordinary differential equations.
- Finite difference methods and its implication for physics problems like Heat/Schrodinger equation, Laplace equation and boundary value problems

Students will also learn about

- Algorithm to develop a computer program.
- Writing, debugging and executing a computer program and gain first hand knowledge in implementation of numerical scheme.

SYLLABUS

Elements of programming language: Algorithms and flow charts; Structures of a high-level language program. Features of C language, constants and variables; operators and expressions; conditional statements and loop statements; functions; arrays; pointers; structures, unions and enumeration.

[14 L]

Elements of computational techniques: Roots of functions and polynomial equations: Bi-section method and Newton-Raphson method; multiple roots.

[6 L]

Interpolation and extrapolation: Lagrange and Newton interpolation ; divided difference method; forward, backward and central difference.

[6 L]

Numerical integration : Trapezoidal and Simpson's rule ; Error estimation

[5 L]

Differential equation : Solution of first order ordinary differential equation by Runge-Kutta method

[6 L]

Finite difference method : Discretization of full and partial derivatives ; parabolic PDE (Heat equation) ; Crank-Nicholson method; elliptic PDE (Laplace equation) ; boundary condition ; hyperbolic PDE (Wave equation)

[8 L]

Laboratory

(Any *five* need to be performed)

To write and execute computer programs in C/C++/Python language for the following problems

1. Solution of equation using bi-section method.
2. Roots of a function using Newton-Raphson method.
3. Interpolation of a given set of data using forward/backward interpolation.
4. Estimate of definite integral using Trapezoial and Simposon's method.
5. Solution of first order ordinary differential equation by Runge-Kutta method.
6. Solution of Heat equation using Crank-Nicholson method.
7. Solution of boundary value problem of Laplace equation.

References

1. Byron S Gottfried*, Programming with C* (2018), McGraw Hill
2. E. Balagurusamy, *Programming in ANSI C* (2019), McGraw Hill
3. V. Rajaraman, *Computer Oriented Numerical Methods* (1993), PHI
4. E. Balagurusamy, *Numerical Methods* (2017), Tata McGRAW Hill
5. F. Acton, *Numerical Methods that Work* (1997), Harper and Row
6. S. D. Conte and C. D. Boor, *Elementary Numerical Analysis* (2005), McGraw Hill
7. S. S. Shastry, *Introductory Methods of Numerical Analysis* (2012), PHI

MAJOR COURSE

Course Name: *Advanced Condensed Matter Physics*

Course Code: MSCPHSMC702

Course Name	Cours Type	Course Code	L - T - P	Course Credit	CA Marks		ESE Marks		Total Marks
					Practical	Theory	Practical	Theory	
Advanced Condensed Matter Physics	MAJOR	MSCPHSMC102	3 - 0 - 4	5	30	15	20	35	100

Course Objectives

In this advanced course on condensed matter physics students will be introduced to structures and properties of solids. They will learn about various kinds of bonding in crystalline solids, lattice vibrations and lattice specific heat. Then they will be introduced to free electron theory of metals as well as band theory of solids arising due to motion of electrons through periodic potentials. They will also learn about advanced topics like superconductivity, Josephson junctions, liquid crystals and quasi-crystals.

Course Outcomes

Upon successful completion of the course students will have knowledge about:

- Bonding in solids
- Lattice vibrations, phonons and lattice specific heat
- Drude theory of metals, Fermi energy and electronic properties like conductivity and thermoelectric power
- Bloch's theorem, band theory of solids and classification of metals, insulators and semi-conductors
- Superconductivity – zero resistance, Meissner effects, thermodynamics and electrodynamics in superconductors and distinction between type-I and type-II superconductors, Josephson junction.
- Defects dislocations, translational vs orientational orders, liquid crystals and quasi-crystals.

SYLLABUS

Different types of Crystal binding-ionic, covalent, metallic and weak-bonding, cohesive energy.

[5 L]

Vibration of lattice, normal modes, spring-mass coupled system, mono and di-atomic chains, periodic lattices, phonons, force constant from experiments, quantization of elastic waves. Lattice specific heat.

[10 L]

Free electron theory of metals, Fermi-Dirac distribution, Free electrons, boundary conditions, Density of levels in 1, 2 & 3 dimensions, Fermi momentum and Fermi energy, Connection between electron density and Fermi energy. Specific heat of metals, thermoelectric power.

[10 L]

Band theory, periodic potential, Bloch's theorem, tight binding approximation, Brillouin zones (first and second) for square, cubic lattices, Energy bands in reduced zone scheme, energy bands and Fermi surfaces in a few metals as example. Metals, insulators and semiconductors.

[15 L]

Properties of Superconductor, Occurrence of Superconductivity, Superconducting Elements, Zero Resistance, Meissner Effect, AC Resistance, Entropy, Specific Heat. Type-I and Type-II Superconductors, London's Theory, Thermodynamics of Superconductor, BCS Theory, Cooper pair.

[10 L]

Josephson junctions; superfluidity. Defects and dislocations. Ordered phases of matter : traslational and orientational order, kinds of liquid crystalline order. Quasi crystals.

[10 L]

Books Recommended:

1. Ashcroft & Mermin, Solid State Physics;
2. C. Kittel, Introduction to Solid State Physics;
3. Marder, Condensed Matter Physics.
4. Quantum Transport : From atoms to Transistors, SupriyoDatta.
5. Elementary Solid State Physics, M. Ali Omar, Pearson

Laboratory:

1. To measure the **Dielectric Constant** of **PZT** sample.

2. To study the **Impedance Spectroscopy** of pure **ZnO** sample

3. To study the **I-V characteristics** curve of a given **ZnO** sample.

4. Determination of **Hall Co-efficient** of **Ge** sample and showing the variation of magnetic field with magnetic current. Variation of Hall voltage with probe current keeping magnetic field constant.

5. Experimentally determine open circuit voltages (V_{OC}) and short circuit currents (I_{SC}) of a **Solar Cell** under varying illuminance of a given light source. Plot V_{OC} versus illuminance and I_{SC} versus illuminance curves. Record current-voltage characteristics data under a constant illuminance value and plot current versus voltage curve. Determine fill factor of the solar cell from the curve.

6. Measurement of **Resistivity and Band gap of Semiconductor** by using **Four Probe Method**.

MAJOR COURSE

Course Name: Advanced Quantum Mechanics- I

Course Code: MSCPHSMC703

Course Name	Course Type	Course Code	L - T - P	Course Credit	CA Marks		ESE Marks		Total Marks
					Practical	Theory	Practical	Theory	
Advanced Quantum Mechanics-I	MAJOR	MSCPHSMC 103	4 - 1 - 0	5	00	30	00	70	100

Course Objectives: -

The course aims to develop a fundamental understanding of the principles and mathematical formalism of quantum mechanics, including wave functions, operators, angular momentum, and approximation methods. It also introduces students to the application of quantum mechanics in describing atomic systems and solving physically relevant problems.

Course Outcomes: -

After successful completion of this course, students will be able to:

- Explain the fundamental postulates of quantum mechanics and apply the operator formalism to analyze quantum states, observables, and measurements.
- Solve selected quantum mechanical problems involving one dimensional potentials, the harmonic oscillator, and the hydrogen atom, and interpret their physical significance.
- Analyze orbital and spin angular momentum, including their algebra, eigenstates, and coupling in atomic systems.
- Apply different formulations of quantum dynamics (Schrödinger, Heisenberg, and Interaction pictures) to describe the time evolution of quantum systems.
- Use perturbation theory, variational methods, and other approximation techniques to obtain approximate solutions for quantum systems where exact solutions are not feasible.

SYLLABUS

Unit I: Foundations of Quantum Mechanics and Exactly Solvable Systems State Function and Operator Formalism

Physical interpretation of the wave function and probability density. State vectors and wave functions; Dirac bra–ket notation (introductory use only). Operators corresponding to physical observables, eigenvalue equations, expectation values, and measurement postulates. Superposition principle and expansion of a state function. Commutation relations, compatible and incompatible observables, uncertainty relations. Change of representation and continuous basis (position representation).

[8 L]

One-Dimensional Quantum Systems (Selected Topics)

Quantum motion in one-dimensional potentials with emphasis on **Dirac delta function potentials**: bound states and scattering states, penetration and tunneling through delta potentials.

[8 L]

Linear Harmonic Oscillator

Linear harmonic oscillator solved **exclusively using the operator (ladder operator) method**. Creation and annihilation operators, energy spectrum and eigenstates. Expectation values.
Coherent states and their properties.

[6 L]

Central Potential and Hydrogen Atom

Motion of a particle in a spherically symmetric potential. Hydrogen atom: qualitative solution and physical interpretation of eigenfunctions. Emphasis on the structure and meaning of $\psi_{nlm}(r, \theta, \phi)$ and discrete energy levels E_n. No detailed derivations; discussion limited to providing conceptual groundwork for angular momentum and spin.

[8 L]

Unit II: Angular Momentum and Spin

Orbital Angular Momentum

Angular momentum operators and their commutation relations. Eigenvalues and eigenfunctions of L^2 and L_z. Spherical harmonics and their physical significance. Degeneracy of energy levels and quantum numbers l and m.

[8 L]

Spin Angular Momentum

Intrinsic spin of particles. Spin operators and spin commutation relations. Spin-½ systems, Pauli spin matrices, spin eigenstates, and measurement of spin components. Addition of angular momentum (qualitative introduction).

[5 L]

Total Angular Momentum and Applications

Coupling of orbital and spin angular momentum. Physical relevance in atomic systems. **[3 L]**

Unit III: Equation of Motion:

Heisenberg, Schroedinger and Interaction pictures. **[2 L]**

Unit IV: Approximation methods:

Time-independent perturbation theory for non-degenerate and degenerate states.

Applications: Anharmonic oscillator, Helium atom, Stark effect in hydrogen atom, Variational methods. Time-dependent perturbation theory; Harmonic perturbation; Fermi's golden rule.

Sudden approximation. Examples and problems. **[12 L]**

References for *Advanced Quantum Mechanics- I*:

1. 'Quantum Physics' by Robert Eisberg and Robert Resnick (John Wiley and sons)
2. 'Introduction to Quantum Mechanics', D, J. Griffiths.
3. 'Quantum Mechanics: Concepts and Applications', N. Zettili.
4. 'Quantum Mechanics', B. H. Bransden and C. J. Joachain
5. 'Quantum Mechanics' by L. I. Schiff (McGraw-Hill Book, New York).
6. 'Quantum Mechanics' by C. Cohen-Tannoudji.
7. 'Principles of Quantum Mechanics' by R. Shankar

MAJOR COURSE

Course Name : Mathematical Physics

Course Code: MSCPHSMC704

Course Name	Course Type	Course Code	L - T - P	Course Credit	CA Marks		ESE Marks		Total Marks
					Practical	Theory	Practical	Theory	
Mathematical Physics	MAJOR	MSCPHSMC104	4 - 1 - 0	5	00	30	00	70	100

Objective:

Students in all branches of physics need to be familiar with several mathematical techniques to understand content of their studies. The main motivation of this course is to develop a mathematical basis such that it can strengthen the ability of students to understand the mathematical treatment of physical problems which are encountered in the entire course.

Course outcome:

Students are expected to be well acquainted with technique to solve different problems related to complex analysis, differential equations, integral transform, linear algebra. Students would be capable to apply their knowledge to read/understand other branches of physics, especially in Quantum Mechanics, Electrodynamics, Solid State Physics, Quantum Optics. The understanding of Group Theory will be useful in studying various symmetry properties in high energy physics, quantum mechanics as well as condensed matter physics.

SYLLABUS:

Functions of a complex variable: Analytic functions, Cauchy-Riemann equations, integration in the Complex plane, Cauchy's theorem, Cauchy's integral formula. Liouville's theorem. Morera's theorem. Proof of Taylor and Laurent expansions. Singular Points and their classification. Branch Point and branch Cut. Riemann sheets. Residue theorem. Application of residue theorem to the evaluation of definite integrals and the summation of infinite series.

(10 L)

Linear vector spaces: Vector spaces, subspaces, bases and dimension, Linear independence and orthogonality of vectors, Gram-Schmidt orthogonalisation procedure. Linear operators. Matrix representation. The algebra of matrices. Special matrices. Rank of a matrix. Elementary transformations. Elementary matrices. Equivalent matrices. Solution of linear equations. Linear transformations. Change of Basis. Eigenvalues and eigenvectors of matrices. The Cayley-Hamilton theorem. Diagonalisation of matrices.

(10 L)

Integral transforms: Fourier and inverse Fourier transforms. Convolution theorem. Parseval Relation, Solution of ordinary and partial differential equations by Fourier transform. Laplace and inverse Laplace transforms, Convolution theorem. Solution of ordinary and partial differential equations.

(10 L)

Green's functions: Green's function and its properties. Solution of inhomogeneous differential equations using Green's function. Laplace wave equation and heat equation in two (2) & three (3) Dimension.

(10 L)

Fundamentals of Tensor: Metric or Fundamental Tensor, Covariant, Contravariant, and Mixed;

Covariant and Contravariant Components of a Vector; Relation Between gij, g^{st}, and $\delta^{s}w$, Inner Product, Coordinate Transformation of the Fundamental Tensor.

Tensor calculus; Base Vector Differentials in the General Case, Tensor Differentiation, Product Rule for Covariant Derivatives, Gradient, Divergence, and Curl of a Vector Field.

(10 L)

Group theory: Definition. Group postulates. Finite and infinite groups, order of a group, subgroup; rearrangement theorem, multiplication table. Cosets, Lagrange's theorem, Invariant subgroups, Isomorphism and homomorphism. Cyclic and other distinct groups. Permutation and alternating groups. Cayley's theorem. Finite group, continuous group: SO (3) and SU (2). Group Representations, Faithful and unfaithful representations. Invariant subspaces and reducible representations. Reducible and irreducible representations.

(10 L)

Books Recommended:

1. M. R. Spiegel (Schaum's outline series), Theory and Problems of Complex Variables, McGraw-Hill Publishing Co. (June 1974)
2. G. Arfken, Mathematical Methods for Physicists, Academic Press (2012)
3. P. Dennery and A. Krzywicki, Mathematics for Physicists, Dover Publications (2012)
4. Mary L. Boas; *Mathematical* Methods in the Physical Sciences, Wiley (2006)
5. W. Joshi, Matrices and Tensors, NEW AGE (1995)
6. M. Hammermesh, Group Theory and Its Application to Physical Problems, Dover Publications (1989)
7. M. Tinkham, Group Theory and Quantum Mechanics, Dover Publications Inc. (2003)
8. A. W. Joshi, Group Theory, New Age International (1997)
9. F. A. Cotton, Chemical Application to Group Theory, Wiley (2008)
10. N. Deo, Graph Theory, Courier Dover Publications (2017)
11. Carl M. *Bender*, Steven A. Orszag, Advanced mathematical methods for scientists and engineers, Springer (2010)

12. Meinhard T. Schobeiri, Tensor Analysis for Engineers and Physicists: With Application to Continuum Mechanics, Turbulence, and Einstein's Special and General Theory of Relativity, *Springer Nature* (2022)
13. Spiegel, Murray R.: Schaum's Outline of Theory and Problems of Vector Analysis and an Introduction to Tensor Analysis. McGraw-Hill, New York, NY, 1959.

Minor Elective Paper

Course Name: HISTORY AND PHILOSOPHY OF SCIENCE
Code: MSCPHSMN701

Course Type: MIE	Course Details: MIEC-1			L-T-P: 4-1-0	
Credit: 5	Full Marks:	CA Marks		ESE Marks	
		Practical	Theory	Practical	Theory
			15		35

Course Objectives

The course aims to enable students to:

- Understand the historical evolution of scientific thought from prehistoric times to the modern era.
- Understand the philosophical foundations of science and the scientific method.
- Analyze the relationship among science, technology, society, and culture.
- Develop a scientific temperament and ethical perspective in research.

Science and scientific method: What is Science? Origin of scientific thinking. Science in the Stone Age: discovery of fire, wheel, agriculture, metallurgy and early astronomy. Types of science and scientific method (including observation and measurement); Scientific explanations Scientific law, revolution in science:

Ancient Indian Knowledge System and Classical Science:

Scientific ideas in the Vedas, Upanishads and Vedangas. Sulba Sutras, concept of zero, decimal system, early algebra and geometry. Aryabhata, Brahmagupta and Bhaskaracharya. Charaka, Sushruta, Ayurveda and ancient metallurgy (Delhi Iron Pillar, zinc extraction, Wootz steel). Kanada's atomic theory, Nyaya logic and their philosophical significance.

Greek philosophy and natural science: Thales, Aristotle, Euclid and Archimedes. Emergence of science with periods between 600 BC upto Dark ages (500 AD to 1000 AD.) Endeavour of Modern Science from 1000 AD; Renaissance termed as Golden age of Science; era of Newton and others. Industrial revolution; remaining part of 19th. Century. Modern Science post 1900 A. D. to the recent past.

Definition of Philosophy of Science; theory of falsibility, Bayesianism. Origin of the Universe, Anaximane, Anaximander, Heraclitus, Aristotle, Plato, Pythagoras, Big Bang theory, Quantum Cosmological theory. Stages in the history of Physics, Chemistry, Biology.

Impact of Science and technology. Medicine, Transport, Pollution, Classification of natural resources, toxicity and its impact. Life and works of great scientists.

Project work: free to choose any topic on science / technology.

Recommended Books:

1. Rosenberg Alexander , Philosophy of Science, Routledge (2000)
2. Gower Barry , Scientific Method, Routledge(1997)
3. Losse John, A Historical Introduction to the Philosophy of Science, Oxford University Press (2001)

SEMESTER – II

MAJOR COURSE

Course Name: Advanced Nuclear and Particle Physics

Course Code: MSCPHSMC801

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Advanced Nuclear and Particle Physics	**MAJOR**	**MSCPHSMC201**	**4-1-0**	**5**	**0**	**30**	**0**	**70**	**100**

Course Objectives:

This course aims to develop a comprehensive understanding of nuclear forces, nuclear structure, and nuclear reactions through modern theoretical models and experimental evidence. It introduces the principles of weak interactions, beta decay, and the role of symmetries in nuclear and particle physics. The course also provides an overview of elementary particles, relativistic kinematics, and the Standard Model, enabling students to relate fundamental interactions to contemporary developments in high-energy physics.

Course Outcomes:

After successful completion of the course, students will be able to:

- Explain the properties of two-nucleon systems, nuclear forces, and low-energy nucleon scattering using appropriate theoretical frameworks.
- Analyze the structure of complex nuclei using shell and collective models, and interpret experimental evidence such as magic numbers and nuclear spectra.
- Evaluate nuclear reaction mechanisms, reaction energetics, resonance phenomena, and the characteristics of weak interactions and beta decay.
- Classify elementary particles using quantum numbers and symmetry principles, and apply conservation laws to particle interactions and decays.
- Apply concepts of relativistic kinematics, discrete symmetries, and the Standard Model to analyze fundamental particle processes and interactions.

SYLLABUS:

Two-Nucleon System and Nuclear Forces:

(a) Bound-state problem – nucleon-nucleon interaction, central, tensor and spin-orbit forces; charge independence and charge symmetry of nuclear forces; isospin formalism and SU (2) symmetry; exchange forces, saturation and repulsive core; relative stability of neutron-neutron, neutron-proton and proton-proton systems; properties of the deuteron, binding energy, spin-parity, magnetic dipole and electric quadrupole moments, S- and D-state admixture.

(b) Scattering problem – low-energy nucleon scattering; partial-wave analysis; scattering length and effective range; effective-range expansion; shape-independent approximation; Coulomb-modified nuclear scattering.

(14 L)

Structure of Complex Nuclei and Nuclear Models

Qualitative review of experimental evidence of shell structure and magic numbers; nuclear many-body problem and need for nuclear models; shell model—single-particle shell model, spin-orbit interaction, prediction of ground-state spin, parity and magnetic moments, successes and limitations of shell model; collective model—evidence of collective motion, vibrational and rotational spectra.

(12 L)

Nuclear Reactions

Q-value and reaction energetics; classification of nuclear reactions; compound nucleus and its decay; resonance reactions and Breit–Wigner formula; direct nuclear reactions.

(6 L)

Weak Interactions and Beta Decay

Review of alpha, beta and gamma decay processes; energetics and theory of allowed beta decay; Fermi and Gamow–Teller transitions; selection rules for beta decay; neutrino hypothesis and weak interaction; parity non-conservation in weak interactions; experimental verification of parity violation; introduction to double beta decay.

(10 L)

Elementary Particles, Symmetries and Relativistic Kinematics

(i) Elementary Particles and Symmetries Classification of fundamental interactions; elementary particles and their quantum numbers—charge, spin, parity, baryon number, lepton number, isospin, strangeness and hypercharge; hadrons, mesons and baryons; Gell-Mann–Nishijima relation; SU (3) flavour symmetry and Eightfold Way; quark model; conservation laws and symmetry principles.

(8 L)

(ii) Particle Dynamics Discrete symmetries: C, P and T transformations and invariance principles; parity non-conservation in weak interactions; applications of symmetry arguments to particle reactions; relativistic kinematics of particle reactions and decays; introductory quantum electrodynamics and Compton scattering (qualitative); elementary ideas of electroweak unification; overview of the Standard Model.

(10 L)

Books/References:

1. Nuclei and Particles: An Introduction to Nuclear and Subnuclear Physics by E. G. Segre
2. Nuclear Physics: Theory and Experiment by Roy and Nigam
3. The structure of Nuclear Physics by Preston and Bhaduri.
4. Nuclear Physics by S N Ghoshal
5. Theory of Nuclear Structure by M.K. Pal
6. Introduction to Elementary Particle Physics by D. Griffith
7. Introductory nuclear Physics by K.S. Krane
8. An Introduction to Nuclear Physics, W L Cottingham and D A Greenwood
9. Nuclear and Particle Physics: An Introduction, Brian R Martin
10. Introductory Nuclear Physics, Samuel S. M. Wong
11. Introduction To High Energy Physics, Donald H Perkins.
12. Modern Elementary Particle Physics, Gordon L Kane

MAJOR COURSE

Course Name: Electrodynamics

Course Code: MSCPHSMC802

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Electrodynamics	MAJOR	MSCPHSMC202	4-1-0	5	0	30	0	70	100

Course Objectives

In this course the students will be introduced to advanced concepts in Electrodynamics. They will learn about conservation laws in electrodynamics, gauge invariance and solution of equations for potentials using Green's function method. They will learn about covariant formulation of electrodynamics – Lorentz invariance of Maxwell's equations and transformation of fields in inertial frames of reference. One major topic will be fields due to moving charges and radiations from accelerated charges, dipoles and quadrapoles.
They will also learn about electromagnetic waves in confined geometry like waveguides and transmission lines. Finally, they will be introduced to elementary concepts of plasma physics and plasma oscillation.

Course Outcomes

Upon successful completion of the course the students will learn about
- Conservation laws in electrodynamics
- Solution of potential equations through Greens function method
- Covariant formulation of electrodynamics and transformation of fields in different inertial frames
- Radiation from accelerated charges, Bremsstrahlung and Cherenkov radiation.
- Radiation from dipoles and quadrapoles.
- Principles of waveguides and transmission lines.
- Elementary concepts in plasma physics and plasma oscillation.

SYLLABUS

Conservation laws: Conservation of energy and momentum ; Newton's third law in electrodynamics; Gauge transformations ; equations for potentials ; Lorentz gauge and Coulomb gauge ; explicit solution using Green's function method ; retarded and advanced Green's function

[9 L]

Relativistic electrodynamics : Lorentz invariance of the Maxwell's equation ; 4-vector potentials and electromagnetic tensor ; **E** and **B** fields in inertial frames of reference ; Lorentz invariant quantities in electrodynamics

[12 L]

Fields due to localized source : Localized but oscillating source ; near and far zone ; electric and magnetic dipole ; electric quadrapole.

[7 L]

Point charge in arbitrary motion : Lenard-Wiechert potential ; fields due to uniformly moving charge ; convection potential ; radiation from accelerated charge ; Larmor's formula and its relativistic generalization ; angular and frequency distribution of radiation ; Bremsstrahlung and Cherenkov radiation (introduction only)

[14 L]

Wave guides and transmission lines : TEM waves through transmission lines ; frequency cut off ; coaxial cables, microstrip lines. TE and TM waves through wave guides ; optical fibres.

[8 L]

Plasma physics : Equations for an ideal plasma ; Debye length and quasi-neutrality in plasma ; magnetic pressure and tension ; Alfven wave ; plasma oscillations ; long wavelength and short wavelength dispersion relations.

[10 L]

References

1. J. D. Jackson, *Classical Electrodynamics,* Wiley (2007)
2. L. D. Landau & D. M. Lifshitz (Vol. 2), *The Classical Theory of Fields,* Elsevier (2010).
3. W. Greiner, *Classical Electrodynamics,* Springer (1998)
4. D. J. Griffiths, *Introduction to Electrodynamics,* Cambridge University Press, (2020)
5. Melvin Schwartz, *Principles of Electrodynamics,* Dover (1987)
6. L. D. Landau & E. M. Lifshitz (Vol 8) , *Electrodynamics of Continuous Media,* Elsevier (2010)
7. Wolfgang K. H. Panofsky & Melbo Phillips, *Classical Electricity and Magnetism,* 2nd Edn (Dover)

MAJOR COURSE

Course Name: Advanced Statistical Mechanics

Course Code: MSCPHSMC803

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Advanced Statistical Mechanics	MAJOR	MSCPHSMC203	4-1-0	5	0	30	0	70	100

Course Objective: -

This course builds on the foundations of statistical mechanics by introducing canonical and grand canonical ensembles, methods for treating interacting and quantum systems, and the theoretical framework for phase transitions and critical phenomena. It equips students to analyze thermodynamic behaviour, fluctuations, and collective effects in a wide range of physical systems. It also gives light on the effects of interaction in statistical systems.

Course Outcomes:

Apply canonical and grand canonical ensembles to determine thermodynamic properties and fluctuations. Analyze interacting classical gases using virial expansion and mean-field approximations. Use density matrices to describe quantum ensembles and compute properties of simple quantum systems. Evaluate ideal Bose and Fermi gases and interpret phenomena like BEC, superfluidity, and Fermi degeneracy. Explain phase transitions and critical behaviour using order parameters, critical exponents, and simple models Cluster expansion technique can be useful to initiate research work on the theoretical advancement in the field of quantum Monte Carlo simulations.

SYLLABUS

Foundational concepts

Phase space distributions; time vs ensemble averages; ergodicity, Review of ensemble theory. Coarse-graining, irreversibility, Review of micro-canonical ensemble, Boltzmann and Gibb's entropy relation, Liouville's theorem, Limitations of microcanonical ensemble.

(5 L)

Canonical Ensemble and Grand Canonical Ensemble

Canonical ensemble: partition function, free energy, entropy, internal energy, heat capacities; energy fluctuations. Grand canonical ensemble: chemical potential and thermodynamic interpretation; grand partition function; grand potential and thermodynamic relations; fluctuations in particle number and internal energy. Thermodynamic limit and equivalence of ensembles; fluctuation–response relations. Applications: two-level system, classical harmonic oscillator, ideal classical gas.

(12 L)

Classical Real Gas

Corrections to Ideal Gas, Virial expansion for real gases, Cluster expansion (qualitative treatment), mean-field theories (van der Waals, Curie-Weiss).

(6 L)

Quantum Statistical Mechanics

Density Operator, Density Matrix formalism, von Neumann entropy, Density matrices for microcanonical, canonical and grand-canonical ensembles, Simple examples of density matrix - one electron in a magnetic field, particle in a box, quantum harmonic oscillator, Density matrix for beam of spin ½ particles, construction of density matrix for different spin states and calculation of the polarization vector.

(10 L)

Ideal Quantum Gas

Grand canonical treatment of ideal quantum gases, density of states, thermodynamic functions. statistics of occupation numbers; pressure of a quantum ideal gas. Ideal Bose gas: equation of state, Bose–Einstein condensation, critical temperature, condensate fraction, thermodynamic properties near BEC transition. Ideal Fermi gas: equation of state; Fermi integrals; pressure, internal energy, entropy, statistical properties. Low-temperature behaviour of degenerate Fermi systems, Specific heat of Bose and Fermi gases.

(12 L)

Phase transition and critical phenomena

Concept of phase transitions, classification of phase transitions, Order parameter and spontaneous symmetry breaking, with examples (ferromagnets, liquid–gas transition, Bose–Einstein condensate, superconductivity). Critical phenomena: critical exponents, scaling relations, universality; correlation functions and correlation length; Ginzburg criterion. Basic idea of spin-exchange between 2 electrons (Heitler-London), Ferro and Antiferromagnetic exchange. Ising model – exact solution in one dimension, Calculation of critical exponents (alpha, beta, gamma and delta) using mean field theory (Weiss) and Landau theory.

(15 L)

***Books Recommended*:**

1. Statistical Mechanics - R.K. Pathria
2. Fundamentals of Statistical and Thermal Physics - F. Reif,
3. An introduction to thermal physics - D. Schroeder
4. Statistical Mechanics -K. Huang
5. Statistical Mechanics: An Elementary Outline – Avijit Lahiri
6. Statistical mechanics - B. K. Agarwal and M. Eisner

MAJOR COURSE

Course Name: Laboratory and Seminar

Course Code: MSCPHSMC804

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Advanced Statistical Mechanics	MAJOR	MSCPHSMC204	0-4-6	5	60		40		100

1. Determine the **Numerical Aperture** of the given optical fibre.
2. Determination of number of lines per unit length of **grating** and wavelength of unknown light using **grating**.
3. Determination of **Planck's constant**.
4. Determination of ultrasonic velocity in liquids using **ultrasonic interferometer**.
5. To study the I-V Characteristics and the Response Characteristics of **Light Dependent Resistor (LDR)**.
6. Study the **Beam-Profile** of a laser source experimentally. Plot the Intensity Characteristics curves across the laser spot along horizontal direction. Hence estimate the divergence angle of the source along that direction.
7. Determination of wavelength of light and the refractive index of glass plate using **Michelson Interferometer**.
8. Study the features of IC timer, type 555. Set up and operate the **Astable Multivibrator** considering at least 3 combinations of Resistors and Capacitors. Compare between experimental and observed value of frequency.
9. Study the features of IC 741. Set up and operate the **High Pass circuit**. Compare between experimental and observed value of cut off frequency. Draw frequency versus gain plot.
10. Study the features of IC 741. Set up and operate the **Low Pass circuit**. Compare between experimental and observed value of cut off frequency. Draw frequency versus gain plot.

Minor Elective Paper

Course Name: Energy and Environmental Science

Course Code: MSCPHSMN801

<table>
<tr><td>Course Type: MIE</td><td colspan="3">Course Details: MIEC-1</td><td colspan="2">L-T-P: 4-1-0</td></tr>
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Course objectives

This course introduces students to basic concepts in energy science. Students are first introduced to basic concepts like flow and conversion of energy, engines and heat pumps, power cycles and design of power plants. Students are then introduced to two most important sources of green energy - nuclear and solar. Students will also learn about other sources of green energy like wind, biomass, geothermal, ocean thermal and tidal waves. Finally they will learn about energy conservation, energy efficient architecture, climate change and the overall energy scenario of the world.

SYLLABUS

Unit I Energy and its use : Units and scales of energy use, Mechanical energy and transport, Heat transport: conversion between heat and mechanical energy. Electromagnetic energy: storage, conversion, transmission and radiation. Introduction to quantum, energy quantization, energy in chemical systems and processes. Flow of CO_2, entropy and temperature. Carnot and Stirling heat engines. Phase change, energy conversion, refrigeration and heat pumps. Internal combustion engines, steam and gas power cycles, physics of power plants.

Unit II Nuclear energy: Fundamental forces in the universe, quantum mechanics relevant for nuclear physics. Nuclear forces, energy scales and structure, nuclear binding energy systematics, reaction and decays. Nuclear fusion, nuclear fission and fission reactor physics. Nuclear fission reactor design, safety, operation and fuel cycles.

Unit III Solar Energy: Introduction to solar energy, fundamentals of solar radiation and its measurement aspects. Basic physics of semiconductors, carrier transport, generation and recombination in semiconductors. Semiconductor junctions : metal-semiconductor junctions and p-n junctions. Essential characteristics of solar photo-voltaic devices. First generation solar cells, second generation solar cells, third generation solar cells.

Unit IV Conventional & non-conventional energy source: Biological energy sources and fossil fuels. Fluid dynamics and power in the wind, available resources, types of fluid flow, viscosity and lift. Wind turbine dynamics and design, wind farms. Geothermal and ocean thermal energy conversion. Tidal wave and hydro power.

Unit V Systems and synthesis : Overview of world energy scenario. Nuclear fuel cycles, waste and proliferation. Climate change, energy storage, energy conservation. Engineering for energy conservation : concept of green building and Green architecture, LEED ratings. Identification of energy related enterprises that represent the breadth of the industry ; embodied energy analysis and use as a tool for measuring sustainability. Energy audit of facilities and optimization of energy conservation.

Course outcome

After successful completion of the course the students will learn about:

- Heat engines and heat pump, Carnot and Stirling cycles.
- Nuclear force and energy, nuclear fusion and fission and design of fission reactors.
- Solar energy, photo-voltaic solar cells and various generations of solar cells.
- Wind turbine, geothermal, ocean thermal energy and tidal wave based energy generation.
- Energy conservation, energy efficient architecture and overall global energy perspectives.

References

1. Energy and the Challenge of Sustainability, World Energy Assessment, UNDP, New York (2000).
2. Perspectives of Modern Physics, A. Beiser, McGraw-Hill International Editions (1968).
3. Introduction to Modern Physics, H. S. Mani and G. K. Mehta, East-West Press (1988).
4. Introduction to Electrodynamics, D. J. Griffiths, 4th edition, Prentice Hall (2016).
5. Introductory Nuclear Physics, R. K. Puri and V. K. Babbar, Narosa Publishing House (1996).
6. Physics of Solar Cells: From Basic Principles to Advanced Concepts, Peter Wurfel, John Wiley & Sons (2016).
7. Principles of Solar Engineering, D. Y. Goswami, F. Kreith and J. F. Kreider, Taylor and Francis, Philadelphia (2000).

SEMESTER – III

MAJOR RESEARCH COURSEWORK ELECTIVE

Course Name : Advanced Quantum Mechanics -II

Course Code: MSCPHSMCE901

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Advanced Quantum Mechanics -II	**MAJOR (Elective)**	**MSCPHSMCE301**	**4-1-0**	**5**	**0**	**30**	**0**	**70**	**100**

Course Objectives

In this course the students will be introduced to advanced concepts in Quantum Mechanics. They will learn about WKB approximation methods and its application to various bound states and tunneling problems. Then they will learn about identical particles – bosons and fermions and their corresponding wavefunctions. They will learn about quantum mechanical formulation of scattering theory, calculation of scattering amplitudes and cross sections under Born approximation and partial wave analysis. A major topic will be relativistic formulation of quantum mechanics, in which Klein-Gordon and Dirac equations will be introduced. They will learn about free particle solutions and non- relativistic limits, Feynman-Stükelberg interpretation of negative energy states. Finally, they will learn about semiclassical theory of radiation- stimulated vs spontaneous emission.

Course Outcomes

Upon successful completion of the course the students will learn about

- Application of WKB methods to bound states and tunneling problems. Its application to α-decay and field emission devices.
- Identical particles, Pauli's exclusion principle, wave functions for singlet and triplet states.
- Elementary theory of scattering, Born approximation, partial wave analysis to obtain scattering amplitudes and cross sections.
- A detailed formulation of relativistic quantum mechanics. Klein-Gordon and Dirac equations and their solutions for free particles. Non-relativistic limits of Klein-Gordon and Dirac equations. Feynman-Stükelberg interpretation of negative energy solutions. Helicity, chirality.
- Semiclassical theory of radiation, stimulated and spontaneous emission.

SYLLABUS

WKB approximation : WKB method ; Connection formulae ; quantization rule ; tunneling through a barrier ; α-decay and field emission devices.

[8 L]

Identical Particles : Distinguishable vs indistinguishable ; Symmetric and anti-symmetric wave function ; Pauli's exclusion principle ; spin statistics connection ; Permutation symmetry ; spin singlet and triplet state.

[10 L]

Elementary theory of scattering : Lippman- Schwinger equation ; scattering amplitude and cross section ; Optical theorem ; Born approximation ; phase shift and partial wave analysis ; S-matrix ; Scattering length ; zero energy scattering and bound state. **[14 L]**

Relativistic quantum mechanics : Klein-Gordon equation – negative probability ; free particle solution ; non-relativistic limit ; Klein-Gordon equation in electromagnetic field. Dirac equation : covariant form ; free particle solution ; Dirac matrices – physical interpretation ; spin operator ; Dirac equation in external electromagnetic field ; non relativistic limit – Zeeman coupling ; spin-orbit coupling ; negative energy states and Feynman-Stükelberg interpretation ; helicity, chirality and charge conjugation ; Majorana and Weyl representation.

[16 L]

Semiclassical theory of radiation : Charged particle in external field ; field as perturbation ; radiation field ; transition between atomic states ; absorption vs stimulated emission ; dipole transition ; Einestein's A, B coefficients ; spontaneous emission.

[12 L]

References

1. J. J. Sakurai, *Modern Quantum Mechanics,* Cambridge University Press (2020)
2. Eugene Merzbacher, *Quantum Mechanics,* Wiley, 3rd Edition
3. H. A. Bethe and R. Jackiw, *Intermediate Quantum Mechanics*, Sarat Book House (2005)
4. J. J. Sakurai, *Advanced Quantum Mechanics,* Pearson (2002)
5. J. D. Bjorken and S. Drell, *Relativistic Quantum Mechanics,* McGraw Hill (1998)

MAJOR RESEARCH COURSEWORK ELECTIVE

Course Name :Advanced Atomic and Molecular Spectroscopy

Course Code: MSCPHSMCE902

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Advanced Atomic and Molecular Physics	MAJOR (Elective)	MSCPHSMCE302	4-1-0	5	0	30	0	70	100

Course Objectives

This course is designed for the fundamental studies on atomic and molecular spectrum. It includes rigorous discussion on interactions of atomic system with externally applied field.

Course Outcome:

- Basic concept of atomic and molecular spectrum is indispensible for advance studies in pure and applied physical science.
- This course can motivate students to pursue research careers especially in material sciences and associated fields.

SYLLABUS

One Electron Atom

Introduction: Quantum States; Atomic orbital; Parity of the wave function; Angular and radial distribution functions.

(6L)

Interaction of radiation with matter

Time dependent perturbation: Sinusoidal or constant perturbation; Application of the general equations; Sinusoidal perturbation which couples two discrete states — the resonance phenomenon. Interaction of an atom with electromagnetic wave: The interaction Hamiltonian — Selection rules; Non-resonant excitation — Comparison with the elastically bound electron model; Resonant excitation — Induced absorption and emission; Einstein A & B coefficients.

(14 L)

Fine and Hyperfine structure

Fine structure of spectral lines; Selection rules; Lamb shift. Effect of external magnetic field - Strong, moderate and weak field.

(12 L)

Rotation and Vibration of Molecules

Solution of nuclear equation; Molecular rotation: Non-rigid rotator, Centrifugal distortion, Symmetric top molecules, Molecular vibrations: Harmonic oscillator and the anharmonic oscillator approximation, Morse potential.

(8 L)

Molecular Electronic States

Concept of molecular potential, Separation of electronic and nuclear wave functions, Born-Oppenheimer approximation, Electronic states of diatomic molecules, Electronic angular momenta, Approximation methods for the calculation of electronic Wave function, The LCAO approach, States for hydrogen molecular ion, Coulomb, Exchange and Overlap integral, Symmetries of electronic wave functions

(12 L)

Spectra of Diatomic Molecules

Transition matrix elements, Vibration-rotation spectra: Pure vibrational transitions, Pure rotational transitions, Vibration-rotation transitions, Electronic transitions: Structure, Franck-Condon principle, Rotational structure of electronic transitions, Fortrat diagram, Dissociation energy of molecules.

(8 L)

Suggested Books:

1. B. H. Bransden and C. J. Joachain, Physics of Atoms and Molecules Pearson (2003)
2. S. Svanberg , Atomic and Molecular Spectroscopy, Springer-Verlag (2004)
3. Max Born, Atomic Physics, Dover Publications Inc.(1989)
4. H.E. White, Introduction to Atomic Spectra, McGraw-Hill Inc.,US (1934)

MAJOR RESEARCH COURSEWORK ELECTIVE

Course Name: Optoelectronics and Laser Science

Course Code: MSCPHSMCE903

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Optoelectronics and Laser Science	MAJOR (Elective)	MSCPHSMCE303	3-0-4	5	30	15	20	35	100

Course Objectives

Optoelectronics, which combines the properties of light with capabilities of micro-electronics, is an essential enabling technology for the information age. In fact, it is said that optoelectronics may be the most significant new technology since semiconductors. The main objective of the course is to formally introduce students to optoelectronics, thereby helping them to guide their studies and career development.

Course Outcome:

- Students will be familiar with different types of advanced light sources and their modulating mechanism widely used in present day information processing.
- Students will also learn about Nonlinear optics (NLO), which is the branch of optics that describes the behaviour of light in nonlinear media.
- This course can motivate students to pursue research careers especially in the field of applied optics and photonics.

SYLLABUS

1. Optoelectronics: ***Source***: Light Emitting Diode (LED), quantum efficiencies (internal and external), responsivities, Characteristics and applications of various kinds of LEDs, dome type LED , homojunction LED, heterojunction LED.

Photodetector : Basic principle of photo detection, Quantum efficiencies (internal and external), responsivities, Characteristics and applications of various kinds of photodetectors, P-I-N photodiode, Avalanche Photodiode.

Optical Fiber: Dispersion and attenuation mechanisms in optical fibers, Different types of coupling procedure of LED with optical fiber. **[12 L]**

2. Basic principles of Laser and Resonators:

Einstein's coefficient and their relations, conditions of population inversion. Absorption and amplifications of light in a medium, population inversion and threshold condition for a laser, gain coefficient, Laser Rate Equation, 2- level laser, 3-level and 4-level lasers.

Stability of resonators-'g' parameter, various types of resonators, design aspect of resonator for various types of lasers, unstable resonator and their application. Solid State Laser (Nd:YAG laser and Nd:Glass laser), Gas Laser (CO_2) , and Semiconductor laser. **[12 L]**

3. Q-switching and Mode Locking: Different Q-switching techniques: mechanical Q-switching, electrooptic Q-switching, acousto-optic Q-switching, dye Q-switching, Principle of generation of ultrafast pulses (mode locking), basic concepts for measurement of fast processes. [**6 L]**

4. Electro-optic effect: Pockel and Kerr effect, electro-optic phase retardation, electro-optic amplitude modulation, phase-modulation of light. [**5 L]**

5. **Nonlinear interactions of light and matter**

Nonlinear polarization of the medium, Wave equation for nonlinear optical media, Optical susceptibility tensor, Generation of second harmonic, Sum frequency and difference frequency generation, Basic idea of phase matching, quasi-phase matching method, various methods of phase matching (angle, temperature, birefringence etc. Optical rectification, Parametric amplifier and oscillation, Generation of third harmonic, Intensity dependent refractive index, Self-focusing. **[10 L]**

Recommended Books:

1. O. Svelto, Principles of Lasers, *Springer* (2010)
2. A Ghatak and K. Thyagarajan, *Optical Electronics, Cambridge University Press (2003)*
3. A Yariv, Quantum Electronics, Wiley (1989)
4. Y. R. Shen, The principles of Nonlinear Optics, Wiley, New York, (1984)
5. R. W. Boyd, Nonlinear Optics, Academic Press Inc. (2008)

Optoelectronics Laboratory

1. Perform experiment on **Faraday effect** using red/green laser light for a particular wavelength. Hence determine the **Verdet constant**.

2. Perform experiment on **Pockels effect** using red laser/green laser light for a particular wavelength. Hence determine the **Birefringence** as a function of applied voltage. Plot Birefringence versus applied voltage graph.

3. Perform the experiment on the given **Optocoupler**. Hence plot the following curves:

i. Coupling characteristics having LED voltage as independent variable.

ii. Current-voltage characteristics of LED.

iii. Current-voltage characteristics of phototransistor.

4. Perform the experiment on **Phototransistor** in presence of a laser source and hence plot current-voltage characteristics curve. Using a polarizer in between the source and phototransistor record phototransistor currents for different polarizer angles and plot current versus angle curve.

MAJOR RESEARCH COURSEWORK ELECTIVE

Course Name: Spintronics

Course Code: MSCPHSMCE904

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Spintronics	MAJOR (Elective)	MSCPHSMCE304	3-0-4	5	30	15	20	35	100

Course Objectives

Spintronics, a portmanteau meaning "spin transport electronics", where both charge and spin degrees of freedom of electrons are employed simultaneously to produce device with new functionality, is a fascinating and promising field of research. It has potential to revolutionize the field of electronics. Two physical basis of Spintronics, i.e., GMR and TMR have already been commercialized in read heads of hard disk drive. It is extremely important and absolutely necessary to have a clear concept of spintronics so that students get exposure of such modern day cutting edge technology. This course could also play crucial role in the development of understanding of the new research initiative like Opto-Spintronics.

Course outcome:

- Students will develop indepth knowledge in magnetism and spintronics.
- Students will understand spin dependent transport processes in spintronics devices.
- Students will get introduction to Spin transfer Torque and Magnetic Domain Wall motion Memory systems.
- This course will help students in cutting edge research technology like hard disk drive read head and Magnetic Random Access Memories.

SYLLABUS:

An Overview of Spintronics: Introduction to Spintronics, Comparative merit-demerit of Spintronics and Electronics, Evolution of Spintronics, Quantum Mechanics of Spin; Spin-Dependent Band Gap in Ferromagnetic Materials, Basic Principle of Working of all Spintronic devices, Different Branches of Spintronics.

(6 L)

Basic elements of Spintronics: Spin Polarization; Spin Injection; Spin Current, Spin Accumulation, Spin Relaxation; Elliott-Yafet Mechanism, D'yakonov-Perel' Mechanism**,** Spin-orbit interaction; Spin Filter Effect; Spin Valve.

(10 L)

Giant Magnetoresistance (GMR)

Definition of Magnetoresistance; Magnetoresistance of ferromagnetic Transition Metals; Introduction on Giant Magnetoresistance (GMR): Spin-dependent Scattering, Spin-flip Scattering, Physical Origin of GMR: Qualitative Explanation, Quantitative Explanation of GMR, Magnetoresistance Theory, Resistor Network Theory.

(10 L)

Tunneling Magnetoresistance (TMR)

Introduction on Tunneling Magnetoresistance: Magnetic Junctions; Magnetic properties of the electrodes; Theory of Tunneling Magnetoresistance; Measurement of spin relaxation length and time in the spacer layer.

(6 L)

Spin Transfer Torque (STT)

Introduction on Spin Transfer Torque: Landau–Lifshitz–Gilbert Equation, Spin Transfer Torque in Layer Structures; Spin-Transfer-Torque driven Magnetization Dynamics; Experimental Results; Possible applications of spin transfer torques.

(5 L)

Magnetic Domain Wall (DW) Motion

Introduction on Magnetic Domain Wall Motion: Magnetic Domain Wall Motion in Spintronics; Ratchet Effect in magnetic DW motion; Domain wall motion velocity measurements; Current-driven DW motion.

(5 L)

Spintronics Applications

Read Head in Magnetic Data Storage; Spin-tunnel junctions.

(3 L)

Books Recommended:

1. Stephen Blundell, *Magnetism in Condensed Matter,* Oxford Master Series in Condensed Matter Physics (2001)
2. B.D. Cullity and C.D. Graham, *Introduction to Magnetic Materials*, Wiley (2009)
3. D. Jiles, *Introduction to Magnetism and Magnetic Materials*, CRC Press, (1998)
4. S. Bandyopadhyay, M. Cahay, Introduction to Spintronics, CRC Press (2008)
5. D. J. Sellmyer, R. Skomski, Advanced Magnetic Nanostructures, Springer (2006)
6. D.D. Awschalom, R.A. Buhrman, J.M. Daughton, S.V. Molnar, and M.L. Roukes, Spin Electronics, Kluwer Academic Publishers (2004)
7. M. Johnson, Magnetoelectronics, Academic Press (2004)
8. S. Maekawa, Concepts in Spin Electronics, Oxford University Press (2006)
9. Y.B. Xu and S.M.Thompson, Spintronic Materials and Technology, Taylor & Francis, (2006)

<u>**Spintronics Laboratory**</u>

1. Perform experiment on **Magnetoresistance (MR)** versus Magnetic field (H) of $La_{0.7}Sr_{0.3}MnO_3$ nanoparticles in the magnetic field range of (As per example 0 to ± 1000 Oe). Plot MR versus H and Magnetoconductivity versus H graphs. Hence, calculate surface spin susceptibility of the sample.

2. Perform experiment on **Magnetoimpedance (MI)** versus Magnetic field (H) of $La_{0.7}Sr_{0.3}MnO_3$ nanoparticles in the magnetic field range of (As per example 0 to ± 2000 Oe). Plot MI versus H graph. Hence draw conclusion on the variation of MI (%) with magnetic field at a constant frequency.

3. To find the **Lande g factor** of an electron using **Electron Spin Resonance (ESR).**

MAJOR RESEARCH COURSEWORK ELECTIVE

Quantum Field Theory

Course Code: MSCPHSMCE905

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Quantum Field Theory	**MAJOR (Elective)**	**MSCPHSMCE305**	**4-1-0**	**5**	**0**	**30**	**0**	**70**	**100**

Course Objectives:

This course aims to provide a rigorous introduction to the formulation and applications of quantum field theory as the fundamental framework for describing relativistic particles and their interactions. Students will develop an understanding of field quantization, symmetry principles, gauge theories, and perturbative methods for calculating scattering processes. The course also introduces computational techniques using C++ for solving problems in relativistic kinematics, particle decays, and gamma matrix algebra.

Course Outcomes:

After successful completion of the course, students will be able to:

- Apply the principles of relativistic quantum mechanics, classical field theory, and Lagrangian formalism to derive field equations and conservation laws.
- Quantize free scalar, Dirac, and electromagnetic fields, and analyze their properties using creation and annihilation operators, propagators, and discrete symmetries.
- Evaluate particle interactions using the interaction picture, S-matrix formalism, Feynman diagrams, and perturbation theory for fundamental scattering and decay processes.
- Explain the role of gauge invariance in quantum electrodynamics and weak interactions, and analyze elementary electroweak processes using Feynman rules.
- Develop and implement C++ programs to perform numerical simulations of relativistic kinematics, particle decays, and gamma matrix calculations relevant to quantum field theory.

SYLLABUS:

Basic Concepts

Relativistic wave equations (Klein-Gordon and Dirac equations); Lorentz transformations and relativistic kinematics; Mandelstam variables; crossing symmetry; phase space; symmetries and conservation laws.

(12L)

Classical Field Theory and Lagrangian Formalism

Fields and field equations; action principle; Lagrangian and Hamiltonian densities; continuous symmetries and Noether's theorem; global and local gauge symmetries.

(12L)

Canonical Quantization of Free Fields

Need for field quantization; field quanta; real and complex scalar fields; Dirac field; electromagnetic field; creation and annihilation operators; propagators; bilinear covariants; projection operators; charge conjugation, parity and time reversal; normal ordering; time-ordered products; Wick's theorem.

(16L)

Interacting Quantum Fields

Interaction picture; S-matrix expansion; Dyson series; Feynman diagrams and Feynman rules; tree-level scattering amplitudes; electron-muon scattering, Møller scattering, Bhabha scattering, Compton scattering, pair annihilation and pair production.

(10L)

Gauge Theories and Applications

Quantum electrodynamics (QED); gauge invariance; Ward identities (elementary level); charged and neutral current weak interactions; Feynman diagrams for weak processes (β-decay, muon decay, neutrino-electron scattering); electron-positron annihilation.

(10L)

Numerical computation using C++:

1) Relativistic Kinematics of Particle Collisions
2) Monte Carlo Simulation of Particle Decays
3) Gamma Matrices Algebra.

Books/References:

1. Introduction to elementary particles by D. Griffiths
2. Quarks and Leptons by F. Halzen and A.D. Martin
3. Introduction to Particle Physics by M.P. Khanna
4. Gauge Theory of Elementary Particle Physics by Ta-Pei Cheng and Ling-Fong-Li
5. Lectures on QFT by Ashok Das
6. Quantum Field Theory by Franz Mandl and Graham Shaw
7. A first book of Quantum Field Theory by Amitabh Pal and Palash N. Pal

MAJOR RESEARCH COURSEWORK ELECTIVE

Course Name: Microwave and Quantum Devices

Code: MSCPHSMCE906

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Microwave and Quantum Devices	MAJOR (Elective)	MSCPHSMCE306	3-0-4	5	30	15	20	35	100

Objective:

To give details working of different microwave sources and waveguides. Both tube and solid state devices are made familiar in this course. To teach students about measurement techniques of microwave power, frequency, and impedance. Introduction to few quantum devices are also included.

Course outcome:

After taking this course, students will be familiar with different techniques of microwave sources and waveguides. They also get knowledge about measuring power, frequency, and impedance in microwave region. They will learn about the working of quantum devices also.

SYLLABUS

Microwave frequencies, characteristic features of microwaves, Applications of Microwaves.
Waveguides: Rectangular waveguide and circular waveguides; Maxwell's equations, TE and TM modes; Resonators: Rectangular waveguide and circular waveguide resonators.

(8 L)

Limitations of conventional tubes for microwave generation; Reentrant cavities, Two cavity Klystron, velocity modulation, bunching process, Efficiency of Klystron; Reflex Klystron, Velocity modulation, condition of maximum energy transfer; Slow wave structure, Helix Travelling wave tube, Amplification process, convection current in the electron beam; Magnetron, Cylindrical Magnetron, Hull cut off magnetic field, Hull cut off voltage, Cyclotron angular frequency, π mode of oscillation, equivalent circuit, power output and efficiency. **(13 L)**

Solid state microwave devices; Gunn Diode: Differential negative resistance, RWH theory, Domain formation, Different modes of operation, LSA diodes; Physical description and principle of operations of Read diodes, IMPATT diodes, TRAPATT diodes; Microwave Tunnel diodes: Principle of operation and microwave characteristics; Heterojunction Bipolar Transistor: Physical structure and operation; High Electron Mobility Transistor (HEMT): Physical Structure and operation.

(12 L)

Microwave Measurements: Detection of microwaves; Diode detectors, Travelling wave detector;

Measurement of VSWR, Impedance, Frequency measurement (electronic technique); Microwave power measurements: Bolometer, Bridge type meters.

(7 L)

Quantum effect devices: Resonant tunnelling Diode: Band diagram, working principle, I-V characteristics; Unipolar Resonant tunnelling transistor: working principle. Simple applications.

(5 L)

Reference Books:

1. Microwave devices and Circuits, Samuel Y. Liao
2. Microwaves, K C Gupta
3. Microwaves, Sisodia and Gupta
4. Microwave devices and applications, Dinesh C Dube
5. Semiconductor Devices, S. M. Sze

MAJOR RESEARCH COURSEWORK ELECTIVE

Course Name: Communication Electronics

Code: MSCPHSMCE907

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Communication Electronics	**MAJOR (Elective)**	**MSCPHSMCE307**	**3-0-4**	**5**	**30**	**15**	**20**	**35**	**100**

Objective:

- To teach students about communication systems, different techniques of modulation and demodulation both digital and analog.
- To give an introduction about information theory.
- To make familiar with working of Radar,
- To give an introduction about satellite and mobile communication and working of TV and TV broadcasting system.

Course Outcome:

After taking the course the students will be familiar with different types of communication systems used in electronics. They will also be familiar with information theory and coding techniques. They will get knowledge about principle of Radar, satellite and mobile communication system. The students will also acquire knowledge about Television.

SYLLABUS

1. **Introduction to communication systems:** Elements of a communication system, Concept of Bandwidth, Sources of information(Speech, Music, Picture, Computer data etc), signal and its classifications(One, two, three and four dimensional signals, Analog and digital signals), Communication channel(elementary idea), guided and free space, Coaxial Cable and Optical fibers, Comparison(advantage and disadvantages), Characteristics of optical fibers, Satelite channel. Fundamental limitations of communication systems(Noise, Bandwidth, Equipment) **(5 lectures)**.

2. Modulation and Demodulation Techniques: Multiplexing, TDM, and FDM, Comparison of AM, FM and PM signals in terms of modulation demodulation complexity, power, bandwidth, VSB modulation and its importance.

   Sampling Theorem, Nyquist rate and Nyquist interval, Effect of under sampling(Aliasing), Ideal, naturaland flat top sampling, Aperture effect.

   Pulse code modulation: Quantization, Pulse code modulation(PCM), PCM transmitter and Reciever, Quantizer (uniform, non-uniform) Transmission bandwidth in PCM system, Quantization noise/error in PCM, signal to quantization noise ratio. (**10 Lectures**).
3. Digital Modulation Techniques: ASK, FSK, PSK, DEPSK, QPSK, QASK, MSK, Principle, modulators and demodulators. (**5 lectures**)
4. Noise in Communication System: Types of noise, Sources of Noise, Noise Figure, Performance of AM, FM receivers in the face of noise;(**4 lectures**)
5. Elements of Information Theory: Concept of amount of Information, average information, Entropy, information rate, Effect of coding and coding efficiency; Shanon Fano Algorithm; Shanon's theorem; Channel capacity, Continuous channel, Capacity of a Gaussian channel, Shannon Hartley Theorem, BW-S/N tradeoff, orthogonal signals and Shannon limit.(**5 lectures**)
6. TV Systems: Color TV standards – NTSC, PAL, SECAM; Transmission format of intensity and color signal; Transmitter and receiver systems of TV broadcasting. (**3 Lectures**)
7. RADAR System: Basic Radar system, Radar Range, pulsed radar system – modulators, duplexer indicators, CW radar; MTI radar, Doppler effect, MTI principle, FM radar(**4 lectures**)
8. Satellite Communication: Orbits, basic components of satellite communication system,Constructional features, Station keeping; Path loss calculation; Link calculation; Multipleaccess techniques; Transponders; Effects of nonlinearity of transponders. (**4 lectures)**
9. Advanced Communication Systems: Mobile Communication – Concepts of cell and frequency reuse description of cellular communication standards; Computer communication– Types of networks; Circuit message and packet switched networks; Medium access techniques – ALOHA, Slotted ALOHA, CSMA/CD; Basics of protocol. (**5lectures**)

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

COURSE NAME: RESEARCH METHODOLOGY WITH AI

COURSE CODE: MSCPHSRMAI901

Course Name	Course Type	Course Code	L-T-P	Course Credit	CA Marks		ESE Marks		Total
					Practical	Theory	Practical	Theory	
Research Methodology with AI	**Research Methodology**	MSCPHSRMAI901	**3-0-4**	**5**	**30**	**15**	**20**	**35**	**100**

Course Objective: *The objective is to impart into the students the theoretical idea and understanding on research and its methodology particularly of reviewing and surveying literature, writing research report with required format; testing of hypotheses and sampling for analysis and quantification research outputs, etc in maintaining research ethics.*

Course outcome:

After completion of the course the students will be able to

- *describe important ideas, concepts, and research styles, such as mixed, qualitative, and quantitative approaches*
- *create testable hypotheses or research questions, outline research challenges, and identify research gaps*
- *create a well-thought-out research plan that includes sampling strategies, data gathering procedures, and the right instruments for data processing*
- *use citing tools correctly, synthesize current research findings, and critically evaluate academic literature*
- *plan and carry out investigations involving human or animal subjects by applying ethical principles and comprehending the ethical issues in research*
- *evaluate data and interpret the findings in a meaningful way by using fundamental statistical or thematic analysis and approaches*
- *compose well-organized research papers or reports and explain their findings either orally or visually as well as to gain the capacity to evaluate research papers and procedures critically for validity, reliability, and limitations*
- *maintain research ethics although his/her research activities*

Course Content

Introduction to Research Methodology

Meaning of Research, Objectives of Research, Motivations in Research, Types of Research, Criteria of good Research, What is Research Problem? Basic and Applied research

5 L

Review of Literature and Literature survey

Meaning and Purpose of the Literature Review & Literature Survey, Identification of the related Literature.

5 L

The Research Report

General format of the Research report, style and formatting of writing, typing of the research report. 5 L

Testing of Hypotheses and Sampling design

Definition, Concepts Concerning Testing of Hypotheses, Formulation of hypotheses and related difficulties; Needs of sampling, Random sampling.

5 L

Quantification of research output

Impact Factor, *h*-index, *i10*-index and *i20*-index, *G*-index 5 L

Research ethics

Research Ethics: Ethical principles and responsible conduct of research (RCR); integrity, transparency, and accountability in scientific research. Scientific misconduct (fabrication, falsification, plagiarism), publication ethics, authorship, peer review, and data management. Ethical issues in human and animal research, informed consent, confidentiality, IEC/IRB approval, conflict of interest, and researcher responsibilities

8 L

Artificial Intelligence in Research Methodology

Evolution of AI in scientific research workflows. AI as a cognitive assistant in research. Human–AI collaboration in scholarly inquiry. AI-assisted academic search and semantic retrieval. AI tools for identifying research gaps and novelty. Citation network analysis using AI tools. AI support in exploratory data analysis and visualization. Machine learning concepts relevant to research methodology. AI-assisted pattern recognition and hypothesis refinement. Role of AI in qualitative data analysis including coding and theme extraction. Risks of hallucination and fabricated citations in generative AI. Limitations of AI in scientific argumentation. Distinction between editing support and authorship. Bias detection in datasets using AI tools. Ethical limits of AI-driven inference. Human validation of AI-generated analytical results.

12 L

Recommended books/ Journals:

- *C R Kothari, Research Methodology: Methods and Techniques, New Age International (P)Ltd. (2010), New Delhi Garg, B.L., Karadia, R., Agarwal, F. and Agarwal, U.K., 2002. An introduction toResearch Methodology, RBSA Publishers.*
- *Handbook of Communication and Social Interaction Skills by John O. Greene, Brant Raney Burleson.*
- *W.M.K.Trochim, 2005. Research Methods: the concise knowledge base, AtomicDog Publishing. 270p.*
- *Ranjit Kumar, Research Methodology: A Step-by-Step Guide for Beginners, SAGE Publications*
- *Inderpal Singh, Research Methodology and Statistical Methods, Kalyani Publishers, Ludhiana.*
- *G Kanji, 100 statistical tests, Sage Publications.*
- *R. A. Day (1992) How to write and publish a scientific paper. Cambridge University press. London.*
- Russell, S. and Norvig, P. *Artificial Intelligence : A Modern Approach*, 3rd Edition, Prentice Hall, 2010.
- Floridi, Luciano. *The Ethics of Artificial Intelligence: Principles, Challenges, and Opportunities*, Oxford University Press, 2023.