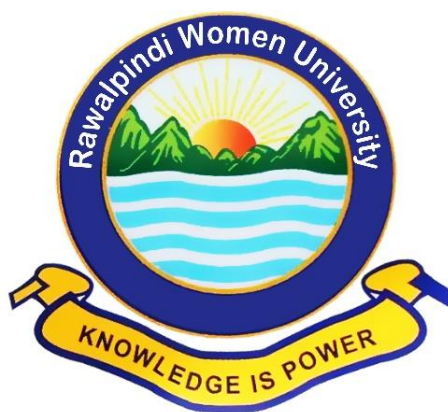


Curriculum Master of Philosophy in Physics

(2026)



**RAWALPINDI WOMEN UNIVERSITY,
RAWALPINDI**

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1. Introduction

Rawalpindi Women University (RWU) is a newly established institute with a vision of forward-thinking, enterprising, and research-oriented activities. Before December 2019, RWU was a well-reputed Govt. Post Graduate College for Women, which was established in 1950. The government of the Punjab established RWU with a twofold objective, such as higher education in Rawalpindi suburbs and character formation of the students in the light of Islamic teachings and grooming them as dignified, disciplined, progressive, and patriotic women of Pakistan. RWU is a public sector university that provides high-quality teaching and cutting-edge learning experiences that can exemplify our undergraduate and postgraduate students in the market. In addition, RWU focuses on working as a catalyst in Pakistan's economic and social transformation. For this purpose, a research-oriented mindset is being created to solve real-world problems and impact Pakistan's economy.

Department of Physics has existed since the foundation of RWU and provides an excellent and comprehensive education to women in physics. A combination of foreign-qualified and locally experienced faculty provides a strategic advantage and makes significant contributions to the academic activities of RWU. Quality teaching and a research-oriented approach motivates the department to offer an M. Phil. program. It can equip the students with the knowledge necessary to deal with the challenges of the contemporary physics, contribute to the research domain, and fulfill the growing demand for highly qualified individuals potentially working on the real-world problems in context of Pakistan. The curriculum emphasizes the development of research capabilities necessary for a graduate to deal with the modern challenges.

2. Program Outcomes

- Critically analyze and synthesize advanced concepts and current research in the field of Physics.
- Apply advanced theoretical, computational and experimental techniques to conduct independent research in Physics.
- Demonstrate the ability to effectively communicate scientific findings and theoretical concepts in Physics.

3. Entry/Admission Requirement

As per Rawalpindi Women University Admission Policy.

4. Duration of Program*

Summary

a) The duration of M.Phil. program as per the HEC criteria is as follows:

Minimum duration 04 semesters (2 years)

Maximum duration 06 semesters (3 years)

b) The M.Phil. program shall have a total of 50 Cr. Hrs. out of which 24 Credit Hours shall be for the course work and 12 Credit Hours for the Thesis.

No. of Semesters 04

Compulsory Courses 12 Credit hours

Mandatory Courses 02 Credit Hours

Elective Courses 12 Credit hours

Dissertation 26 Credit hours

Total Credit Hours 52 Credit hours

Semester	Cr. Hrs.	Details	Remarks
1	13	Two Compulsory and Two Elective Courses of 03 credit hours each, One Mandatory Course of 1 Credit Hour	Course work
2	13	Two Compulsory and Two Elective Courses of 03 credit hours each, One Mandatory Course of 1 Credit Hour	Course work
3 and 4	26	Dissertation	Research work

5. Semester-Wise Breakup of Courses

5.1.1. Semester 1

Code	Course Title	Type	Cr. Hrs.
PHY-7--	Core Course I	Compulsory	3
PHY-7--	Core Course II	Compulsory	3
PHY-7--	Elective I	Elective	3
PHY-7--	Elective II	Elective	3
UHQ--- / ETH----	Understanding of Holy Quran-I / Ethics-I	Mandatory	1
		Total	13

5.1.2. Semester 2

Code	Course Title	Type	Cr. Hrs.
PHY-7--	Core Course III	Compulsory	3
PHY-7--	Core Course IV	Compulsory	3
PHY-7--	Elective III	Elective	3
PHY-7--	Elective IV	Elective	3
UHQ--- / ETH----	Understanding of Holy Quran-II / Ethics-II	Mandatory	1
		Total	13

5.1.3. Semesters 3 and 4

Code	Course Title	Type	Cr. Hrs.
PHY-799	Research Thesis	Research Project	26
		Total	26
Number of Credit Hours During Coursework			26
Total Credit Hours in the Program			52

6. Title of Degree Program

The exact title of the M.Phil. program that will appear on relevant degrees is as follows:

- Master of Philosophy in Physics

7. Details of Full-time PhD Faculty

S#	Name of Faculty	Area of Specialization
1.	Dr. Irfan Qasim	Materials Physics (Computational and Experimental)
2.	Dr. Waqar Mahmood	Semiconductor Materials (Experimental)
3.	Dr. Muhammad Naveed-Ul-Haq	Condensed Matter Physics (Experiment and Computation)
4.	Dr. Bushra Parveen	Condensed Matter Physics (Experimental)
5.	Dr. Gul-e-Ali	Theoretical Plasma Physics

8. Curriculum

9. List of Core Courses

Core Courses		
Sr. #	Course Code	Course Title
1.	PHY-701	Advanced Mathematical Methods of Physics
2.	PHY-702	Advanced Electrodynamics
3.	PHY-703	Advanced Quantum Mechanics
4.	PHY-705	Techniques of Experimental and Computational Physics

10.Course Outlines of Core Courses

Advanced Mathematical Methods of Physics

M.Phil. Physics

Course Code: PHY-701

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire knowledge to demonstrate the utility and limitations of a variety of powerful calculation techniques and to provide a deeper understanding of the mathematics underpinning theoretical physics. The students will be able to review the theory of complex analysis and applications to special functions, asymptotic expansions, ordinary and partial differential equations characteristics, integral transform, Green function techniques and Sturm-Liouville theory.

Learning Outcomes

- Demonstrate proficiency in utilizing advanced mathematical methods and techniques to formulate and solve intricate problems in Physics.
- Assess the relevance, limitations, and applications of various mathematical tools in addressing contemporary challenges in theoretical and applied Physics.
- Integrate advanced mathematical concepts to model complex physical systems, analyze outcomes, and make informed predictions in the domain of mathematical Physics.

Course Outline

Unit 1. Fourier Series

Fourier series: introduction and general properties, Integral transform, development of the Fourier integral, Fourier transform, inversion theorems,

Unit 2. Fourier Transform

Fourier transform of derivatives, transfer functions, Complex arguments in Fourier transforms. Laplace transform, Laplace transform of derivatives, convolution products and Faltung's theorem, inverse Laplace transform.

Unit 3. Differential Equations

Partial differential equations. Separation of variables in three dimensions, method of characteristics (1st and 2nd order). Boundary value problems, Ordinary Differential Equations, Frobenius method, Sturm Liouville equation.

Unit 4. Special Functions

Legendre, associated Legendre, Bessel function, Orthogonality of Bessel's function, Hermite Polynomials, Green functions.

Unit 5. Complex Analysis

Functions of a complex variable, The Cauchy–Riemann relations, Singularities and zeros of complex functions, Complex integrals, Cauchy's theorem, Taylor and Laurent series, Residue theorem, Definite integrals using contour integration.

Recommended Books/Reference Material

1. Arfken, G. B., Weber, H. J., & Harris, F. E. (2020). *Mathematical Methods for Physicists: A Comprehensive Guide* (7th ed.). Academic Press.
2. Chow, T. L. (2002). *Mathematical Methods for Physicists*. Cambridge University Press.
3. Boas, M. L. (2005). *Mathematical Methods in the Physical Sciences* (3rd ed.). John Wiley and Sons.
4. Kreyszig, E. (2011). *Advanced Engineering Mathematics* (10th ed.). John Wiley and Sons.
5. Zill, D. G., & Cullen, M. R. (2008). *Differential Equations with Boundary Value Problems* (7th ed.). Cengage Learning.
6. Altland, A., & Delft, J. V. (2019). *Mathematics for Physicists*. Cambridge University Press.

Advanced Electrodynamics

M.Phil. Physics

Course Code: PHY-702

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding about the advanced concepts of potentials and fields under static and time-varying conditions.

Learning Outcomes

- Exhibit expertise in applying principles of electrodynamics to investigate and solve advanced and complex electromagnetic phenomena.
- Critically analyze practical implications of different electrodynamic concepts and applications used in contemporary research in Physics.
- Integrate advanced electrodynamic concepts to formulate solutions for boundary – value problems.

Course Outline

Unit 1. Systems of Coordinates Revision

Review of separation of variables; solution of Laplace equation in rectangular co-ordinates, Example of Laplace equation in rectangular co-ordinates, Laplace equation in plane polar co-ordinates, Example of Laplace equation in plane polar co-ordinates, Solution of Laplace equation in spherical co-ordinates.

Unit 2. Special Functions in Electrodynamics

Legendre Equation and Legendre polynomials, Boundary value problems with azimuthal symmetry, Laplace equation in cylindrical co-ordinates, Boundary value problems in cylindrical co-ordinates.

Unit 3. Maxwell Equations

Review of Maxwell's Equations, Gauge transformations, Green's function for Ordinary differential Equation, Green's function as a superposition of eigen functions, Review of complex integration, Cauchy's theorem, Cauchy's Integral formula, Residue theorem and its application, Solving Green's function for a wave equation.

Unit 4. Green Functions

Advanced and Retarded Green's function, Retarded solutions for the fields, Poynting's Theorem and conservation of energy and momentum, Poynting's Theorem in a media, Plane waves in a non-conducting media.

Unit 5. Electric Polarization

Linear and Circular polarization, Reflection and refraction of electromagnetic waves at a plane interface between dielectrics, Fields at the surface of and Within a conductor, Cylindrical cavities and Waveguides, Fields and radiation of a localized Oscillating source, Electric dipoles fields and radiation, Magnetic Dipole and electric quadrupole expansion for localized source.

Recommended Books/Reference Material

1. Griffiths, D. J. (2013). *Introduction to Electrodynamics* (4th ed.). Prentice Hall.
2. Jackson, J. D. (2000). *Classical Electrodynamics* (3rd ed.). John-Wiley.
3. Keohane, J. W., & Foy, J. P. (2019). *An Introduction to Classical Electrodynamics*. Maricourt Academic Press.

4. Marion, J. B., & Heald, M. A. (1994). *Classical Electromagnetic Radiation*. Thomson Brooks.
5. Wald, R. (2022). *Advanced Classical Electromagnetism*. Princeton University Press.

Advanced Quantum Mechanics

M.Phil. Physics

Course Code: PHY-703

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding of quantum mechanics that will provide a base for many applied fields in physics such as quantum information and computation, quantum optics, condensed matter theory and high energy physics.

Learning Outcomes

- Demonstrate mastery in applying principles and techniques of quantum mechanics to solve complex problems.
- Critically evaluate and interpret the implications of quantum mechanical methods in various modern Physics research contexts.
- Apply approximate methods of quantum mechanics to address advanced problems.

Course Outline

Unit 1. Fundamental Concepts and Dirac Formalism

State vectors and observables, Hilbert space, bra-ket notation, projection operators. Measurement postulates, quantum dynamics, time evolution via Schrödinger and Heisenberg pictures. Two-level quantum systems (e.g., spin- $\frac{1}{2}$) and matrix mechanics formulation, Position, Momentum, and Translation, Continuous Spectra, Position Eigenkets and Position Measurements, Translation, Momentum as a Generator of Translation

Unit 2. Quantum Dynamics and Symmetries

Time-Evolution Operator, The Schrodinger Equation, Energy Eigenkets, Time Dependence of Expectation Values, Spin Precession, Unitary Operators, State Kets and Observables in the Schrodinger and the Heisenberg Pictures, The Heisenberg Equation of Motion, Free Particles: Ehrenfest's Theorem, Base Kets and Transition Amplitudes, Simple Harmonic Oscillator, Energy Eigenkets and Energy Eigenvalues, second quantization in quantum mechanics, creation and annihilation operators, Time Development of the Oscillator, Coherent states, density matrices

Unit 3. Path Integral Formalism

Classical action and the principle of least action as a foundation for quantum mechanics; formulation of the propagator using the Feynman path integral; path summation and connection to transition amplitudes; evaluation of simple systems including the free particle and the quantum harmonic oscillator in the path integral representation; introduction to semiclassical approximations, Wick rotation, instantons

Unit 4. Identical Particles and Quantum Statistics

Symmetrization postulate and the role of exchange symmetry; bosons and fermions and their connection to spin-statistics theorem; Slater determinants and antisymmetric wavefunctions for fermionic systems; Thouless's theorem and fermionic excitations; introduction to anyons and fractional statistics in low-dimensional systems; brief outlook on supersymmetric quantum mechanics.

Unit 5. Adiabatic Processes and Geometric Phases

Adiabatic evolution of quantum systems; adiabatic theorem and level crossing; geometric phase and Berry phase in quantum mechanics; applications in atomic and

molecular systems, Aharonov-Bohm effect, introduction to the quantum Hall effect and topological aspects.

Unit 6. Quantum Information and Computation

Quantum measurement theory and entanglement; Einstein–Podolsky–Rosen (EPR) paradox and implications for locality; Bell’s theorem and experimental tests of quantum nonlocality; quantum logic gates and qubits; principles of quantum computation; overview of quantum algorithms and quantum error correction; connection to foundational questions in quantum theory.

Recommended Books/Reference Material

1. Dick, R. (2016). *Advanced Quantum Mechanics: Materials and Photons*. Springer Publications.
2. Marino, M. (2021). *Advanced Topics in Quantum Mechanics*. Cambridge University Press.
3. Mattuck, R. D. (1992). *A Guide To Feynman Diagrams In The Many-body Problem*. Dover.
4. McIntyre, D. H. (2012). *Quantum Mechanics: A Paradigms Approach*. Pearson.
5. Sakurai, J. J. Napolitano J. (2021). *Modern Quantum Mechanics*. Cambridge.
6. Shankar, R. (1994). *Principles of Quantum Mechanics* (2nd ed.). Springer.

Techniques of Experimental & Computational Physics

M.Phil. Physics

Course Code: PHY-705

Credit Hours: 03

Prerequisites: Nil

Objectives

This course aims to develop advanced skills in both experimental and computational methods used in modern physics research. Emphasis is placed on data acquisition, numerical modeling, simulation, and the integration of these tools to formulate and investigate complex physical problems. Students will critically assess the methodologies involved and gain hands-on experience in designing and analyzing research-level investigations.

Learning Outcomes

- Demonstrate advanced proficiency in utilizing experimental and computational techniques to investigate and analyze various physical systems.
- Critically evaluate the efficacy, limitations, and applications of various experimental and computational tools and methods in contemporary research in physics.
- Integrate experimental and computational approaches to design, execute, and interpret advanced experiments and simulations, leading to data-driven conclusions.

Course Outline

Unit 1. Advanced Experimental Techniques

Precision measurement and data acquisition; Lock-in amplifiers, signal-to-noise optimization, interfacing and automation (LabVIEW or Python-based). Error analysis, propagation of uncertainties, and statistical treatment of experimental data.

Unit 2. Instrumentation and Materials Characterization

Use of modern instruments in research: XRD, SEM, AFM, FTIR, UV-VIS, and SQUID magnetometry. Thin film deposition techniques, cryogenic systems, and vacuum technology.

Unit 3. Computational Tools and Programming

Scientific computing using Python/Matlab: arrays, plotting, curve fitting, root finding, ODE/PDE solvers. Introduction to symbolic computation (e.g., Mathematica or SymPy) and numerical linear algebra.

Unit 4. Simulation Techniques in Physics

Monte Carlo methods, random number generation, Markov Chains. Molecular dynamics and simple N-body simulations. Finite difference methods for heat/diffusion equations, boundary-value problems in electrostatics.

Unit 5. Integrated Experimental-Computational Projects

Examples of real-case problems combining measurement and simulation: Damped harmonic oscillator (real + simulated), Thermocouple calibration + numerical regression, I-V characteristics of semiconductors + transport modeling, Magnetic hysteresis + numerical data smoothing and modeling, Students work on mini-projects with combined experimental-computational focus.

Recommended Books/Reference Material

1. Bevington, P. R., & Robinson, D. K. (2003). *Data Reduction and Error Analysis for the Physical Sciences* (3rd ed.). McGraw-Hill.
2. Giordano, N. J., & Nakanishi, H. (2020). *Computational Physics* (2nd ed.). Pearson.
3. DeVries, P. L. (2011). *A First Course in Computational Physics*. Wiley.

4. Fernandez, F. M. (2021). *Introduction to Experimental Physics: From Basic Principles to Practical Applications*. Springer.
5. Haskell, R. E., & Hanna, D. M. (2009). *Introduction to Scientific Programming: Computational Problem Solving Using Maple and C*. CRC Press.
6. Landau, R. H., Páez, M. J., & Bordeianu, C. C. (2015). *A Survey of Computational Physics: Introductory Computational Science*. Princeton University Press.

11. List of Elective Courses

Sr. no.	Course Code	Title	Cr. Hrs
1.	PHY-704	Advanced Statistical Physics	03
2.	PHY-707	Magnetism and Applications	03
3.	PHY-708	Experimental Techniques in Physics	03
4.	PHY-709	Electronic Properties of Crystalline Solids	03
5.	PHY-710	Electrochemical Energy Systems	03
6.	PHY-711	Materials Science	03
7.	PHY-712	Physics of Semiconductor Devices	03
8.	PHY-714	Physics of Surfaces and Interfaces	03
9.	PHY-716	Optical Properties of Solids	03
10.	PHY-717	Advanced Computational Physics	03
11.	PHY-718	Special Topics in Condensed Matter Physics	03
12.	PHY-719	Advanced Plasma Physics	03
13.	PHY-720	Quantum Field Theory-I	03
14.	PHY-721	Non-Linear Plasma Physics	03
15.	PHY-722	Quantum Field Theory-II	03
16.	PHY-723	General Relativity and Cosmology	03
17.	PHY-724	Quantum Information and Computation	03
18.	PHY-725	Particle Physics	03
19.	PHY-726	Quantum Computation	03
20.	PHY-727	Solar Cell Physics	03
21.	PHY-728	Electronic Density Theory	03
22.	PHY-729	Physics of Superconductors	03
23.	PHY-730	Condensed Matter Theory	03
24.	PHY-731	Advanced Condensed Matter Physics	03
25.	PHY-732	Physics of Nanomaterials	03
26.	PHY-733	Spintronics	03
27.	PHY-734	Mathematical Techniques in Physics	03
28.	PHY-735	Experimental Methods	03
29.	PHY-736	Quantum Theory of Materials	03
30.	PHY-737	Cold Plasma Science	03
31.	PHY-738	Semiconductors and Applications	03
32.	PHY-739	Surface Physics	03
33.	PHY-740	Climate Physics	03
34.	PHY-741	Advances in Spectroscopy	03
35.	PHY-742	Magnetic Materials	03
36.	PHY-743	Thermoelectrics	03
37.	PHY-744	Photovoltaic Devices	03

38.	PHY-745	Density Functional Theory	03
39.	PHY-746	Advanced Topics in Superconductivity	03
40.	PHY-747	Optoelectronics	03
41.	PHY-748	Electronic Structure Theory of Solids	03
42.	PHY-749	Phase Transformations in Matter	03

12. Course Outlines of The Elective Courses

Advanced Statistical Physics

M.Phil. Physics

Course Code: PHY-704

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire an understanding about fundamentals of thermodynamics and statistical mechanics. The first part of this course develops fundamental ideas of thermodynamics and is aimed at developing students' ability to deal with various thermodynamic systems. The second part introduces principles of statistical mechanics to study both classical and quantum mechanical thermodynamic systems.

Learning Outcomes

- Students will be able to understand fundamental ideas of thermodynamics and statistical mechanics for various systems.
- They will also learn useful concepts of entropy, ensemble theory and quantum statistics of identical particles.

Course Outline

Unit 1. Review of Thermodynamics

Microscopic view of matter, viewing the world at different scales, thermodynamics, the thermodynamic limit, thermodynamics transformations, classic ideal gas, first law of thermodynamics, magnetic systems, heat, and entropy, the heat equations, application to ideal gas, Carnot cycle, second law of thermodynamics, absolute temperature, temperature as integrating factor, entropy, entropy of ideal gas, the limits of thermodynamics, using thermodynamics, the energy equation, some measurable coefficients, entropy and loss, TS diagram, condition for equilibrium, Helmholtz free energy, Gibbs potential, Maxwell relations, chemical potential.

Unit 2. Basic Statistical Concepts

The Statistical approach, the atomic view, random walk, phase space, distribution function, Ergodic hypothesis, statistical ensemble, correct Boltzmann counting, distribution entropy: Boltzmann's H, the most probable distribution, determining the parameters, pressure of ideal gas, equipartition of energy, distribution of speed, entropy, derivation of thermodynamics, fluctuations, the Boltzmann factor.

Unit 3. Ensembles

Canonical ensemble, review of microcanonical ensemble, classical canonical ensemble, the partition function, connection with thermodynamics, energy fluctuations, minimization of free energy, classical ideal gas, grand canonical ensemble, the particle reservoir, grand partition function, number fluctuations, connection with thermodynamics, parametric equation of state and virial expansion, critical fluctuations.

Unit 4. Quantum Statistics

Quantum statistics, thermal wavelength, identical particles, occupation numbers, spin, microcanonical ensemble, Fermi statistics, Bose statistics, determining the parameters, pressure, entropy, free energy, equation of state, classical limit, quantum ensemble, incoherent superposition of states, density matrix, canonical ensemble (quantum mechanical), grand canonical ensemble (quantum mechanical), occupation number fluctuations, photon benching, Fermi energy, ground state, fermi temperature.

Unit 5. Low Temperature Properties

Low-temperature properties, particles and holes, electrons in solids, semiconductors, the Bose gas, photons, Bose enhancement, phonons, Debye specific heat, electronics specific heat, conservation of particle number.

Recommen ded Books/Reference Material

1. Heisenberg, C., & Sagnotti, A. (2022). *Classical and Quantum Statistical Physics*. Cambridge University Press.
2. Huang, K. (2009). *Introduction to Statistical Physics*. Chapman and Hall CRC.
3. McCoy, B. M. (2015). *Advanced Statistical Mechanics*. Oxford University Press.
4. Reif, F. (2010). *Fundamentals of Statistical and Thermal Physics* (1st ed.). Levant Books.
5. Wang, J.-S. (2021). *Advanced Statistical Mechanics*. World Scientific Publishing.

Magnetism and Applications

M.Phil. Physics

Course Code: PHY-707

Credit Hours: 03

Pre-requisite: Nil

Objectives

Magnetism and applications is an important course for the students intending to do specialization in magnetism, nanoscience, and nanotechnology. The course covers the fundamental concept of magnetism. The course is aimed at preparing students for the state-of-the-art technologies based on magnetism viz. Spintronics.

Learning Outcomes

- The concept and origin of magnetism and various kinds of magnetic phenomenon such as paramagnetism, diamagnetism in materials.
- The magnetic domains and related effects.
- Ferromagnetic ordering and its applications.

Course Outline

Unit 1. Introductory magnetism

Review of diamagnetism and paramagnetism; Quantum mechanical treatment of magnetism; Brillouin Function, Curie Law and applications. Pauli paramagnetism, Wave functions of magnetic ions (3d, 4f); spin-orbit coupling; crystal field effects, Jahn-Teller theorem, Thermodynamics of magnetism, free energy and entropic considerations. Adiabatic demagnetization

Unit 2. Ferro and Antiferromagnetism

Basic Phenomenon, Mean Field Theory, Thermodynamics of ferromagnetic systems. Quantum mechanical treatment, Exchange interactions, Heisenberg and Ising model. Indirect exchange (super-exchange and RKKY). Spin excitations, spin waves, magnons, application to the temperature dependences of magnetization and specific heat. Band ferromagnetism. Criteria for band ferromagnetism; examples of metallic ferromagnets. Anti-Ferromagnetism: Basic phenomenon, Mean Field treatment. Type I, Type II Antiferromagnets, Parallel and perpendicular susceptibilities, Spin flop transition. Ferrites, Applications of ferrites.

Unit 3. Domain Structures and related properties of ferromagnets

Magnetic Anisotropy, basic phenomenology. Uniaxial, Cubic and surface Anisotropies; Effects in bulk materials and thin films. Domain Formation, Domain wall width. Relation to magnetic anisotropy. 90° , 180° domain walls. Observation of domains, Domain wall motion, pinning of domain walls; Magnetization in soft and hard magnets.

Unit 4. Finite size effects

Single Domain Particles and their Magnetic Properties: Anisotropies, Coercive fields and magnetization Stoner- Wohlfarth theory, Magnetization reversal mechanisms, Coherent modes of spin reversal, Multiferroics, Type I and Type II Multiferroics, Intrinsic and Extrinsic Multiferroics.

Unit 5. Superparamagnetism

Superparamagnetism and time decay of magnetization; Neel-Brown models; Exchange bias effects; Dynamic response and applications of single domain particles in magnetic recording. Reversal mechanisms in single domains. Thin films and surface effects.

Recommended Books/Reference Material

1. Introduction to Magnetic Materials by B. D. Cullity, Wiley, (2011)
2. Introduction to the theory of Ferromagnetism by Amikam Aharoni, Oxford Press (1998).
3. Magnetic Materials Fundamentals and Applications by N. A. Spaldin, H. Nakanishi, 2nd ed. Cambridge University Press (2011).
4. Magnetic Materials: Fundamentals, Products, Properties, Applications by R. Hilzinger and W. Rodewald, Wiley, (2013).
5. Magnetism in Condensed Matter by Stephen Blundell, Oxford Press (2001).
6. The Physical Principles of Magnetism by Allan H. Morrish, John Wiley (1965).

Experimental Techniques in Physics

M.Phil. Physics

Course Code: PHY-708

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course is designed to introduce students with experimental techniques in physics with emphasis on data analysis. Experiments from various fields of physics are chosen to give experimental perspective of these fields to students at graduate level.

Learning Outcomes

- Students will gain understanding about various data analysis methods.
- They will be able to learn several experimental characterization techniques.
- They will also get expertise on various scientific software.

Course Outline

Unit 1. Introduction to Data and Error Analysis Techniques

Measurements and error analysis, the uncertainty of measurements, types of errors, estimating experimental uncertainty for a single measurement, estimating uncertainty in repeated measurements, standard deviation, standard deviation of the mean, anomalous data, fractional uncertainty, propagation of uncertainty, significant figures, combining and reporting uncertainties, *Statistical analysis of experimental data*: the mean as the best value, curve fitting, straight line fitting, Linear regression, nonlinear fitting, χ^2 as the goodness of fit, covariance and correlations, distributions, Binomial distribution, Poisson distribution, Gaussian distribution.

Unit 2. Characterization Methods

Introduction to characterization methods of solid materials: Solid materials, an overview, growth, bulk characterization, surface characterization, interface characterization, ambient requirements, and sample preparation.

Unit 3. X-ray Diffraction and Related Techniques

X-Ray Photoelectron spectroscopy (XPS), Ultraviolet Photoelectron Spectroscopy (UPS): Introduction, principles, instrumentation, applications, surface and chemical analysis. X-Ray Diffraction: Properties of X-rays, Diffraction of X-rays, experimental methods, crystal structure determination.

Unit 4. Electron Spectroscopy Techniques

Electron Emission Processes, Theory of secondary electron emission, energy distribution of secondary electrons, secondary electron yield, yields measurement methods.

Unit 5. Scanning Probe Microscopy

Scanning Probe Microscopy, Atomic force microscopy, scanning tunneling microscopy, magnetic force microscopy, working principle, instrumentation, applications and limitations.

Recommended Books/Reference Material

1. Buber, H., Rivière, J. C., & Werner, W. S. M. (2011). *Auger Electron Microscopy*. Wiley–VCH.
2. Cullity, B. D., & Stock, S. R. (2003). *Elements of X-ray Diffraction*. Prentice Hall.
3. Lang, Y. (2013). *Materials Characterization: Introduction to Microscopic and Spectroscopic Methods*. Wiley-VCH.
4. Pergament, M. I. (2014). *Methods of Experimental Physics*. CRC Press.
5. Smith, W. F. (2022). *Experimental Physics: Principles and Practice for the Laboratory*. CRC Press.
6. William, D. B., & Carter, C. B. (2009). *Transmission Electron Microscopy*. Springer.

Electronic Properties of Solids

M.Phil. Physics

Course Code: PHY-709

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course explores the fundamental principles governing the behavior of electrons in crystalline materials, covering topics such as band theory, conductivity, semiconductors, and optical properties.

Learning Outcomes

- The students will learn the difference between electronic structures and physical properties of semiconductors, metals, and dielectrics.
- They will understand basic electrical and magnetic properties of crystalline solids.
- They will study the physics behind solid state electronics and optoelectronic devices.

Course Outline

Unit 1. Metals: The Drude and Sommerfeld models

The Drude model, The relaxation-time approximation, The failure of the Drude model, Electronic heat capacity, Thermal conductivity and the Wiedemann-Franz ratio, Hall effect, The Sommerfeld model, The Fermi-Dirac distribution function, The electronic density of states, The electronic density of states at $E = E_F$, The electronic heat capacity, Successes, and failures of the Sommerfeld model.

Unit 2. The Nearly-Free Electron Model

Vanishing potential, Single electron energy state, Several degenerate energy levels, Two degenerate free-electron levels, Consequences of the nearly-free-electron model, The alkali metals, Elements with even numbers of valence electrons.

Unit 3. The Tight-Binding Model

Band arising from a single electronic level, Electronic wavefunctions, Simple crystal structure, The potential and Hamiltonian, General points about the formation of tight-binding bands, The group IA and IIA metals; the tight-binding model, Viewpoint, The Group IV elements, The transition metals.

Unit 4. Semiconductors and Insulators

Bandstructure of Si and Ge, Heavy and light holes, Optical absorption, Constant energy surfaces in the conduction bands of Si and Ge, Bandstructure of the direct-gap III-V and II-VI semiconductors, Optical absorption and excitons, Constant energy surfaces in direct-gap III-N, semiconductors, Thermal population of bands in semiconductors, The law of mass action, The motion of the chemical potential, Intrinsic carrier density, Impurities and extrinsic carriers, Extrinsic carrier density, Degenerate semiconductors, Impurity bands.

Unit 5. Thermal and electrical Transport in Metals and Semiconductors

Metals: the 'Kinetic theory' of electron transport, Matthiessen's rule, Emission and absorption of phonons, Electron-phonon scattering at room temperature, Electron-phonon scattering at $T \ll \theta_D$, Low temperature conductivity behavior, Very low temperatures, Electron-electron scattering, Electrical conductivity of semiconductors,

Temperature dependence of the carrier densities, The temperature dependence of the mobility, Disordered systems and hopping conduction, Thermally-activated hopping, Variable range hopping.

Recommended Books/Reference Material

1. Bube, R. (2012). *Electronic Properties of Crystalline Solids: An Introduction to Fundamentals*. Elsevier.
2. Hummel, R. E. (2013). *Electronic Properties of Materials*. Springer New York.
3. Irene, E. A. (2005). *Electronic Materials Science*. John Wiley and Sons.
4. Phillips, P. (2003). *Advanced Solid State Physics* (1st ed.). Westview Press.
5. Sander, L. M. (2009). *Advanced Condensed Matter Physics* (1st ed.). Cambridge University Press.

Electrochemical Energy Systems

M.Phil. Physics

Course Code: PHY-710

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course is intended to introduce the principles and mathematical models of electrochemical energy conversion and storage. Students will study various electrical, thermodynamic, and transport phenomenon. In addition, this course includes applications to batteries, fuel cells, super-capacitors, and electro-kinetics.

Learning Outcomes

- The students will learn the physics of electrochemical energy conversion, formulation of mathematical models, and approximations.
- Interpretation of experimental data, design, and optimization of electrochemical systems.

Course Outline

Unit 1. Background Theory

Origin of potential – electrical double layer – reversible electrode potential – standard hydrogen electrode – emf series – measurement of potential – reference electrodes (calomel and silver/silver chloride) indicator and ion selective electrodes – Nernst equation – irreversible processes – kinetic treatment – Butler Volmer equation – Overpotential, activation, concentration and IR overpotential – its practical significance – Tafel equation and Tafel plots – exchange current density and transfer coefficients.

Unit 2. Batteries

Primary batteries: The chemistry, fabrication and performance aspects, packing classification and rating of the following batteries: (The materials taken their function and significance, reactions with equations, their performance in terms of discharge, capacity, and energy density to be dealt with). Zinc-carbon (Leclanche type), zinc alkaline (Duracell), zinc/air, zinc-silver oxide batteries; lithium primary cells – liquid cathode, solid cathode and polymer electrolyte types and lithium-ferrous sulphide cells (comparative account).

Unit 3. Secondary batteries

ARM (alkaline rechargeable manganese) cells, Lead acid and VRLA (valve regulated (sealed) lead acid), nickel-cadmium, nickel-zinc, nickel-metal hydride batteries, lithium ion batteries, ultrathin lithium polymer cells (comparative account). Advanced Batteries for electric vehicles, requirements of the battery – sodium-beta and redox batteries.

Unit 4. Reserve batteries and Fuel cells

Reserve batteries – water activated, electrolyte activated and thermally activated batteries – remote activation – pyrotechnic materials. Fuel Cells: Principle, chemistry and functioning – carbon, hydrogen-oxygen, proton exchange membrane (PEM), direct methanol (DMFC), molten carbonate electrolyte (MCFC) fuel cells and outline of biochemical fuel cells.

Unit 5. Electrochemical Processes

Principle, process description, operating conditions, process sequence and applications of Electroforming – production of waveguide and plated through hole (PTH) printed circuit boards by electrodeposition; Electroless plating of nickel, copper and gold; Electropolishing of metals; Anodizing of aluminum; Electrochemical machining of metals and alloys.

Recommended Books/Reference Material

1. Allen, J., J., & Faulkner, L. R. (2000). *Electrochemical Methods: Fundamentals and Applications* (2nd ed.). Wiley.
2. Huggins, R. (2008). *Advanced Batteries: Materials Science Aspects*. Springer.
3. Newman, J., & Thomas-Alyea, K. E. (2004). *Electrochemical Systems* (3rd ed.). Wiley-Interscience.
4. O'Hayre, R., & Cha, S.-W. (2009). *Fuel Cell Fundamentals* (2nd ed.). Wiley.
5. Rand, D. M., & David, A. J. (2001). *Understanding Batteries*. Royal Society of Chemistry.

Materials Science

M.Phil. Physics

Course Code: PHY-711

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course is designed to emphasize on developing, application of basic materials science concepts: atomic bonding; crystallography; defects and diffusion; thermodynamics, phase diagrams and phase transformations; deformation and failure mechanisms in crystalline and non-crystalline solids. This course includes ceramics, metals, polymers, electronic materials, and composites.

Learning Outcomes

After completing this course, the student will be able to:

- Discuss, understand, and compare the structure of crystalline and amorphous solids
- Identify the structure and chemistry of point, line, and planar defects in solids
- Read and interpret a unary and binary phase diagram
- Understand the crystalline lattice and the nomenclature used to describe it
- Articulate the physical properties associated with ceramic, semiconducting, metallic, and amorphous solids
- Understand the roles of thermodynamics and kinetics in regulating phase transitions

Course Outline

Unit 1. Interatomic Bonding in Materials

Bonding in Elemental Materials (Covalent, Metallic and van der Waals bonding), Bonding in Multi element Materials (Ionic, Mixed Ionic-Covalent Bonding, and Hydrogen Bonding), and Effects of Nature of Bonding on Materials Properties.

Unit 2. Structure of Crystalline Solids

Basic Structural and Symmetry Concepts, Concept of Diffraction in a Periodic Lattice, Structural Information from X-ray Diffraction and other Diffraction Techniques. Crystal Structures of Metals and Ceramic Materials.

Unit 3. Non Crystalline Solids

Amorphous Materials / Glasses (Glass formation, Glass Transition and Crystallization of Glasses, Various Glass Forming Systems). Random Closed Packing in Metallic Glasses, Continuous Random Network in Covalent Glasses.

Unit 4. Phase Diagrams and Phase Transformations

Basic Concepts, Equilibrium Phase Diagrams, Phase Transformations – Basic Concepts, Kinetics, Metastable versus Stable Transformations, Microstructure Development, Precipitation and Dispersion Hardening, Multi Component and Multi Phase Systems, Alloys, Equilibrium Structures, Phase Separation.

Unit 5. Surfaces and Interfaces

Geometry of Interfaces, Coherent and Commensurate Interfaces, Stacking Period and Interplanar Spacing, Defects on Surfaces, Experimental Determination and Creation of Surfaces, Surface Characterization Techniques (LEED, RHEED, MBE, STM and AFM) and Their Principles.

Unit 6. Defects and Imperfections in Crystalline Solids

Point Defects (vacancies, interstitials, impurities, F-centres) and their stability Line and Extended Defects (Dislocations, Grain Boundaries, Stacking Faults, Interfacial, Surface and Volumetric Defects). Effect of Defects on the Properties of Materials.

Recommended Books/Reference Material

1. Blakemore, J. S. (1995). *Solid State Physics* (2nd ed.). Cambridge University Press.
2. Callister, W. D. Jr. (2007). *Materials Science and Engineering: An Introduction*. John Wiley & Sons Inc.
3. Gersten, J. I., & Smith, F. W. (2001). *The Physics and Chemistry of Materials*. John Wiley & Sons Inc.
4. Gottstein, G. (2013). *Physical Foundations of Materials Science*. Springer Science and Business.
5. Jones, R. A. L. (2002). *Soft Condensed Matter*. Oxford University Press.
6. Kittel, C. (2010). *Introduction to Solid State Physics* (10th ed.). Wiley & Sons Inc.
7. Sutton, A. P. (2021). *Concepts of Materials Science*. Oxford University Press.

Physics of Semiconductor Devices

M.Phil. Physics

Course Code: PHY-712

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course delves into the fundamental principles underlying the behavior, design, and applications of semiconductor devices, exploring topics such as semiconductor physics, carrier transport, device fabrication, and device characteristics essential for advancements in electronics and technology.

Learning Outcomes

- The students will gain a comprehensive understanding of semiconductor fundamentals.
- They will acquire knowledge of device functionality.
- Frequency response of semiconductor devices.

Course Outline

Unit 1. Electronic levels in Semiconductors

Particles in attractive potentials, quantum wells, Electrons in crystalline materials, Important band structures, Distribution functions, Metals and insulators, Mobile carriers, Doping: Dopants and polar doping, Heterostructures: Lower dimensional systems, Strained heterostructures

Unit 2. Charge Transport

Transport and scattering, Velocity-Field relations, Transport by diffusion, Carrier generation and recombination, Current continuity equation

Unit 3. P-N Diodes and Semiconductor Junctions

P-N junction under equilibrium, Junction under bias: Ideal case, Non-Ideal effects, High voltage effects, Diode applications Metal interconnects, Schottky Barrier Diode, Ohmic contacts, Insulator semiconductor junctions, Semiconductor heterojunctions.

Unit 4. Bipolar Junction Transistor and devices

Current voltage relations, Device design and optimization, Secondary effects in BJTs, Heterojunction bipolar transistors P-N diode: Small and large signal Schottky diode temporal response, Bipolar transistor: Charge control model, High frequency response of bipolar transistors

Unit 5. Field Effects Transistors- MESFET and HFETs

JFET and MESFET: Charge control and current-voltage, Charge control for MODFETs, Polar HFETs: Charge Control, HFET Design issues, Temporal response and high power issues, MOS Capacitor, Current-voltage characteristics, Sub-threshold current flow, Short channel and scaling issues in FETs.

Recommended Books/Reference Material

1. Ghosh A. (2023). *Fundamentals of electronic materials and devices : a gentle introduction to the quantum-classical world*. World Scientific.
2. Kasap S. (2018). *Principles of electronic materials and devices*. McGraw-Hill Education.
3. Poplavko, Y. (2018). *Electronic materials, principles, and applied science* (1st ed.). Elsevier.

4. Rezende, S. M. (2022). *Introduction to electronic materials and devices*. Springer.
5. Waser R. (2012). *Nanoelectronics and information technology : advanced electronic materials and novel devices*. Wiley-VCH.

Physics of Surfaces and Interfaces

M.Phil. Physics

Course Code: PHY-714

Credit Hours: 03

Pre-requisite: Nil

Objectives

The objective of this course is to understand the phenomenon, thermodynamics and physics of fundamental processes occurring at surfaces and interfaces.

Learning Outcomes

- The students will be able to study surface reconstruction.
- They will be able to analyze the thermodynamic stability of a given interface.

Course Outline

Unit 1. Introduction to surfaces and interfaces

Thermodynamics of surfaces, importance of surfaces and interfaces in materials performance, role of interface in ultrathin materials, Electronic properties of surfaces, work function, surface dipoles.

Unit 2. Crystal structures and surface properties

Relaxation, Reconstruction, Defects, Two-dimensional lattices, Superstructure, Reciprocal space Crystallographic representation of surfaces, Epitaxial growth, Surface energy, interfacial energy, work of adhesion, Solid-solid interfaces, grain boundaries, interfacial energy.

Unit 3. Electronic surface states

Semi-infinite chain in the nearly free electron model, 3D crystal and charging character, photoemission theory, Metal surfaces, Semiconductor surfaces, photoemission and inverse photoemission spectroscopy.

Unit 4. Characteristic energy losses in solids

Ionization losses, secondary electron yield, secondary emission coefficient, back scattering coefficient, angular variation of yield, high yield secondary emitters, low yield materials, surface effects (contamination, roughness) on yield, Auger Electron Emission, emission mechanism of Auger electron, Auger electron data acquisition and analysis, chemical shifts in Auger spectra.

Unit 5. Surface Characterization Techniques

Auger electron spectroscopy, Secondary ion mass spectroscopy, Secondary electron microscopy, Scanning tunneling microscopy, Low-energy electron diffraction, reflection high-energy electron diffraction, Rutherford backscattering.

Recommended Books/Reference Material

1. Guarrotxena, N. *Research methodology in physics and chemistry of surfaces and interfaces*. (2021). Apple Academic Press.
2. Ibach, H. (2006). *Physics of Surfaces and Interfaces*. Springer.
3. Luth, H. (2015). *Solid Surfaces, Interfaces and Thin Films*. Springer.
4. Myers, D. (1999). *Surfaces, Interfaces and Colloids: Principles and Application* (2nd ed.).

5. Starov, V. M. & Manuel G. *Wetting and spreading dynamics*. (2020). CRC Press Taylor & Francis Group.

Optical Properties of Solids

M.Phil. Physics

Course Code: PHY-716

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course is aimed at introducing the concepts of light-matter interaction from theoretical and experimental viewpoints. Additionally, this course is intended to study optical response of materials.

Learning Outcomes

The student must be able to explain basic optical phenomena in materials.

They will be able analyze complex optical response of materials.

- Explain the working principle of optoelectronic devices
- Quantify the figures of merit of optical and optoelectronic devices

Course Outline

Unit 1. Introduction to Optical Processes

Classification of optical processes, optical coefficients, Absorption and Reflection, Complex refractive index and dielectric constant.

Unit 2. Theoretical Aspects of Light-I

Optical materials, microscopic models, classical propagation of light in optical medium, the classical dipole oscillator model, band structure in solids, interband optical transitions, transition probability from time dependent perturbation theory, wavevector conservation and parity selection rules, joint density of states, direct and indirect transitions, excitons, Wannier-Mott excitons – hydrogenic model.

Unit 3. Theoretical Aspects of Light-II

Exciton-Polariton, Frenkel excitons, low-dimensional systems, effect of confinement on the joint density of states, quantum well with infinite potential barriers: selection rules and band structure modifications, effect of confinement on excitons, optical response of an electron gas, dipole oscillator model for the free electron gas.

Unit 4. Experimental Measurements on Optical Materials-I

AC conductivity, low/high-frequency regime, reflectivity from alkalis, transition metals and doped semiconductors, plasmons, optical studies of phonons, harmonic oscillator model for a linear chain of ions, lattice-response in the low-damping limit: Lyddane-Sachs-Teller relationship and Reststrahlen band, measurement of and examples for lattice reflectivity spectra.

Unit 5. Experimental Measurements on Optical Materials-II

Phonon-polariton, inelastic light scattering: Raman/Brillouin scattering, experimental details and examples, phonon lifetimes, optics of anisotropic media, electric susceptibility tensor, propagation of electromagnetic waves in an isotropic medium, ordinary, and extraordinary rays in uniaxial crystals, refractive index ellipsoid.

Recommended Books/Reference Material

1. Aharony A. & Entin-Wohlman O. (2020). *Introduction to solid state physics*. World Scientific.
2. Dresselhaus, M., & Dresselhaus, G. (2018). *Solid State Properties*. Springer.

3. Drogman, D. (2002). *Optical Characterization of Solids*. Springer.
4. Fox, M. (2001). *Optical Properties of Solids*. Oxford.
5. Kitterson, J. B. (2016). *Physics of solids*. Oxford.
6. Kittel C. & McEuen P. (2018). *Introduction to solid state physics* (Global). Wiley.
7. Locharoenrat, K. (2016). *Optical Properties of Solids*. Pan Stanford.
8. Omar, M. A. (1987). *Elementary solid state physics*. Addison-Wesley.
9. Tanner, D. B. (2020). *Optical effects in solids / David B. Tanner*. (1st ed.). Cambridge University Press.

Advanced Computational Physics

M.Phil. Physics

Course Code: PHY-717

Credit Hours: 03

Pre-requisite: Nil

Objectives

The basic aim of this course is to introduce useful computational methods for simulation of simple (single particle, or linear), and complex (many particle, or non-linear) quantum or classical statistical systems.

Learning Outcomes

- Mastering advanced numerical methods and approaches to simulations of systems with many degrees of freedom in statistical and quantum physics.
- Students should know how to apply the new knowledge in theoretical modelling and computer simulations of complex systems in physics.

Course Outline

Unit 1. Introduction to Programming Languages

Brief Introduction to Python/Mathematica/C/C++/MATLAB.

Unit 2. Programming basics

Conditional statements, loops and arrays, modules, functions and subroutines, scoping of variables.

Unit 3. Symbolic computation

Algebraic simplifications, matrix algebra, symbolic differentiation and integration, analytical solutions of differential equations.

Unit 4. Solving Differential equations

Ordinary and partial differential equations, initial value problems, boundary value problems, Taylor expansion method, Runge-Kutta method, local and accumulated truncation errors, error control.

Unit 5. Modelling-I

Trajectories and particle motion, linear and nonlinear initial value problems, Schrodinger equation, normalization of wave functions, energy levels, orthogonality of wave functions, expectation values, probability calculations, Monte-Carlo based Markov-Chain techniques for simulating the Ising spin model in statistical mechanics, problems in electromagnetism and solution by finite elements.

Unit 6. Modelling-II

Interpolation, interpolating polynomials, errors, curve fitting and best fits using linear and non-linear least-squares fits, inverting matrices.

Recommended Books/Reference Material

1. Gerald, C. F. (2004). *Applied Numerical Analysis*. Pearson Education.
2. Hajorth-Jensen, M. (2023). *Computational Physics: An Advanced Course*. IOP Publishing.
3. Landau, R. H., et al. (2015). *Computational Physics: Problem Solving with Python*. John Wiley and Sons.

4. Scherer, P. (2013). *Computational Physics: Simulation of Classical and Quantum Systems*. Springer.
5. Thijssen, J. M., & Thijssen, J. (2007). *Computational Physics*. Cambridge University Press.

Special Topics in Condensed Matter Physics

M.Phil. Physics

Course Code: PHY-718

Credit Hours: 03

Pre-requisite: Nil

Objectives

Advanced topics are selected to aid students with their advanced research in Condensed Matter Physics. These topics are either partially covered in Condensed Matter Theory-I and II or not covered at all.

Learning Outcomes

The students will be able to understand the theoretical and experimental aspects of:

- Scattering,
- transport in 3D and low dimensions,
- the intricacies of the phase transitions and their role in material properties.

Course Outline

Unit 1. Scattering from ordered structures

General Theory of scattering from a crystal. X-ray, neutron and electron scattering. Magnetic and small angle scattering.

Unit 2. Electron Transport Phenomenon

Motion of electrons in bands. Boltzmann transport equation, relaxation time approximation. Onsager relations and reciprocity. Electrical conductivity generalized treatment of conductivity in bands. Thermoelectric phenomenon (Seebeck and Peltier effects.) Introduction to Fermi liquid theory.

Unit 3. Dielectric and Optical Properties

General background: Maxwell equations, dielectric functions, Kramers–Kronig relations. Absorption of electromagnetic radiation; Optical properties of semiconductors, direct and indirect transitions, excitons. Optical properties of insulators. Longitudinal and transverse normal modes, local field, Polarization, and polarization catastrophe, Ferroelectrics and ferroelectricity. Optical modes in ionic crystals, coupling of electromagnetic and lattice modes (polarons and polaritons), point defects and color centers. Optical properties of metals, plasma frequency, metals at low frequencies, plasmons, Brillouin scattering.

Unit 4. Electrons in low dimensional systems

Electronic states in bands: review of free, nearly free and tightly bound electrons. Confined states in zero, one and two dimensions. Effects of confinement on band structures and optical properties: band gap variations and surface plasmon effects. Density of states in quantum wells, wires and dots. Quantum Hall effect. semiconductor laser action. Single electron tunneling. Tunneling structures and devices.

Unit 5. Critical phenomenon and phase transitions

Molecular field theory and application to simple systems e.g. ferromagnetism or Van der Waals equation of state. Generalized theory of phase transitions (Landau theory),

order parameter, Free energy, equilibrium behavior, temperature dependence of order parameter and generalized susceptibilities, coherence lengths, specific heats. Application to different examples e.g. ferromagnetic, ferroelectrics, superconductors(Ginzburg-Landau theory). Basic ideas of fluctuations and of critical exponents.

Recommended Books/Reference Material

1. Goodstein, D. L. (2002). *States of Matter*. Dover Publications Inc.
2. Ibach, H., & Luth, H. (2003). *Solid State Physics* (2nd ed.). Springer Verlag.
3. Malder, M. P. (2000). *Condensed Matter Physics*. John Wiley.
4. O'Reilly, E. P. (2002). *Quantum Theory of Solids*. Taylor and Francis.
5. Owens, F. J., & Poole Jr., C. P. (2008). *The Physics and Chemistry of Nanosolids*. John Wiley.
6. Phillips, P. (2012). *Advanced Solid State Physics* (2nd ed.). CUP.

Advanced Plasma Physics

M.Phil. Physics

Course Code: PHY-719

Credit Hours: 03

Pre-requisite: Nil

Objectives

This convey will convey how our understanding of plasma physics extends to a description of a huge diversity of systems over hugely varying scales of space, time, density, and temperature.

Learning Outcomes

The students will be able to explain the MHD equations, their role in understanding of various plasmas in nature, understand the various of drifts present in plasma, use kinetic theory of plasma evolution.

Course Outline

Unit 1. Introduction

Relation between fluid equations and guiding center drifts, diamagnetic drift in uniform and non-uniform magnetic fields, polarization current in the fluid model and parallel pressure balance.

Unit 2. Magnetohydrodynamic equations

Single fluid magnetohydrodynamic equations, quasi-neutrality approximation, small Larmor radius approximation, approximation of infinite conductivity of plasma, conservation of magnetic flux and energy, MHD equilibrium, magnetic pressure: the concept of plasma beta, the cylindrical pinch: the cylindrical tokamak.

Unit 3. Diffusion in fully and partially ionized plasmas

Diffusion as a random walk, the diffusion equation, steady state solutions, diffusion across a magnetic field, diffusion in fully ionized plasma, Bohm diffusion and solution of diffusion equation.

Unit 4. Classification of instabilities

Two-streaming instability, the Rayleigh-Taylor and flute instabilities, the gravitational R-T instability, physical mechanisms of R-T instability, Flute instability due to field curvature, MHD stability of the tokamak.

Unit 5. Kinetic theory of plasmas

The need for a kinetic theory, the particle distribution function, the Boltzmann-Vlasov equation, the Vlasov-Maxwell equations, kinetic effects on plasma waves: Vlasov's treatment, the linearized Vlasov equation for electrostatic perturbations, time asymptotic solutions, simplified derivation for electrostatic waves for Maxwellian and non-Maxwellian plasmas: Langmuir waves, ion-sound waves and Landau damping.

Recommended Books/Reference Material

1. Chen, F. F. (2015). *Introduction to Plasma Physics and Controlled Fusion* (3rd ed.). Plenum.
2. Freidburg, J. P. (2008). *Plasma Physics and Fusion Energy* (1st ed.). Cambridge University Press.
3. Garnett, D. A., & Bhattacharjee, A. (2017). *Introduction to Plasma Physics: with space and laboratory applications* (2nd ed.). Cambridge University Press.

4. Goldston, R. J., & Rutherford, P. H. (1995). *Introduction to Plasma Physics* (1st ed.). IoP, Bristol and Philadelphia.
5. Krall, N. A., & Trivelpiece, A. W. (1973). *Principles of Plasma Physics* (1st ed.). McGraw-Hill Book Company, New York.

Quantum Field Theory-I

M.Phil. Physics

Course Code: PHY-720

Credit Hours: 03

Pre-requisite: Nil

Objectives

The aim of this course is to introduce the students with the fundamentals of interactions. These include: quantization of free scalar and fermion fields and development of perturbation theory for interacting theories; examples of scattering processes in quantum electrodynamics; analysis of radiative corrections, regularization and renormalization methods; path integral methods.

Learning Outcomes

The student is expected to obtain knowledge about the fundamental principles and formalisms of quantum field theories, and the use of Feynman diagrams for quantitative analysis.

Course Outline

Unit 1. Classical Field Theory

Lagrangian formulation, Hamiltonian formulation, Poisson's brackets for fields, continuous symmetries and Noether theorem.

Unit 2. Quantization of Spin-0 fields

Field commutators, microscopic causality, energy momentum operators, vacuum fluctuations, charged scalar field, Feynman propagator for spin-zero.

Unit 3. S Matrix and Perturbation Theory

Self-interacting field with ϕ^4 interaction, S-matrix calculation for elastic scattering of neutral pions/Higgs to order λ^2 , dimensional regularization, renormalization of ϕ^4 , renormalization group flow equation.

Unit 4. Quantization of spin $\frac{1}{2}$ fields

Dirac fields, Feynman propagator for spin $\frac{1}{2}$, charge conjugation of Dirac field, spin $\frac{1}{2}$ interaction with spin 0 neutral field, Feynman rules for Yukawa theory, nucleon-nucleon scattering, pion-nucleon scattering, nucleon-anti nucleon annihilation into two pions, fermion self-energy and pion self-energy operators, mass and coupling constant renormalization, degree of divergence and classification of renormalizability.

Unit 5. Quantization of spin 1 fields

Transverse gauge, definition of covariant propagator, Feynman rules for QED, traces and their properties, Moller and coulomb scattering.

Unit 6. Radiative corrections in QED

Fermion self-energy, vacuum polarization, vertex correction, Ward identity, renormalization constants, renormalization group.

Unit 7. Path integral quantization

Path integral quantization of scalar field theory, generation of Feynman diagrams from path integrals.

Recommended Books/Reference Material

1. Mandl, F., & Shaw, G. (1993). *Quantum Field Theory*. Wiley.
2. Peskin, M. E., & Schroeder, D. V. (1995). *An Introduction to Quantum Field Theory*.
3. Srednicki, M. (2007). *Quantum Field Theory*. Cambridge University Press.
4. Zee, A. (2003). *Quantum Field Theory in a Nutshell*. Princeton University Press.

Non-Linear Plasma Physics

M.Phil. Physics

Course Code: PHY-721

Credit Hours: 03

Pre-requisite: Nil

Objectives

The main objective of this course is to learn formulation of non-steady plasma dynamics. Use mathematical techniques to extract physical information of charge particle systems. Analyze dynamical parameters associated with non-linearities in plasma. Identify and apply appropriate mathematical model for specific research applications.

Learning Outcomes

The students will achieve a clear understanding of non-linear phenomenon, especially solitary waves in plasma and asymptotic methods in perturbed plasma.

Course Outline

Unit 1. An introduction to linear waves in plasma

Magnetic fluid description, two-fluid description, electrodynamic description, wave energy and momentum, non-uniform medium waves.

Unit 2. The Planar Sheath Equation

Ion Acoustic Shock Waves, The Sagdeev Potential, Solitary waves in plasma, Wave breaking, soliton.

Unit 3. Introduction to solitary waves

Nonlinear ion acoustic wave, Nonlinear Langmuir wave, Drift wave soliton, Alfvén solitary waves, Electromagnetic solitary waves in relativistic plasma, self - focusing and self - compression of waves.

Unit 4. The vortex in the plasma

Charney Equation and Rossby vortex, Electrostatic drift vortex in magnetized plasma, Electromagnetic vortex in magnetized plasma, A vortex in a magnetized plasma.

Unit 5. Asymptotic Method in Nonlinear Wave Theory

Parametric Process and Parametric Instability, Singular perturbation, asymptotic expansion, scattering inversion method.

Recommended Books/Reference Material

1. Bellan, P. M. (2008). *Fundamentals of Plasma Physics* (1st ed.). Cambridge University Press.
2. Chen, F. F. (2015). *Introduction to Plasma Physics and Controlled Fusion* (3rd ed.). Plenum.
3. Freidburg, J. P. (2008). *Plasma Physics and Fusion Energy* (1st ed.). Cambridge University Press.
4. Goldston, R. J., & Rutherford, P. H. (1995). *Introduction to Plasma Physics* (1st ed.). IoP, Bristol and Philadelphia.
5. Krall, N. A., & Trivelpiece, A. W. (1973). *Principles of Plasma Physics* (1st ed.). McGraw-Hill Book Company, New York.

Quantum Field Theory-II

M.Phil. Physics

Course Code: PHY-722

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding about advanced topics in Quantum Field Theory.

Learning Outcomes

- Students will gain understanding about various theories related to Quantum Field.
- Students will be able to understand quantum chromo dynamics.

Course Outline

Unit 1. Non-Abelian gauge theories

Yang-Mills Lagrangian, local and global gauge transformation. Multiple vacua.

Unit 2. Brief review of group theory

Quantization of non-abelian gauge theories, ghost field (BRS transformations).

Unit 3. Unitarity

Ghost field and unitarity, optical theorem and Cutkosky rules, examples: $e + e \rightarrow$ hadrons (evidence of color).

Unit 4. Radiative corrections in QCD

One loop divergences (gauge boson self-energy, fermion self-energy), fermion gluon vertices, beta function and asymptotic freedom.

Unit 5. Callan-Symanzik equation

Renormalization scale, methods of characteristics, examples in ϕ^4 theory and QCD.

Recommended Books/Reference Material

- Mandl, F., & Shaw, G. (1993). *Quantum Field Theory*. Wiley.
- Peskin, M.E., & Schroeder, D. V. (1995). *An Introduction to Quantum Field Theory*.
- Srednicki, M. (2007). *Quantum Field Theory*. Cambridge University Press.
- Zee, A. (2003). *Quantum Field Theory in a Nutshell*. Princeton University Press.

General Relativity and Cosmology

M.Phil. Physics

Course Code: PHY-723

Credit Hours: 03

Pre-requisite: Nil

Objectives

The structure of the course is aimed at the mathematically advanced students, and skills in mathematics are essential, given that a substantial part of the course deals with tensors and other advanced mathematical concepts, such as elements of differential geometry.

Learning Outcomes

The students will be able to:

- Demonstrate understanding of the Physics of space-time and its interaction with matter and light in the General Theory of Relativity and contrast the theory with earlier descriptions of gravity.
- Apply Physics knowledge and mathematical skills to solve problems, including applying the field equations with different metrics.
- Analyze gravitational phenomena in nature including black holes, wormholes, warp drives, and the cosmological history of the Universe.

Course Outline

Unit 1. Principles of special relativity and relativistic mechanics

The addition of velocities and Michelson-Morley experiment, Einstein's resolution and its consequences, space-time, time dilation and twin paradox, Lorentz boosts, four vectors, special relativistic kinematics and dynamics, variational principle for free particle motion, light rays, observers and observations.

Unit 2. The curved space time of general relativity

Testing of equality of gravitational and inertial mass, equivalence principle, geodesics, metric coordinate transformations, Christoffel symbols, geodesics and coordinate transformations.

Unit 3. The physics and geometry of geodesics

Geodesic equation from variational principle, the Newtonian limit, the gravitational red-shift, locally inertial and Riemann normal coordinates, affine and non-affine parameterization.

Unit 4. Tensor algebra and tensor analysis

From Einstein equivalence principle to the principle of general covariance, tensor algebra, tensor density, the covariant derivative of vector fields, extension of covariant derivative and other tensor fields, main properties of covariant derivatives, the principle of minimal coupling, covariant differentiation along a curve, parallel transport and geodesics, generalizations.

Unit 5. Physics in a gravitational field

Particle mechanics and electrodynamics in a gravitational field, conserved quantities from covariantly conserved currents and tensors.

Unit 6. Lie derivatives, symmetries and Killing vectors

Symmetries of a metric, the Lie derivative for scalars, vector fields, tensor fields, metric and Killing vectors.

Unit 7. Curvature

The Riemann curvature tensor, intrinsic geometry, parallel transport, geodesic derivative equations, Einstein equations, weak field limit, Bianchi identities, cosmological constant, Weyl tensor, Einstein-Hilbert action, the matter Lagrangian and consequence of the variational principle.

Unit 8. Tests of general relativity

Black holes, relativistic star models, cosmological models, early stages of evolution of the universe, gravitational waves.

Recommended Books/Reference Material

1. Carroll, S. (2004). *Space-Time and Geometry: An Introduction to General Relativity*. Addison-Wesley.
2. Hartle, J.B. (2003). *Gravity: an Introduction to Einstein's General Relativity*. Addison-Wesley.
3. Weinberg, S. (1972). *Gravitation and Cosmology*. Wiley.

Quantum Information and Computation

M.Phil. Physics

Course Code: PHY-724

Credit Hours: 03

Pre-requisite: Nil

Objectives

It aims at students having basic knowledge on quantum mechanics. The course introduces basic structure and procedures of quantum information and its applications. A section of the course is also dedicated to quantum computation and quantum error correction.

Learning Outcomes

The students will be able to:

- Understand basic principles of quantum information
- Understand most known applications using entanglement
- Understand quantum information theory
- Apply quantum gates to achieve quantum information processing

Course Outline

Unit 1. Motivation

Qubits, orthogonal states; Non orthogonal states; Stern Gerlach experiment, Qubit, Operators, Bloch Sphere.

Unit 2. Density operator and measurements

Density operator for single qubit, Measurement of a density matrix of qubit, generalized measurements, POVM, Quantum Key distribution (using single qubits), System of qubits, Density matrix, faster than light communication.

Unit 3. Quantum entanglement

Bell states, non-separability of EPR pairs, Bell inequalities, maximal violation of Bell inequalities, Uses of entanglement: quantum key distribution (quantum no-cloning), quantum dense coding, quantum state discrimination, quantum teleportation.

Unit 4. Information and Entropy

The Shannon entropy, classical data compression, Von Neumann entropy, quantum data compression, Accessible information, Quantifying entanglement: entanglement concentration and von Neumann entropy, the Peres separability criteria.

Unit 5. Introduction to computer science

Turing machines, classical gates, complexity classes, Quantum computation: quantum circuits, quantum gates, simulations, Deutsch algorithm, Quantum search algorithm: the Grover's algorithm.

Unit 6. Quantum Fourier transform

Phase estimation and application to order finding and factoring, Quantum computation of dynamical systems, physical realization of quantum computers, Decoherence model for a single qubit, the bit-flip channel, the phase-flip channel, the bit-phase-flip channel, the depolarizing channel, amplitude damping, phase damping, de-entanglement.

Recommended Books/Reference Material

1. Benenti, G., Casati, G., & Strini, G. (2007). *Principles of Quantum Computation and Information*. World Scientific.
2. Cover, T.M Thomas, J.A. (1991). *Elements of Information Theory*. John and Wiley Sons.
3. Mermin, N. D. (2007). *Quantum Computer Science: An Introduction*. Cambridge University Press.
4. Nielson, M.A., & Chuang, I.I. (2000). *Quantum Computation and Quantum Information*. Cambridge University Press.
5. Vedral, V. (2006). *Introduction to Quantum Information Science*, Oxford University Press.

Particle Physics

M.Phil. Physics

Course Code: PHY-725

Credit Hours: 03

Pre-requisite: Nil

Objectives

This is an introductory particle physics course. It gives an introduction to central facts and notions of particle physics, symmetries, invariances, and conservation laws.

Learning Outcomes

The students will be able to:

- Be able to account for central concepts within particle physics, such as symmetries, invariants, and conservation laws. In addition, the student shall be able to use these concepts in practical calculations.
- Be able to account for the main content of quantum electrodynamics and weak interactions, in particular with regard to scattering processes for particles.

Course Outline

Unit 1. Relativistic quantum mechanics

Klein Gordon and Dirac equations. Pauli and Weyl representations of gamma matrices, antiparticles, Majorana representation, left and right handed particles, Zitterbewegung.

Unit 2. Symmetry Considerations

Continuous symmetries and the Noether theorem, space reflection, time reversal, charge conjugation, and other discrete symmetries, scattering matrix, relation to cross-sections, crossing symmetry, dispersion relations, Cutkosky rules.

Unit 3. Scattering in electromagnetic fields

Minimal coupling to electromagnetic field, diagrammatic perturbation theory, Rutherford, Moller, and Bhabha scattering.

Unit 4. Introduction to the gauge principle

Non-abelian transformations, examples of SU(2) and SU(3) gauge theories.

Unit 5. The Parton model

Deep inelastic scattering, running of the coupling constant, beta function, limitations of the perturbative approach.

Unit 6. V-A Theory of weak interactions

Beta decay, tests of C and P-violation, time reversal invariance, leptonic and semi leptonic decays.

Unit 7. Spontaneous symmetry breaking

Goldstone theorem, Higgs mechanism, standard model, experimental tests of standard model of particle physics.

Unit 8. Neutrino oscillations

Mass matrices and mixing, tests for generations beyond three.

Recommended Books/Reference Material

1. Fayyazuddin, Riazuddin. (2011). *A Modern Introduction to Particle Physics*. (3rd Ed.). World Scientific Publishing Company.
2. Halzen, F., & Martin, A.D. (2008). *Quarks and Leptons, An Introductory Course in Modern Particle Physics*. Wiley India.
3. Peskin, M.E., & Schroeder, D.V. (2019). *An Introduction to Quantum Field Theory*. (1st Ed.). CRC Press.

Quantum Computation

M.Phil. Physics

Course Code: PHY-726

Credit Hours: 03

Pre-requisite: Nil

Objectives

It aims at students having basic knowledge of classical computing and quantum mechanics. The course introduces basic structure and procedures of quantum computation. It explains quantum speed up in computation and then its applications in Shor's factoring algorithm, Grover's search algorithm and quantum error correction. A section of the course is also dedicated to the application of quantum gates in quantum information processing.

Learning Outcomes

The students will be able to:

- Understand basic principles of quantum computation
- Understand most known quantum algorithms and their significance
- Understand quantum error correction codes
- Apply quantum gates to achieve quantum information processing

Course Outline

Unit 1. Motivation

Quantum bits. Introduction to quantum mechanics, Density matrix, Schmidt decomposition, tensor products, quantum entanglement, Quantum measurement, Projective measurement, POVM

Unit 2. Introduction to computer science

How to quantify computational resources, Computational complexity, Decision problems and the complexity classes P and NP, A plethora of complexity classes, Energy and computation.

Unit 3. Quantum gates

Quantum algorithms, Single qubit operations, Controlled operations Measurement, Universal quantum gates Quantum Gates: Simulation of quantum circuits, Quantum algorithms, Deutsch, Josza, Quantum Fourier Transform, factoring, order-finding.

Unit 4. Application of Quantum Fourier Transform

Period finding, discrete logarithms, The hidden subgroup problem, Quantum Phase estimation, Bernstein Vazirani algorithm.

Unit 5. Quantum Search algorithm

Grover's algorithm, Solving Linear equations HHL Algorithm, Quantum error correction: The three-qubit bit flip code, Three-qubit phase flip code, The Shor code, CSS codes, Stabilizer codes, Application to Quantum Information, QKD, Quantum Dense coding, quantum teleportation, Physical realization of quantum computers: overview of all and three in detail.

Recommended Books/Reference Material

1. Benenti, G., Casati, G., & Strini, G. (2007). Principles of Quantum Computation and Information. World Scientific.
2. Mermin, N. D. (2007). Quantum Computer Science: An Introduction. Cambridge University Press.

Solar Cell Physics

M. Phil. Physics

Course Code: PHY-727

Credit Hours: 03

Prerequisites: Nil

Objectives

Students will explore the fundamental principles of Solar Cell Physics, covering semiconductor physics, photon-electron interactions. Understand solar energy conversion mechanisms for sustainable energy applications.

Learning Outcomes

- Analyze semiconductor properties crucial for efficient solar cell operation.
- Demonstrate understanding of photon-electron interactions within solar cell materials.
- Apply knowledge to design and optimize solar cell devices effectively.

Course Outline

Unit 1. Semiconducting Properties

Review of Semiconductor Physics, Charge carrier generation and recombination, p-n junction model and depletion capacitance.

Unit 2. Current-Voltage Characteristics

Solar Cell design and characteristics in dark and light, Device Physics of Solar Cells, Principle of solar energy conversion, Power conversion efficiency

Unit 3. Systems of Solar Cells

Different generations of Solar Cells: Single, tandem multi-junction solar cells, Crystalline silicon and III-V solar cells, Thin film solar cells: Amorphous silicon, Quantum Dot solar cells, Dye Sensitized Solar Cells, Fabrication of Dye Sensitized Solar Cells, Design of novel dyes, Design of solid electrolytes materials, Organic Solar Cells, Physics of Bulk Heterojunction(BHJ) Solar Cells,

Unit 4. Perovskite Solar Cells

Solar Cells with ABX_3 Perovskite structure, Fabrication of perovskite solar cells, Photo physics in perovskite solar cells, Stability in perovskite solar cells, Lead free perovskite solar cells, Photovoltaic system engineering,

Unit 5. Thermo-Photovoltaic

Thermo-Photovoltaic generation of electricity, Concentration and storage of electrical energy, Photovoltaic modules, system and application, Green energy, Nanomaterials for photovoltaic devices, Photo thermal cells

Recommended books/reference material

1. Adrian Kitai, Principles of Solar Cells, LEDs and Diodes, Jon & Willey Sons 2011.
2. Juan Bisquert, The Physics of Solar Cells, CRC press, USA, 2018
3. Jenny Nelson, "The Physics of Solar Cells", Imperial College Press, 2003
4. Gavin J. Conibeer, Solar Cell Materials, Willy Series, 2014
5. Jasprit Singh, "Semiconductor Devices, Basic Principles". Wiley, 2001

Electronic Density Theory

M. Phil. Physics

Course Code: PHY-728

Credit Hours: 03

Prerequisites: NIL

Objectives

The students explore the principles and use of Density Functional Theory in understanding electronic structures. Gain proficiency in foundational concepts, approximations fostering competence in computational materials science.

Learning Outcomes

- The students will learn foundational DFT principles for analyzing diverse electronic structures in materials.
- Apply DFT methodologies to simulate and interpret material behaviors.
- Demonstrate proficiency in utilizing DFT for quantum mechanics and materials science.

Course Outline

Unit 1. Basics of Electronic Theory

Electronic density Theory, Quantum Theory and the Origins of Electronic Structure, Success of independent-Electron Picture, Emergence of Quantitative Calculations, The Greatest Challenge, Electron Interaction and Correlation, Materials by Design.

Unit 2. Materials Properties

Electronic structure and the properties of matter: Electronic Ground State, Bonding and characteristic structures, volume and pressure as fundamental variable, Calculation of structural properties.

Unit 3 Structural Analysis

Structures of Crystals, Lattice, Reciprocal Lattice and Brillouin zone, excitations and the Bloch Theorem, Integration over the Brillouin zone and special symmetry Points.

Unit 4. Electronic Density Calculations

The Schrodinger equation for one-electron atoms; Energy levels. The Many-Electron Problem (N-electron interacting and non-interacting wave functions, 1- and 2-body probability densities, Overview of electronic structure methods and DFT).

Unit 5. Theoretical Modelling

Density Functional Theory, Foundations, Thomas–Fermi–Dirac Approximation, Hohenberg–Kohn Theorems, Constrained Search formulation of DFT, Extensions of Hohenberg–Kohn Theorems. Different available approximations. Born Oppenheimer Approximation. Mathematical Necessities as Functional, Hartree-Fock and Correlation, The Uniform Electron Gas characteristics and calculations.

Recommended Books/Reference Material

1. Richard M. Martin : “*Electronic structure: Basic Theory and practical methods*” Cambridge university press, 2020 (ISBN 978-1-108-42990-0 Hardback)
2. John P. Perdew and Stefan Kurth: “*Density Functionals for Non-Relativistic Coulomb Systems*”, in “*A Primer in Density Functional Theory*” V.620, 2003).

3. R. M. Dreizler, E. K. U. Gross, "*Density Functional Theory*" Springer Verlag New York, USA, 2013.

Physics of Superconductors

M. Phil. Physics

Course Code: PHY-729

Credit Hours: 03

Prerequisites: NIL

Objectives

The primary focus of this course is to provide the students a deep understanding of superconductivity, covering foundational concepts, development, and phenomenology. The students will explore critical parameters, microscopic theories, and vortex dynamics, fostering expertise in superconductors.

Learning Outcomes

- The students will be able to analyze superconducting phenomena, explaining Meissner's effect, critical superconducting parameters.
- Utilize Electromagnetic concepts to describe magnetic field penetration into superconductors.
- Examine weak links, vortex dynamics, critical fields, and flux flow in Type II superconductors.

Course Outline

Unit 1. Foundation Concepts

Basics of Superconductivity: Introductory survey, basic phenomenon, lossless currents, energy gap, critical parameters.

Unit 2. Electrodynamics of Superconductors

Development of superconductivity, Meissner effect, London equations, magnetic field penetration into a superconductor, Penetration depth and coherence length.

Unit 3. Ginzburg-Landau Model

In-depth analysis of GL model, critical field of thin films and other applications of GL equations. Microscopic theory of superconductivity.

Unit 4. Quantum Mechanical Theory

Formation of superconducting pairs, pairing energy and energy gap. BCS theory, The Bardeen-Cooper-Schrieffer (BCS) theory, Cooper pairs, lattice vibrations mediate the attractive interaction between electrons,

Unit 5. Phenomenology and Applications

Physics of different types of superconductors, Critical limitations in Superconductivity, Flux quantization, Josephson junctions and effects, weak links, Vortices in Type II superconductors, Motion of vortices, flux flow Vortex pinning, Superconducting Quantum Interference Devices (SQUIDs).

Unit 6. Unconventional superconductivity

Topological superconductors, Majorana fermions, High-temperature superconductivity, drift currents, cuprate and iron-based superconductors, Superconductivity in extreme conditions: high pressure, low dimensions, and ultrafast dynamics, Quantum materials and interfaces: interface engineering, heterostructures, and proximity effects.

Recommended Books/Reference Material

1. Peter P. Edwards, *Basic Research Needs for Superconductivity*, Wiley-VCH, 3rd edition, 2016.
2. Dzhumanov Safarali, *Theory of Conventional and Unconventional Superconductivity in the \ High- T_c Cuprates and Other Systems*, Nova Science Pub Inc, UK ed. Edition, 2013.
3. M. Tinkham, *Introduction to Superconductivity*, Dover Publications, 2nd edition, 2004.
4. Andrei Lebed, *The Physics of Organic Superconductors and Conductors*, Smart Materials, springer Series, volume 110, USA, 2011.

Condensed Matter Theory

M.Phil. Physics

Course Code: PHY-730

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding to introduce the basic notion of condensed matter physics and to familiarize the students with the various aspects of the interaction's effects. This course will be bridging the gap between basic solid state physics and quantum theory of solids.

Learning Outcomes

- Students will be able to understand various important topics of advanced modern condensed matter physics.
- They will be able to use new mathematical methods and applications to develop physics intuition, critical thinking, and problem solving skills and to conduct advanced physics research on a better foundation.

Course Outline

Unit 1. Overview of modern condensed matter physics

Emergent properties, Broken symmetry, quasiparticles, and collective phenomena: Symmetry, importance of broken symmetry, adiabatic continuity, and universality.

Unit 2. Landau's Fermi liquid theory

The free electron theory, why does the free electron theory work so well? Adiabatic continuity applied to Fermi systems, Landau's Fermi liquid theory, and physical consequences.

Unit 3. Second quantization and its applications

Bosons, Fermions, Fermion operators, quantum magnetism, spin waves and magnons, Su-Shrieffer-Heeger model of a conducting polymer chain.

Unit 4. Electron interactions

Hartree and Hartree-Fock theory, Metals in the Hartree-Fock approximation, correlation energy of jellium, Wigner crystallization, Inhomogeneous electron systems, Kohn-Hohenberg theory, The Kohn-Sham equation, Exchange-correlation functional.

Unit 5. Response functions

An overview of modern experimental techniques, linear response theory, fluctuation-dissipation theorem, dielectric response function.

Unit 6. Electron-lattice interactions

Harmonic chain, electron-phonon interaction, electrical conduction, effective electron-electron coupling.

Recommended Books/Reference Material

1. Altland, A., & Simons, B. (2006). *Condensed Matter Field Theory* (1st ed.). Cambridge University Press.
2. Cohen, M. L., & Louie, S. G. (2016). *Fundamentals of Condensed Matter Physics*. Cambridge University Press.

3. Girvin, S. M., & Yang, K. (2019). *Modern Condensed Matter Physics*. Cambridge University Press.
4. Philips, P. (2003). *Advanced Solid State Physics* (1st ed.). Westview Press.
5. Sander, L. M. (2009). *Advanced Condensed Matter Physics* (1st ed.). Cambridge University Press.

Advanced Condensed Matter Physics

M.Phil. Physics

Course Code: PHY-731

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding to introduce the basic notion of condensed matter physics and to familiarize the students with the various aspects of the interaction's effects. This course will be bridging the gap between basic solid state physics and quantum theory of solids.

Learning Outcomes

- Students will be able to understand various important topics of advanced modern condensed matter physics and to use new mathematical methods and applications.
- They will be able to develop physics intuition, critical thinking, and problem solving skills to conduct advanced physics research on a better foundation.

Course Outline

Unit 1. Interacting Bosons and superfluidity

Quantum liquids, Bose-Einstein condensation, the macroscopic wave function, superfluid properties of He II, flow quantization and vortices, quasiparticle excitations, Landau-Ginzburg theory of phase transitions, the macroscopic coherent state, spontaneous symmetry breaking, off-diagonal long range order, macroscopic quantum interference, the weakly interacting Bose gas, Bogoliubov's theory.

Unit 2. Conventional superconductivity

Phenomenology, electron-phonon effective interaction, Cooper pairs, pair amplitude, BCS ground state, pair fluctuations, ground state energy, critical magnetic field, energy gap, quasiparticle excitations, thermodynamics, experimental applications, Josephson tunneling.

Unit 3. Superfluid ^3He and unconventional superconductivity

The Fermi liquid normal state of ^3He , the pairing interaction in liquid ^3He , and superfluid phases of ^3He , unconventional superconductors.

Unit 4. Quantum Hall effects

Introduction, Landau levels, the role of disorder, currents at the edge, Laughlin state and its quasiparticles, effective Chern-Simons theory for Quantum Hall States.

Unit 5. Quantum phase transitions

Quantization with path integral methods, the path integral for Bosons, the path integral for Fermions, quantum rotor models, symmetry breaking transition and Mott insulator in a quantum rotor model, scaling, mean field solution.

Unit 6. The renormalization group

The one-dimensional Ising model, general theory of renormalization group, Berezinski-Kosterlitz-Thouless transition.

Recommended Books/Reference Material

1. Altland, A., & Simons, B. (2006). *Condensed Matter Field Theory* (1st ed.). Cambridge University Press.
2. Cohen, M. L., & Louie, S. G. (2016). *Fundamentals of Condensed Matter Physics*. Cambridge University Press.
3. Girvin, S. M., & Yang, K. (2019). *Modern Condensed Matter Physics*. Cambridge University Press.
4. Philips, P. (2003). *Advanced Solid State Physics* (1st ed.). Westview Press.
5. Sander, L. M. (2009). *Advanced Condensed Matter Physics* (1st ed.). Cambridge University Press.

Physics of Nanomaterials

M.Phil. Physics

Course Code: PHY-732

Credit Hours: 03

Pre-requisite: Nil

Objectives

The course is aimed at giving a basic introduction to chemical and physical principles in the synthesis of nanostructured materials. In addition, basic principles of fundamental physical and chemical properties of nanomaterials will be covered.

Learning Outcomes

- The student will be able to describe several synthesis methods for the fabrication of nanostructured materials.
- Qualitatively describe how nanoparticle size can affect the morphology, crystal structure, reactivity, and electrical properties.

Course Outline

Unit 1. Introduction to Nanotechnology

Nanomaterial science, Historic Developments, Classification of Nanomaterials, nanotechnology in classic art works, Quantum confinement, relevant length scales, Feynman talk on small structures, Nanoscale dimension, Moore's law and the SIA road map.

Unit 2. Theoretical Aspects of Nanostructures

Nanomaterials with unconventional electronic properties, Density of states in 3-D (bulk), 2-D (quantum well), 1-D (nanowires) and 0-D (quantum dots) structures, graphene and carbon nanotubes. Correlated Electron systems, Oxide heterostructures, 2D physics at interfaces, temperature vs. composition phase diagrams, Carbon based materials

Unit 3. Nanostructures Growth

Introduction to nanomaterials processing, Nano particle synthesis, top-down vs bottom-up approach, Fabricating nano structures (thin films), Choice of substrate, Epitaxy and growth modes, stresses in thin films, Physical Vapor Deposition (PVD) Methods for growth of thin films, molecular beam epitaxy (MBE), Sputtering, Pulsed laser deposition (PLD), a brief survey of other methods, Device fabrication.

Unit 4. Nanostructures Characterizations

Reflection High-Energy Electron Diffraction (RHEED), Spectroscopy and microscopy techniques for nanomaterials Probing electronic and optical properties, Techniques for assessing electronic behavior in nanomaterials.

Unit 5. Electrical and Magnetic Characterizations with Applications

Electrical characterizations, Magnetic characterizations. Nanomaterials applications (selected): Fundamental and industrial, Nanomaterials as drug carriers. Nanomaterials in electronics, photonics, and catalysis. Recent advancements in nanomaterials research.

Recommended Books/Reference Material

1. Binns, C. (2010). *Introduction to Nanoscience and Nanotechnology*. Wiley.
2. Guo, J., & Lu, L. (2020). *Nanoscience: Nanomaterial Nanotechnology Applications*. Engineered Science.
3. Johal, M. S., & Johnson, L. E. (2020). *Understanding Nanomaterials* (3rd ed.). CRC.
4. Lindsay, S. (2009). *Introduction to Nanoscience*. Oxford.
5. Martin, P. M. (2009). *Handbook of Deposition Technologies for Films and Coatings: Science, Applications and Technology* (3rd ed.). William Andrew.
6. Pagliaro, M. (2011). *Nano-age: How Nanotechnology Changes Our Future*. Wiley.

Spintronics

M.Phil. Physics

Course Code: PHY-733

Credit Hours: 03

Pre-requisite: Nil

Objectives

The overall aim of this course is to understand the physical principles of magnetism and transport in nanostructures with a special emphasis on applications in spin-based memory and logic.

Learning Outcomes

- Analyze a surface reconstruction
- Anticipate the stability of a given interface
- Decide what are the necessary thermodynamics concept to describe an interface
- Anticipate the behavior of molecules close to the interface

Course Outline

Unit 1. Introduction to spintronics, historic development

Introduction to electron spin-based electronics, The first-generation chalcogenide materials, and their properties, The second-generation II–VI-based diluted magnetic semiconductors (DMSs), The third-generation III–V-based diluted semiconductors, the giant magnetoresistance (GMR) effect of the magnetic metal/nonmagnetic metal hybrid structure, the tunnel magnetoresistance (TMR) effect at room temperature, The spin-transfer torque (STT), The spin Hall effect (SHE).

Unit 2. Theoretical aspects of materials with spin properties

Introduction to magnetic materials, magnetic order, exchange, anisotropy, Pauli equation, Spin-Orbit coupling, Zeeman splitting, Current density, Magnetization, Bloch states with SO coupling, Dresselhaus and Rashba spin splitting, Optical orientation and spin pumping, Stern-Gerlach experiments with electron spins, Detection of free electron spin.

Unit 3. Dynamic properties

Susceptibility and permeability tensors, FMR, Demagnetization tensors, shape-induced effects, Spin waves: Volume waves, Surface waves.

Unit 4. Spin-dependent transport and torque

AMR, GMR, TMR, and related phenomena, Spin-transfer torque, spin-orbit torque, and voltage control of magnetism

Unit 5. Device applications

High-frequency magnetic devices (inductors, circulators), Device applications: Memory, sensors, microwave oscillators and detectors.

Recommended Books/Reference Material

1. Bandyopadhyay, S., & Cahay, M. (2015). *Introduction to Spintronics*. CRC.
2. Bran, C., & Bran, C. (2022). *Novel Magnetic Properties in Curved Geometries*. MDPI
3. Dietl, T. (2010). *Spintronics, Vol. 82*. Wiley.
4. Dyakonov, M. I. (2008). *Spin Physics in Semiconductors*. Springer.
5. Hirohata, A., & Hirohata, A. (2022). *Advances in Antiferromagnetic Spintronics*. MDPI.

6. Lombardi, C. G., & Ginerva, (2009). *Spintronics Materials, Applications, and Devices*. Nova.
7. Maekawa, S. (2006). *Concepts in Spin Electronics*. Oxford.
8. Shinjo, T. (2013). *Nanomagnetism and Spintronics*. Elsevier.

Mathematical Techniques in Physics

M. Phil. Physics

Course Code: PHY-734

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding and implementation about the differential equations, their use in the real world and its quantitative analysis. They will also learn and develop an understanding about special functions and its applications.

Learning Outcomes

- Students will gain understanding about various analytical techniques used in physics.
- Students will be able to learn advanced principles and techniques used in differential equations, basic to advance level instrumentation and significance of these techniques.

Course Outline

Unit 1. Matrix and Tensors

Matrix products, Method of Faddeev, Caley-Hamilton's theorem, Functions of Matrices, Kronecker and Tensor products, eigenvalue problems. Differential geometry, chains & forms, exterior derivative, adjoint exterior derivative.

Unit 2. Operators

Wedge product, Hodge star operator, closed and co-closed forms, Laplace Beltrami operator, and connection of DG with vector algebra and matrices, applications of DG.

Unit 3. Partial Differential Equations

Partial differential equations, Heat equation, wave equations, some nonlinear equations. Klein-Gordon equation, sine-Gordon equation Burgers equation, Kortweg de Vries (KdV) equation, Backlund transformation.

Unit 4. Ordinary Differential Equations

Approximate solutions of ordinary differential equations, power series, Frobenius series, Picard iterative method. Perturbation series, normal forms, the WKB approximation, the Lioville-Green technique.

Unit 5. Green's Function

Differential equations and Green's functions, types of boundary conditions, source and boundary points, Green's function for steady waves, wave equation, diffusion equation.

Recommended books/reference material

1. Arfken G B, H J Weber, (1995), *Mathematical Methods for Physicists*, A. Press, New York.
2. Kreyszig E, (1999) *Advanced Engineering Mathematics*, John Wiley.
3. Stephenson G, P M Radmore, (1990) *Advanced Mathematical Methods for Engineering and Science Students*, Cambridge University Press.

Experimental Methods

M. Phil. Physics

Course Code: PHY-735

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding and implementation about the experimental techniques, their use and its qualitative analysis. They will also learn and develop understanding about special features and their applications.

Learning Outcomes

- Students will gain understanding about various experimental techniques used in physics.
- Students will be able to learn advanced principles and techniques used.
- Basic to advance level instrumentation and significance of these techniques.

Course Outline

Unit 1. Data Collection

Data collection and organization statistical treatment of data, the importance of estimating errors, systematic and random errors systematic errors, Error calculations in Practice, complicated functions, Errors and Experimental Procedure. Accuracy and Precision.

Unit 2. Vacuum

Basics of vacuum and its importance in experimental physics vacuum production and its measurement. General characteristics of measuring instruments.

Unit 3. X-rays Diffraction

Basics of X-ray diffraction, x-ray spectra, Bragg's law and importance, construction and operation of diffractometer, data analysis, Qualitative (Hanna Walt method), Quantitative (matrix flushing methods).

Unit 4. Spectroscopy

Basics of spectroscopy and importance, Lambert-Beer's law, statement, explanation, advantages, disadvantages, limitations. Construction and Operation of spectrophotometer, Qualitative, Quantitative analysis of data.

Unit 5. Microscopy

Basics of NMR, experimentation, benefits, health hazards, spectra interpretations. SEM/TEM components, ray diagrams, operation, performance, micrographs analysis. Basics of experimental techniques in Nuclear Medicine.

Recommended books/reference materials

1. Amelinckx, S., Dyck, D. V., Landuyt, J. V., & Tendeloo, G. V. (1997). *Electron Microscopy*. John Wiley & Sons.
2. Beck, J. A. (1979). *Electron Microscopy and Microanalysis of Crystalline Materials*. Applied Science Publishers Ltd.
3. Cullity, B. D. (1987). *Elements of X-ray Diffraction*. Addison-Wesley Publishing Company.
4. Sze, S. M. (1981). *Physics of Semiconductor Devices*. John Wiley & Sons.
5. Vial, J. C., & Derrian, J. (1999). *Porous Silicon Science & Technology*. Springer Verlag.

6. Wroolfson, R., & Jay, M. (1999). *Physics for Scientists and Engineers*. Addison Wesley/Longman.

Quantum Theory of Materials

M. Phil. Physics

Course Code: PHY-736

Credit Hours: 03

Pre-requisite: Nil

Objectives

Students will acquire understanding and implementation about the electronic structures, their use, and their functioning. They will also learn and develop understanding about advanced principles and their applications.

Learning Outcomes

- Students will gain understanding about various advanced structures used in physics.
- Students will be able to learn advanced principles and techniques used.
- Basic to advance level instrumentation and significance of structures.

Course Outline

Unit 1. Electronic Structure

Electronic Structure of Solids, Independent particles in periodic potential, Bloch's theorem, Nearly free electron in three dimensions, band structures of solids, tight binding model.

Unit 2. Hartree-Fock approximation

Hartree-Fock approximation, case of helium atom, exchange and correlation in electron gas, screening, methods of calculation band structures, Wannier functions, pseudo-potentials.

Unit 3. Electronic Properties

Transport phenomena, Boltzmann equation and electrical conduction, Solids in External magnetic field, Pauli-paramagnetism of conduction electrons, Landau-diamagnetism of conduction electrons, De Haas-van Alphen effect, and Quantum Hall effect.

Unit 4. Optical Properties

Optical properties, Kramer-Kronig relation, excitons, Mott-Wannier excitons.

Unit 5. Optical Properties

Bardeen-Cooper-Schrieffer (BCS) Theory, Ginzburg-Landau theory, Flux quantization, Josephson Effect, high T_c superconductivity.

Unit 6. Magnetic Properties

The two dimensional electron gas, Quantum wells, Multi-quantum wells structures and super lattices, Doping super lattices, Band structure engineering of semiconductor super lattices, Quantum well lasers, Use of quantum wells in enhancement of the efficiency of solar cells, MBE, its role in forming low dimensional structures, Classical Hall Effect, Quantum Hall Effect, In 2-DEG, Si-MOSFET at low temperature and high magnetic field, In 2-DEG, Al Ga As / Ga As system, Landow Energy levels with effect of low temperature and high magnetic field.

Recommended books/reference materials

1. Ashcroft, N. W., & Mermin, N. D. (1976). *Solid State Physics*.
2. Elliott, S. R. (1998). *The Physics and Chemistry of Solids*. Wiley.
3. Grasso, P. G., & Parravicini, G. P. (2000). *Solid State Physics*.
4. Kittel, C. (1996). *Introduction to Solid State Physics* (7th ed.).
5. Ziman, J. M. (1972). *Principles of the Theory of Solids*.

Cold Plasma Science

M. Phil. Physics

Course Code: PHY-737

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course is aimed to provide a comprehensive understanding of cold plasma physics, encompassing its natural occurrences, technological applications, and fundamental principles.

Learning Outcomes

- Students will demonstrate proficiency in analyzing plasma phenomena in nature and technology.
- They will be able to explain collision processes in plasma, including elastic and inelastic collisions.
- They will develop an understanding of different types of discharges in plasma, their structures, and sustaining mechanisms.

Course Outline

Unit 1. Plasma in Nature

Plasma, Plasmas in Nature, Plasmas in Technology, Orders of Magnitude, Introduction to low temperature plasmas, Non-equilibrium non-thermal plasma, Degree of ionization, Concept of a Distribution Function, Forms of the Distribution Function, Boltzmann Equilibrium, Electron temperature, Electron energy distribution function (EEDF), Interactions between Charged Particles, Coulomb's law, Debye Length, Quasi-neutrality, Plasma Parameter, Plasma Frequency, Defining Characteristics of a Plasma,

Unit 2. Collision in Plasma

Collisions, Elastic collisions, Inelastic collisions, Collision processes, Collision cross section, Mean free path, Creating a low temperature plasma, Low pressure plasmas, High pressure plasmas, Fluid Approach, Fluid equations, Continuity, Momentum conservation, Equations of state, Particle Transport and Loss, Diffusion, Mobility, Ambipolar Diffusion, Electrical breakdown, Secondary electron emission and avalanches, Townsend's theory, Paschen's law, Minimum breakdown voltage.

Unit 3. Discharge in Plasma

Self-sustaining glow discharge, Discharge structure, DC discharges, Sheath formation in a dc discharge, Sheath potential at a floating wall, DC magnetron discharges, Pulsed DC discharges, Plasma Sources, Capacitively coupled plasmas (CCP), Circuit models, RF sheaths, Ion energy distribution functions, Plasma sustaining mechanisms, Dual frequency capacitively coupled plasmas, Plasma Sources, Inductively coupled plasmas (ICP), Inductive power coupling, E to H transition, Wave-driven discharges.

Unit 4. Breakdown in Plasma

Electrical Breakdown at Atmospheric Pressure, Streamer Production, Sparking, Arc Sources, Linear Arcs, Plasma Torches and Arc Jets, Transferred Arc, Corona Discharges, Non-thermal plasmas at high pressure,

Unit 5. Application of low temperature Plasma

The Dielectric Barrier Discharge (DBD), Filamentary discharges, Uniform discharges, Atmospheric pressure plasma jets, Micro-plasmas, Diagnostics/Probes, Applications of low temperature plasmas.

Recommended books/reference materials.

1. Chambert, P., & Braithwaite, N. (2011). *Physics of Radio-Frequency Plasmas*. Cambridge University Press.
2. Chapman, B. (1980). *Glow Discharge Processes*. John Wiley and Sons.
3. Chen, F. F., & Chang, J. P. (2003). *Lecture notes on Principles of Plasma Processing*. Kluwer Academics/Plenum Publishers.
4. Grill, A. (1993). *Cold Plasma in Materials Fabrication*. IEEE Press.
5. Lieberman, M. A., & Lichtenberg, A. J. (2005). *Principles of Plasma Discharges and Materials Processing* (2nd ed.). John Wiley and Sons.
6. Raizer, Y. P. (1991). *Gas Discharge Physics*. Springer-Verlag.
7. Roth, J. R. (2001). *Industrial Plasma Engineering: Vol I*. IOP.

Semiconductors and Applications

M. Phil. Physics

Course Code: PHY-738

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course provides an in-depth exploration of semiconductor materials, devices, and fabrication techniques. Through a combination of lectures, discussions, and hands-on laboratory exercises, students will gain a comprehensive understanding of the principles underlying semiconductor technology and its applications in various fields such as electronics, photonics, and renewable energy.

Learning Outcomes

- To analyze the fabrication processes involved in semiconductor device manufacturing.
- To evaluate the performance characteristics and limitations of semiconductor devices.
- To explore different semiconductor device structures and their operating principles.
- To investigate emerging trends and advancements in semiconductor technology.
- To understand the fundamental properties of semiconductor materials.

Course Outline

Unit 1. Semiconductors

Atomic structure and bonding in semiconductors, Band theory and energy band diagrams, Intrinsic and extrinsic semiconductors, Doping and carrier concentration, Silicon and other semiconductors as device materials; Effect on carrier lifetime and mobility; bulk crystal growth; effect of segregation coefficient, GaAs crystal growth techniques, crystal characterization,

Unit 2. Growth Mechanisms

Epitaxial growth, with molecular beam epitaxy and multiplayer structures, defects in epitaxial layers. Active regions; Dopants and their limits of solubility; diffusion doping, thermal oxidation, dielectric and polysilicon deposition, metallization, wet and dry etching, optical and next-generation lithographic methods.

Unit 3. Semiconductor Fabrication Processes

Physical Vapor Deposition (PVD), Evaporation, Sputtering, Molecular Beam Epitaxy (MBE), Chemical Vapor Deposition (CVD), Thermal CVD, Plasma Enhanced CVD (PECVD), Atomic Layer Deposition (ALD), Chemical Bath Deposition (CBD), Spin Coating, Electroplating and Electrochemical Deposition, metallization, and electroplating processes. Crystal growth techniques: Czochralski method, epitaxy, Photolithography, and patterning.

Unit 4. Advanced Semiconductor Devices and Applications

Schottky and ohmic contacts. Study of quantum wells, Photovoltaics, super lattice, and their application in the efficiency enhancement of solar cells and other related devices. Tandem Thin film Solar cells, HEMT, Solid state heterojunction lasers. FET devices and theory; MOSFET; MOS capacitor, accumulation, depletion and inversion modes, enhancement, and depletion modes of operation; n-and p-channel devices.

Unit 5. Operating Relations and Scaling in Semiconductor Devices

I-V operating relations in active and saturation regions, threshold voltage, NMOS and CMOS inverters, gates and flip-flops, implication for performance of scaling down device size, GaAs FET; principle of operation, linear and saturation characteristics, GaAs FET physical and empirical modeling.

Recommended books/reference materials

1. Strassman, B. G., & Banerjee, S. K. (2009). *Solid State Electronic Devices* (6th ed.). PHS.
2. Sze, S. M. (1981). *Physics of Semiconductor Devices*. John Wiley & Sons.
3. Sze, S. M. (2002). *Semiconductor Devices: Physics and Technology* (2nd ed.). John Wiley & Sons.
4. Taur, Y., & Ning, T. H. (1998). *Fundamentals of Modern VLSI Devices* (1st ed.). CUP.
5. Warner, R. M., & Grung, B. L. (1999). *MOSFET: Theory and Design* (1st ed.). OUP.

Surface Physics

M. Phil. Physics

Course Code: PHY-739

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course structure aims to provide PhD-level students with a comprehensive understanding of surface energy physics, covering both theoretical foundations and practical applications in interdisciplinary fields

Learning Outcomes

- Demonstrate a deep understanding of the theoretical principles governing surface energy.
- Apply advanced mathematical and computational models to describe and predict surface energy effects in various materials and systems.
- Develop understanding of characterizing surface energy properties using state-of-the-art techniques such as surface tension measurements, atomic force microscopy, and contact angle analysis.

Course Outline

Unit 1. Fundamentals of Surface Energy Physics

Introduction to surface energy concepts and definitions, Surface tension and its implications in material science, Thermodynamics of surfaces and interfaces, Basic mechanisms (diffusion, sputtering, ablation and evaporation) involved in the deposition process, concept of microstructure (qualitative analysis), micro-structural scale and parameters.

Unit 2. Defects in Thin Films

Grain size, dislocation and dislocation density, inter-atomic bonding in solids, polarization forces, crystalline and amorphous phases, specimen preparation (sampling, mounting, grinding, polishing and etching).

Unit 3. Deposition Techniques

Physical vapor deposition, thermal evaporation, electron beam evaporation, DC sputtering, DC Magnetron sputtering, Magnetron sputtering, RF sputtering, molecular beam epitaxy, chemical solution deposition, chemical vapor deposition (CVD), low pressure CVD, plasma enhanced CVD, electro-deposition, pulse laser deposition.

Unit 4. Nucleation and Growth

Nucleation and growth of films on substrate, ion beam deposition, electron microscopy (why we use x-rays instead of electron beam for diffraction analysis), microanalysis in electron microscopy, chemical analysis of surface composition, quantitative analysis of microstructures.

Unit 5. Surface Analysis Techniques

Auger electron spectroscopy, Secondary ion mass spectroscopy, Secondary electron microscopy, Scanning tunneling microscopy, Low-energy electron diffraction, reflection high-energy electron diffraction, Rutherford backscattering.

Recommended books/reference material

1. Brandon, D., & Kaplan, W. D. (Year). *Microstructural Characterization of Materials*. Technion, Israel Institute of Technology, Israel: John Wiley & Sons.
2. Russ, J. C. (Year). *The Image Processing Handbook* (2nd ed.). Boca Raton, FL: CRC Press.
3. Villars, P., Calvert, L. D., & Pearson. (Year). *Handbook of Crystallographic Data for Intermetallic Phases* (Vols. 1-3). Metals Park, OH: American Society for Metals.

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Climate Physics

M. Phil. Physics

Course Code: PHY-740

Credit Hours: 03

Pre-requisite: Nil

Objectives

Climate Physics course provides a comprehensive understanding of the physical processes governing Earth's climate system, encompassing atmospheric dynamics, thermodynamics, oceanography, and their interactions, to analyze and predict climate patterns and variability

Learning Outcomes

- Students will develop advanced proficiency in applying fundamental principles of physics to analyze and model complex climate systems, enabling them to understand and predict climate phenomena.
- They will acquire critical skills in evaluating climate data, conducting advanced research, and communicating their findings effectively, contributing to the broader scientific discourse on climate change and its implications.

Course Outline

Unit 1. Green House Effect

The economic system, living in green house, enjoying the sun, Transport of matter, Energy and momentum, the social and political context. Black body radiation, The emission spectrum of sun, The transition electric dipole moment, The Einstein Coefficients, Lambert – Beer's law, The spectroscopy of bio-molecules, Solar UV and life, The ozone filter. The energy Balance, (Zero-dimensional Greenhouse Model), elements of weather and climate, climate variations and modeling.

Unit 2. Fluid Dynamics

Diffusion, flow in rivers, ground water. Flow equations of fluid Dynamics, Turbulence, Turbulence Diffusion, Gaussian plumes in air, Turbulent jets and planes the concept of sound, sound pressure level, frequency & propagation, sound level, measuring transient noise, the acoustic environment, Hazardous effects of noise, noise control.

Unit 3. Radioactivity

Radioactive decay law, sources of radiation, Interaction of Radiation with matter, Measuring Radiation, Nuclear Fuel Cycle, Sources of Radioactive waste, Health Hazards, Radioactive waste management. Measuring Radiation, Nuclear Fuel Cycle, Sources of Radioactive waste, Health Hazards, Radioactive waste management.

Unit 4. Data Analysis

Data collection and organization, statistical analysis of climatic data, climatic indices, General characteristics of measuring equipment. Measurement of temperature, air humidity, surface wind velocity, Radiation balance, precipitation, Atmospheric Pressure, automatic weather stations. Composition & Structure of atmosphere, Air mass classification.

Unit 5. Thermodynamics

Thermodynamic characteristics, General Circulation. First law of thermodynamics and enthalpy; adiabatic processes and potential temperature. The second law of thermodynamics; entropy; thermodynamics of water vapour and moist air;

thermodynamic properties of the water substance; phase transition of water; water vapour and moist air; Clausius-Clapeyron's equation

Recommended books/reference material1.

1. Booker, E., & Van Gron Belle, R. (1999). *Environmental Physics* (2nd ed.). John Wiley and Sons.
2. Grasseur, G. P. (1999). *Atmospheric Chemistry & Global Change* (1st ed.). Oxford.
3. Houghton. (1985). *Handbook of Applied Metrology* (1st ed.). Wiley.
4. Praxis Publication. (1998). *Physics of Environmental and Climate*.
5. SMRC. (2004). *The Status of Climate Variation In Pakistan & Its Impact* (1st ed.). SAARC Met. Research Centre, No. 10.
6. Thompson, R. D. (1997). *Applied Climatology* (1st ed.). Routledge.
7. Vonstroch, H. (2001). *Statistical Analysis in Climate Research* (1st ed.). Oxford.
8. Wallace, J. M. (1997). *Atmospheric Science* (1st ed.). Academic Press.

Advances in Spectroscopy

M. Phil. Physics

Course Code: PHY-741

Credit Hours: 03

Pre-requisite: Nil

Objectives

Advanced Atomic Spectroscopy course delves into the theoretical foundations and practical applications of spectroscopic techniques at an advanced level, exploring cutting-edge methodologies for analyzing atomic structures and interactions.

Learning Outcomes

- Students will gain proficiency in advanced spectroscopic techniques, enabling them to analyze complex atomic structures and interactions with precision.
- They will develop the ability to design and implement innovative spectroscopic experiments, interpret spectral data accurately, and apply findings to diverse scientific disciplines such as materials science, chemistry, and astrophysics.

Course Outline

Unit 1. Atomic Spectra

One-electron atoms: Atomic spectra and energy levels of Hydrogen atom, Schrödinger equation for one electron system, wave functions of hydrogen atom, spatial distribution and expectation values of electron in different quantum states.

Unit 2. Single and two electron system

Energy corrections: relativistic correction, spin orbit correction and Darwin correction. Extension to other single valence electron atoms. Two electron system: electrostatic interaction, ground and excited state of Helium atom, Pauli Exclusion Principle and Hund's Rules.

Unit 3. LS and JJ coupling

Electron configuration and coupling of angular momenta, Different coupling schemes like L S coupling, J J coupling and intermediate coupling schemes. Einstein coefficients, transition probabilities and electric dipole approximation selection rules.

Unit 4. Photon theory

Single photon absorption and emission, two photon and multi-photon absorption, fine structure and hyperfine structure, Rydberg atom and its properties, lifetimes and line profiles of spectral lines, interaction of atoms with static external fields.

Unit 5. Experimental Spectroscopy

Experimental techniques in spectroscopy: laser absorption spectroscopy, opto-galvanic spectroscopy, laser induced breakdown spectroscopy and Doppler free spectroscopy.

Recommended books/reference materials

1. Arkin, W. T. (2006). *Trends in Lasers and Electro-Optics Research*. Nova Science Publishers.
2. Bransden, B. H., & Joachain, C. J. (1997). *Physics of Atoms and Molecules*. Addison-Wesley Longman Ltd.
3. Demtroeder, W. (1999). *Laser Spectroscopy*. John Wiley & Sons.

4. Gallagher, T. F. (1994). *Rydberg Atoms*. Cambridge University Press.
5. Heckmann, E., & Trabert. (1989). *Introduction to the Spectroscopy of Atoms*. Elsevier Science Publishing Company.
6. Pradhan, A. K., & Nahar, S. N. (2010). *Atomic Astrophysics and Spectroscopy*. Cambridge University Press.

Magnetic Materials

M. Phil. Physics

Course Code: PHY-742

Credit Hours: 03

Pre-requisite: Nil

Objectives

Magnetic Materials Science course explores the principles, properties, and applications of magnetic materials, delving into advanced theories and experimental techniques essential for designing next-generation magnetic devices and technologies.

Learning Outcomes

- Students will gain a deep understanding of the principles underlying the magnetic behavior of materials, including magnetism origins, magnetic domains, and magnetic interactions.
- They will develop advanced skills in experimental techniques for characterizing magnetic materials, enabling them to design and engineer novel materials with tailored magnetic properties for various technological applications such as data storage, sensors, and magnetic imaging.

Course Outline

Unit 1. Basic Magnetism

Introductory magnetism; Review of diamagnetism and paramagnetism. Magnetic moments, magnetic dipoles, Magnetic parameters and their relation. Pauli paramagnetism. Wave functions of magnetic ions (3d, 4f); spin-orbit coupling.

Unit 2. Thermodynamics of magnetism

Crystal field effects, Jahn-Teller theorem. Thermodynamics of magnetism. Adiabatic demagnetization. Ferromagnetism; Thermodynamics of ferromagnetic systems. Quantum mechanical treatment, Exchange interactions, Heisenberg and Ising model. Indirect exchange (super exchange and RKKY).

Unit 3. Spintronics

Spin excitations, spin waves, magnons, application to the temperature dependences of magnetization and specific heat. Band ferromagnetism. Criteria for band ferromagnetism; examples of metallic ferromagnets. Anti-Ferromagnetism; Type I, Type II Antiferromagnets, Ferrimagnetism, Ferrites, Applications of ferrites.

Unit 4. Magnetic Anisotropy

Domain Structures and related properties of ferromagnets, Magnetic Anisotropy, basic phenomenology. Uniaxial, Cubic and surface Anisotropy, Effects in bulk materials and thin films. Domain Formation, Domain wall width. Relation to magnetic anisotropy. 90° , 180° domain walls.

Unit 5. Magnetic Domains

Observation of domains, Domain wall motion, pinning of domain walls; Magnetization in low and high fields. Magnetization in soft and hard magnets, Magnetization reversal mechanisms. Finite size effects in magnetic materials, thin films, and surface effects

Recommended books/reference material1.

1. Aharon, A. (1998). *Introduction to the theory of Ferromagnetism*. Oxford Press.
2. Blundell, S. (2001). *Magnetism in Condensed Matter*. Oxford Press.

3. Cullity, B. D. (1972). *Introduction to magnetic materials*. Addison-Wesley Publishing Company.
4. Kittel, C. (2005). *Introduction to Solid State Physics* (8th ed.). John Wiley.
5. Morrish, A. H. (1965). *The Physical Principles of Magnetism*. John Wiley.
6. Skomski, R., & Coey, J. M. D. (1999). *Permanent Magnetism*. IOP Publishing.

Thermoelectrics

M. Phil. Physics

Course Code: PHY-743

Credit Hours: 03

Pre-requisite: Nil

Objectives

The Thermoelectric Materials course explores the principles, synthesis methods, characterization techniques, and applications of materials with thermoelectric properties, crucial for energy conversion and waste heat recovery technologies.

Learning Outcomes

- Students will gain a deep understanding of the fundamental principles governing the thermoelectric behavior of materials, enabling them to design and optimize materials for efficient conversion between thermal and electrical energy.
- They will acquire practical skills in synthesizing, characterizing, and evaluating thermoelectric materials, empowering them to contribute to advancements in sustainable energy technologies and address challenges in waste heat recovery and renewable energy generation.

Course Outline

Unit 1. Thermoelectricity

Introduction to thermoelectricity, Seebeck Effect, Peltier Effect, Thomson Effect, Theory of transport, Thermoelectric power generation, Thermoelectric refrigeration, Magnetic field effects, use of metals, insulators and semiconductors for thermoelectric applications.

Unit 2. Conductivity

Seebeck coefficient, power factor, figure of merit, mobility and effective mass, thermal conductivity, electrical conductivity, effect of temperature, Thermomagnetic effects, Techniques for minimizing thermal conductivity, Techniques for improving electrical conductivity, Thermoelectric material growth techniques, sintering, thin films, thick films, Characterization techniques, Seebeck system, Hall Effect, Photoluminescence Spectroscopy

Unit 3. Thermoelectric structures

classification of different materials; metals, semiconductors and insulators, Bismuth Telluride and related compounds, Lead telluride and related compounds, Zinc Oxide, Gallium Nitride, Indium Gallium Nitride, Silicon-Germanium Alloy.

Unit 4. Performance parameters

Skutterudites and Clathrates, performance parameters; Seebeck coefficient, power factor, figure of merit, mobility and effective mass, thermal conductivity, electrical conductivity, effect of temperature.

Unit 5. Thermoelectric Power Generation

Thermoelectric modules for power generation, Theory of nanostructures, Thermal conduction in low dimensional, Growth of nanostructures.

Recommended books/reference materials

1. Goldsmid, H. J. (2019). *Introduction to Thermoelectricity* (9th ed.). Springer Series.
2. Rowe, D. M. (Ed.). (2006). *Thermoelectrics Handbook: Macro to Nano*. CRC Press/Taylor & Francis.
3. Spry, M. (2019). *Reframing Thermoelectric Fundamentals For Greater Understanding*. Independently Published.

Photovoltaic Devices

M. Phil. Physics

Course Code: PHY-744

Credit Hours: 03

Prerequisites: Nil

Objectives

Students will explore a variety of photovoltaic devices such as solar cell, photo detectors and Solar thermal. They will gain expertise in materials, technologies and advanced concepts, fostering innovative research and applications in solar energy.

Learning Outcomes

- The students will be able to analyze semiconductor physics intricacies to evaluate materials for high-efficiency devices
- Design photovoltaic devices architectures.
- Examine optoelectronic processes and utilize computational tools for analysis.

Course Outline

Unit 1. Material Characteristics for Photovoltaic Effects

Energy band theory treatment of low and wide bandgap semiconductors, Charge carrier transport, Interface characteristics between materials. Effective mass of carriers (electrons and holes).

Unit 2. Basics of Photovoltaic Devices

Sunlight characteristics and earth environment. Light matter interaction, Optical response of materials, absorption coefficient, Principles of energy conversion, analytical performance parameters.

Unit 3. Energy Efficiency Processes

Solar Spectrum, Incident irradiation characteristics, angles and wavelengths, operating temperature of devices, defects and interface defects. Reflections and losses, soiling effects, Shading and sunlight tracking.

Unit 4. Thin Films and Dye Sensitized Photovoltaic Cells

Thin films, Fabrication and working, Physical and chemical methods, Principles, materials, and design of dye-sensitized solar cells (DSSCs), PV system design and engineering, Efficiency and stability enhancement of dye-sensitized photovoltaic cells

Unit 5. Photo detectors and Solar Thermal Applications

Photo detection principles, thermal photo detector technologies and their working mechanisms, quantum dots, and emerging Nanomaterials, solar thermal systems and their performance optimization, environmental impact and sustainability aspects of photo detectors and solar thermal systems.

Recommended books/reference material

1. Conibeer, G. J. (2014). *Solar Cell Materials*. Wiley Series.
2. Dupré, O., Vaillon, R., & Green, M. A. (2017). *Thermal Behavior of Photovoltaic Devices*. Springer-Verlag Berlin Heidelberg.
3. Honsberg, C., & Bowden, S. (2013). *Photovoltaics: Devices, Systems and Applications*. Springer-Verlag Berlin Heidelberg.

4. Singh, J. (2001). *Semiconductor Devices, Basic Principles*. Wiley.

Density Functional Theory

M. Phil. Physics

Course Code: PHY-745

Credit Hours: 03

Prerequisites: Nil

Objectives

The students delve into understanding electronic structures through Density Functional Theory, mastering foundational concepts and approximations. Proficiency is gained, fostering competence in computational materials science.

Learning Outcomes

- The students will acquire foundational principles of Density Functional Theory for analyzing varied electronic structures in materials.
- Use DFT methodologies to model and interpret material behaviors effectively.
- Exhibit adeptness in applying Density Functional Theory for a variety of materials science applications.

Course Outline

Unit 1. Electron and electronic density

The Schrodinger equation for one-electron atoms; Energy levels. The Many-Electron Problem (N-electron interacting and non-interacting wave functions, 1- and 2-body probability densities,

Unit 2. Characteristics of Materials

Stability and properties of matter, Nature of materials determination, Density of states and partial density of states, Hybridization effects in material properties.

Unit 3 Structural Evaluation and Characteristics

Structures of materials, Brillouin zones formation, Bloch Theorem, Integration over the Brillouin zone and symmetry Points.

Unit 4. Quantum Mechanical Treatment of Electron density

Hamiltonian for electron density, Thomas–Fermi–Dirac Approximation, Hohenberg–Kohn Theorems, Born Oppenheimer Approximations. Mathematical Necessities as Functional, Hartree-Fock and Correlation, The Uniform Electron Gas characteristics and calculations. The Kohn–Sham variational equations, Solution of the Self-Consistent Coupled Kohn–Sham Equations, Achieving Self-Consistency, Force and Stress, Interpretation of the Exchange–Correlation Potential V_{xc} , Meaning of the Eigenvalues, Intricacies of Exact Kohn–Sham Theory, Time-Dependent Density Functional Theory, Other Generalizations of the Kohn–Sham Approach

Unit 5. Approximations and Applying Density Functional Theory

Local Density Approximation (LDA), Gradient Expansion and Generalized-Gradient Approximations (GGAs), Local (Spin) Density Approximation (LSDA), Hybrids, Orbital Functional, Time-Dependent Density Functional Theory, Runge-Gross Theorem, E_{xc} and the Exchange–Correlation, , , LDA and GGA Expressions for the Potential $V \sigma_{xc}(r)$, Beyond the Local Density and Generalized Gradient Approximations, Generalized Kohn–Sham and Bandgaps, Hybrid Functionals and range separation, functionals of the Kinetic Energy Density: Meta-GGAs, Optimized

Effective Potential, Localized-Orbital Approaches: SIC and DFT+U, Functionals Derived from Response Functions, Nonlocal Functionals for van der Waals Dispersion Interactions, Modified Becke–Johnson Functional for V_{xc} , Comparison of different functionals.

Recommended Books/Reference Material

4. Dereizler, R. M., & Gross, E. K. U. (2013). *Density Functional Theory*. Springer New York.
5. Martin, R. M. (2020). *Electronic Structure: Basic Theory and Practical Methods*. Cambridge University Press.
6. Sholl, D. S., & Steckel, J. A. (2011). *Density Functional Theory: A Practical Introduction*. John Wiley & Sons.
7. Tsuneda, T. (2014). *Density Functional Theory in Quantum Chemistry*. Springer Science & Business Media.

Advanced Topics in Superconductivity

M. Phil. Physics

Course Code: PHY-746

Credit Hours: 03

Prerequisites: Nil

Objectives

The students will delve deeply into the intricacies of superconductivity, encompassing foundational principles, historical development, and advanced phenomenology. The curriculum explores critical parameters, microscopic theories, and vortex dynamics, cultivating specialized expertise in superconductive phenomena.

Learning Outcomes

- The students will learn principles of High- T_c Superconductors' evolution, optimization, and cuprate superconductivity analysis.
- Explore correlated fermions, exotic superconductors, and crystal-field excitations in advanced materials.
- Understand phase transitions, transport properties, and novel phenomena in high-temperature superconductors.

Course Outline

Unit 1. High Temperature Superconductivity

High Temperature Superconductivity, Evolution of High- T_c Superconductors (HTSC's), Different Factors which govern the optimization of High- T_c Superconductive Cuprates Involving Bi, Tl or Pb, Cu, CuTl, Superconductivity in Cuprates and Other Oxides.

Unit 2. HTSCs Analysis

Superconducting Pairing in Layered Superconductors, Superconductivity in High Magnetic Fields, Non-equilibrium Superconductivity, Crystal-Field Excitations in High- T_c Superconducting Materials, correlated fermions systems, Dirac materials, exotic superconductors, Kondo effect, and Anderson localization.

Unit 3 Characteristic Effects

Transport Properties in the Mixed State of High Temperature Superconductors, Physics of Josephson Effect and Recent Advances, Superconductivity and Magnetism in Heavy-Fermion Compounds, Nuclear Magnetic Resonance Studies in highly correlated systems

Unit 4. Phase Transitions

Phase Transitions: Transitions in presence of supercurrents, BKT Transitions, Quasi-particle excitations associated in a lattice, Fluctuation effects during transitions.

Unit 5. Novel Superconducting Materials

Emerging trends in novel superconductor research, graphite based superconductors C_6Y_b and C_6C_a and MgB_2 Superconductors. Lanthanum decahydride (LaH_{10}), superconductivity in Iron selenide (FeSe) monolayers deposited on strontium titanate ($SrTiO_3$) and High T_c hydrogen sulfide (H_2S) superconductors.

Recommended Books/Reference Material

1. Annett, J. F. (2004). *Superconductivity, Superfluids and Condensates* (1st ed.). Oxford University Press.
2. Dzhumanov, S. (2013). *Theory of Conventional and Unconventional Superconductivity in the High-T_c Cuprates and Other Systems* (UK ed.). Nova Science Publishers.
3. Edwards, P. P. (2016). *Basic Research Needs for Superconductivity* (3rd ed.). Wiley-VCH.
4. Lebed, A. (2011). *The Physics of Organic Superconductors and Conductors* (Smart Materials, Vol. 110). Springer.
5. Tsuneto, T. (2005). *Superconductivity and Superconductivity* (1st ed.). Cambridge University Press.

Optoelectronics

M. Phil. Physics

Course Code: PHY-747

Credit Hours: 03

Pre-requisite: Nil

Objectives

The course is aimed at gaining the understanding of electromagnetic wave properties , quantum effects of light including their applications in optoelectronic devices and to learn about the electron-photon processes, image sensor technologies, and recent advancements in optoelectronics for industry relevance.

Learning Outcomes

- Students will gain a deep understanding of light as an electromagnetic wave, including the solar energy spectrum, wave equations, and the correlation between energy and wavelengths across the electromagnetic spectrum.
- Students will learn about electron-photon and photon-electron processes, including the principles, design, and applications of light-emitting devices (LEDs), lasers, and image sensors

Course Outline

Unit 1. Light as Electromagnetic wave

Solar energy spectrum, Energy-wavelengths co-relation of Electromagnetic Spectrum, Wave Equation, group and phase velocity, Snell's law, Maxwell and Fresnel's equations, Optical Resonators.

Unit 2. Quantum Effects of Light

Optical Tunneling, Coherence, Diffraction, Quantum mechanical physics, semiconductors physics, Einstein relations, , device principles, I-V characteristics, equivalent circuit, temperature effects, materials, devices, and efficiencies.

Unit 3. Electron–photon & Photon-electron processes

Principles, design, and applications light-emitting-devices (LED), Carrier radiative recombination and Stimulated processes, lasing mechanism, types of lasers. Photoconductivity and Photovoltaic effect, photo-conductor, photo-detector, photo diode and solar cells. Electromagnetic wave propagation, Optical fiber, Optical waveguides, Optical amplifiers, Optical sources, Optical detectors, light polarization, and modulation Optical systems for communication.

Unit 4. Image Sensors

P-N junction, photodiode science and operation, avalanche and hetero-junction photodiodes, phototransistors, photoconductive gain, Charge-Coupled Devices (CCDs), complementary metal-oxide semiconductor Devices (CMOS) Image Sensors.

Unit 5. Complement technologies and recent advancement

Thin film based inorganic homo/hetero-structures for enhancing the optoelectronic capability of fabricated devices and other related perspectives to strengthen the optoelectronic industry.

Recommended books/reference material

1. Anderson, B. L., & Anderson, R. L. (2013). *Fundamentals of semiconductor devices* (3rd ed.). McGraw Hill Companies, Inc.
2. Ashcroft, N. W., & Mermin, N. D. (2011). *Solid state physics* (Reprint). Cengage Learning.
3. Bhattacharya, P. (1994). *Semiconductor optoelectronic devices*. Prentice Hall.
4. Kasap, S. O. (2001). *Optoelectronics and photonics: Principles and practices*. Prentice Hall.
5. Wilson, J., & Hawkes, (2001) J. *Optoelectronics: An introduction* (3rd ed.). Prentice Hall.

Electronic Structure Theory of Solids

M. Phil. Physics

Course Code: PHY-748

Credit Hours: 03

Pre-requisite: Nil

Objectives

The core notion is the electronic band dispersion: how it is formed, how it defines the charge dynamics, how it is modified upon perturbing the Hamiltonian and accounting for additional electronic interactions.

Learning Outcomes

- Students will be able to analyze and predict the electronic properties of crystalline materials using quantum mechanical models and computational methods.
- Upon completion, students will develop the skills to interpret experimental data related to electronic structure in crystals, enabling them to make informed decisions in materials science and engineering applications.

Course Outline

Unit 1. Formation of the electronic band structure

Tracking the formation of the electronic band structure with different models, Singling out common aspects of the electronic states in the periodic potential, Similarity of the electronic states in the periodic crystal to the free electronic states in vacuum Packets of plane waves and Bloch waves, Band structure as a basis for understanding electronic properties of materials

Unit 2. Multiple electrons inside a crystal

Band filling, Fermi surface, electron count Mean-field approximation, Photoemission, essence of electron spectroscopy, spectrum of a matrix in mathematics, photoemission process, conservation of energy and momentum; photoemission as a projection of the initial state to the (single-particle) plane waves, Examples of the electronic structure for real materials from angle-resolved photoemission spectroscopy (ARPES)

Unit 3. Response of the particle to the external perturbation

Electron distribution at finite temperatures, Fermi function Heat capacity and plasma frequency, Electrical transport, response to external electrical and magnetic field, Bloch wave packet in the applied field, electron scattering, mean free path, lifetime, derivation of the expressions for the electrical conductivity, Hall coefficient and magnetoresistance based on the electronic band dispersion Measured and calculated Hall coefficient, band structure obtained in the theoretical calculation, band structure from experimental ARPES measurements, magnetoresistance, Seebeck coefficient, other transport coefficients.

Unit 4. Symmetry breaking

Impurity states Surface states, Additional static periodic potential, charge-density-wave, electron susceptibility, Fermi surface nesting, examples from ARPES.

Unit 5. Interacting electronic systems

Electron-phonon interactions Superconductivity, Bose-Einstein condensation, basic understanding of electron pairing, BCS theory, materials with record critical temperatures, Electron-electron interactions, many-body problem in classical physics, success and breakdown of the mean field theory, Wigner crystal, Mott insulator, localization of electrons in solids, electron-electron scattering, electronic self-energy, Fermi liquid theory Spectral function, ARPES studies of the interacting electronic systems

Recommended books/reference material

6. Bube, R. (2012). *Electronic Properties of Crystalline Solids: An Introduction to Fundamentals*. Elsevier.
7. Hummel, R. E. (2013). *Electronic Properties of Materials*. Springer New York.
8. Irene, E. A. (2005). *Electronic Materials Science*. John Wiley and Sons.
9. Phillips, P. (2003). *Advanced Solid State Physics* (1st ed.). Westview Press.
10. Sander, L. M. (2009). *Advanced Condensed Matter Physics* (1st ed.). Cambridge University Press.

Phase Transformations in Matter

M. Phil. Physics

Course Code: PHY-749

Credit Hours: 03

Pre-requisite: Nil

Objectives

This course provides an overview of the phenomenological concepts and mathematical tools that have been developed to study the thermodynamics, kinetics and mechanics of solid-state phase transformations.

Learning Outcomes

- The students will be proficient in analyzing complex phase diagrams and predicting phase transformations in materials,
- They will be able to gain insight into the principles underlying advanced material synthesis techniques for tailored properties.

Course Outline

Unit 1. Review of the mathematical structure of thermodynamics and kinetics

Recap of fundamental concepts in thermodynamics and kinetics. Introduction to mathematical formalisms and equations governing thermodynamic and kinetic processes. Discussion on key principles such as entropy, energy conservation, and reaction rates.

Unit 2. Thermodynamics of first-order and second-order phase transitions

Examination of thermodynamic properties associated with first-order and second-order phase transitions. Analysis of phase diagrams and critical points. Discussion on latent heat, free energy, and entropy changes during phase transitions.

Unit 3. Order parameters for phase transformations

Introduction to order parameters and their significance in characterizing phase transformations. Discussion on how order parameters relate to structural changes in materials. Exploration of different types of order parameters for various phase transitions.

Unit 4. Thermodynamic descriptions of inhomogeneous systems

Study of thermodynamic models for describing inhomogeneous systems. Analysis of phase separation and phase coexistence phenomena. Discussion on interface thermodynamics and surface tension effects.

Unit 5. Kinetics of phase transformations

Overview of kinetic theories and mechanisms governing phase transformations. Examination of nucleation and growth processes. Analysis of diffusion-controlled and interface-controlled kinetics.

Unit 6. Mechanics of phase transformations

Introduction to mechanical aspects of phase transformations. Study of stress and strain effects on phase transitions. Discussion on the role of mechanical properties in shaping phase diagrams and transformation kinetics.

Recommended books/reference material

1. Khachaturyan, R. V. (2008). *Theory of Structural Transformations in Solids*. Dover Publications.
2. Balluffi, R. W., Allen, S. M., & Carter, W. C. (2005). *Kinetics of Materials*. Wiley.
3. Porter, D. A., & Easterling, K. E. (2021). *Phase Transformations in Metals and Alloys*. Taylor & Francis.

10. List of Mandatory Courses

No.	Course Code	Course Title	Prereq	Cr Hrs
1.	UHQ----	Understanding of Holy Quran-I	Nil	1
2.	ETH----	Ethics-I	Nil	1
3.	UHQ----	Understanding of Holy Quran-II	Nil	1
4.	ETH----	Ethics-II	Nil	1

11. Course Outlines for Mandatory Courses

Understanding of Holy Quran-I

Course Code: UHQ-101

Credit Hours: 01

Prerequisites: Nil

Course Objectives:

This course will enable the students to understand the Holy Quran by learning Arabic in a simple and easy way. Through relating their basic Urdu vocabulary with Quran, and without engaging them in complex Arabic Grammar, Sarf or Balagha. Students will gradually build the skills to read and understand Quranic verses directly—without needing translation. The course focuses on making Arabic accessible for everyone, even those with no prior background.

Learning Outcomes:

This course will enable the students to:

- Develop the ability to understand basic words of the Quran, phrases and sentences that do not contain verbs (unit 1 to 5 of Muallim ul Quran Book) and then sentences having present tense (first half of unit 6 of Muallim ul Quran Book).
- Acquire a strong foundation for understanding long verses of the Quran with clarity.
- Comprehend Quranic vocabulary, particles (operative & non operative particles), compounds (Adjective & Possessive compound), pronouns (singular & plural) and types of plurals through hundreds of Quranic sentences.
- Recognize and understand different styles of Quranic sentences, including nominal sentence, emphatic sentence, double emphatic sentence, negative sentence, interrogative sentence, oath –based sentences.
- Strengthen understanding of fundamental Quranic linguistic styles, expressions and idioms.
- Understand at least 30 to 40 % of each page of the Holy Quran.

Course Outline:

Unit 1: Simple Quranic Words

Muallim ul Quran: Book 1: Unit: Lesson 1-19

Unit 2: Words that comes before (The simple Quranic words)

Muallim ul Quran: Book 1: Unit#2: Lesson 1-13

Unit 3: Quranic words in terms of their relationship and characteristics

Muallim ul Quran: Book 1: Unit#3: Lesson 1-10

Unit 4: Singular Pronouns

Muallim ul Quran: Book 2: Unit#4: Lesson 1-17

Unit 5: Singular pronouns & Demonstrative Pronouns

Muallim ul Quran: Book 2: Unit#5: Lesson 1-23

Unit 6: Present Tense

Muallim ul Quran: Book 3: Unit#6: Lesson 1-5

Reference Books:

1- بشير، دكتور. عبيد الرحمن - معلم القرآن - اسلام آباد: دار العلم، ۲۰۲۴. جلد ۱، ۲ & ۳

Ethics-I

Course Code: ETH-103

Credit hours: 01

Pre-Requisites: Nil

Objectives

Upon successful completion of the course, students will be able to know the basics of ethics, & know how to develop an ethical approach. Also, analyze the importance of ethical and ethical values for a human being. And identify the Semitic & Non-Semitic Religions. Moreover, develop the concept of Ethics in Semitic & Non-Semitic religions. Also, analyze the similarities and differences between ethical teachings of various religions.

Learning Outcomes:

- Students will be able to demonstrate their understanding about the concept of ethics & ethical approach.
- Analyze the difference between the concept of Ethics in Semitic and Non-Semitic religions.

Course Outline:

Unit 1: Introduction and Importance of Ethics & Basic Ethical Principles

Definition of Ethics, Importance of Ethics, Beneficence, Non-maleficence, Autonomy, Justice as basic Ethical behaviors.

Unit 2: Theories of Moral Standards

Moral Standards as Law, Moral Standards as Pleasure, Moral standards as Perfection. (Theories of Various Philosophers such as Kant, Spencer, John S. Mackenzie etc)

Unit 3: The concept of Ethics in Major Religions- Christianity, Judaism

Introduction of the Religion, Its Basic Concepts and major ethical teachings.

Unit 4: The concept of Ethics in Major Religions- Hinduism & Buddhism

Introduction of the Religion, Its Basic Concepts and major ethical teachings.

Unit 5: The concept of Ethics in Major Religions- Islam

Introduction of the Religion, Its Basic Concepts and major ethical teachings.

References/Recommended Books:

1. Davis, N.K. (2023). *Elements of Ethics*, Legare Street Press.
2. Edmonds, D. (2019). *Ethics and the Contemporary World*, Taylor & Francis,
3. Hastings, J. Alexander, J. Gray S.L. (2023). *The Encyclopedia of Religion and Ethics*, Creative Media Partners, LLC
4. Robinson, D. Garratt C. (2008). *Introducing Ethics-a Graphic Guide*, Icon Books Ltd.Uk.
5. اخلاق اور فلسفہ اخلاق، سیویا روی، حفظ الرحمن، ندوۃ المصنفین، دہلی، ۱۹۷۶
6. دنیا کے بڑے مذاہب، فاروقی، عماد الحسن، مکتبہ جامعہ لمیٹڈ، دہلی، ۱۹۸۶

Websites & Articles

1. Articles on Ethics www.infotrac-college.com
2. Brown. (2017). The ethical dimensions of Global Environmental Issues. American Academy of Arts and Sciences. Retrieved July 7, 2017 from amacad.org
3. Business Ethics Magazine www.business-ethics.com/annual.htm
4. Bussmann, J. (2016). Top 9 ethical Issues in artificial intelligence. Retrieved 7 July 2017 from world Economic Forum weforum.org
5. Ethics and Religion, Shefali Narange <http://www.paperpublications.org/>
6. <http://www.jstor.com/stable/resrep12025.7>
7. <http://www.learnwell.org/ethicalproblems.htm>
8. Institute for Global Ethics www.globalethics.org
9. Klimes, Rudolf e. (2000). Ethical Problems.
10. Ten Ethical Problems of the Present World <https://www.lifepersona.com/10-ethical-problems-of-the-present-world>

11. Ward, Stephen J.A (March 2005). "Philosophical Foundations for Global Journalism Ethics"
Journal of Mass Media Ethics:20(1)

Understanding of Holy Quran-II

Course Code: UHQ-102

Credit Hours: 01

Prerequisites: Nil

Course Objectives:

This course will enable the students to understand the Holy Quran by learning Arabic in a simple and easy way. Through relating their basic Urdu vocabulary with Quran, and without engaging them in complex Arabic Grammar, Sarf or Balagha. Students will gradually build the skills to read and understand Quranic verses directly—without needing translation. The course focuses on making Arabic accessible for everyone, even those with no prior background.

Learning Outcomes:

This course will enable the students to:

- Directly comprehend hundreds of Quranic sentences & verses.
- Understand at least 80 to 85 % of each page of the holy Quran.
- Understand common verses across different Quranic topics.
- Achieve proficiency in the basic and advance linguistic aspects of the Arabic language.
- Understand the difference between Quranic verbs in various forms, such as present, past and imperative.
- Develop the ability to understand long verses of the holy Quran independently and then comprehend their interpretation.

Course Outline:

Unit 1: Past Tense

Muallim ul Quran: Book 4: Unit#7: Chapter 1: Lesson 1-9

Unit 2: Past Tense

Muallim ul Quran: Book 4: Unit#7: Chapter 2: Lesson 1-7

Unit 3: Past Tense

Muallim ul Quran: Book 4: Unit#7: Chapter 3: Lesson 1-9

Unit 4: Past Tense

Muallim ul Quran: Book 5: Unit#7: Chapter 4: Lesson 1-5

Unit 5: Past Tense & Passive Voice

Muallim ul Quran: Book 5: Unit#7: Chapter 5 - 9

Unit 6: imperative Verbs for Singulars

Muallim ul Quran: Book 6: Unit#8: Lesson 1-8

Reference Books:

1- بشير، دكتور. عبيد الرحمن - معلم القرآن - اسلام آباد: دار العلم، ۲۰۲۴. جلد ۳، ۴، ۵، ۶

Ethics-II

Course Code: ETH-104

Credit hours: 1

Pre-Requisites: Nil

Objectives

Upon successful completion of the course, students will be able to have better understanding of ethics in various walks of life like in workplace, in business, journalism etc. Moreover, they will be able to be familiarize with Contemporary World's Ethical Issues. And, try to develop answers about them.

Learning Outcomes:

- Students will be able to demonstrate their understanding about the importance of ethics in their lives today.
- Identify Contemporary World's Ethical Issues.
- Create problem solving for these contemporary Ethical issues.

Course Outline:

Unit 1. Professional Ethics & Bioethics

Meaning of Work/Professional Ethics, Professional Ethics and Human Values, Elements of professional Ethics: Person attitude, Beliefs about work, Positive Attributes (honesty, integrity, dedication, commitment, responsibility, interpersonal relationship) Genetic engineering, Organ, Donation, Cloning, Head Transplant

Unit 2. Ethical Conduct in Business Ethics & it's important

Types of Business Ethics, Common Business Ethical Challenges, Conflict of interest, honesty & integrity, whistle blowing, loyalty vs truth

Unit 3. Journalism

Principles of Ethical Journalism: Truth & Accuracy, Independence, Fairness & Impartiality, Humanity, Public Accountability

Unit 4. Environmental Ethics

Core Principles of environmental ethic: Justice & sustainability, Sufficiency & compassion, Solidarity & public participation, Pollution prevention, Current issues of environmental ethics: Pollution, The depletion of natural resources, Loss of biodiversity, Destruction of ecosystem, Global climate change

Unit 5. Social Inequalities

Meaning of Social Inequalities, Issues related to social inequality, Difference in source of income, Health care, Freedom of speech, Gender inequality, Toxic workplace culture, Education, Political representation & participation

Unit 6. Social Media Ethics

Facebook, YouTube, WhatsApp, Instagram, TikTok, Snapchat, LinkedIn, X, Current Ethical issues in social media: Plagiarism, Fake news, Harassment, Photo ethics, Post without caution, inappropriate behavior privacy

References/Recommended Books:

1. Davis, N.K. (2023). *Elements of Ethics*, Legare Street Press.
2. Edmonds, D. (2019). *Ethics and the Contemporary World*, Taylor & Francis,
3. Hastings, J. Alexander, J. Gray S.L. (2023). *The Encyclopedia of Religion and Ethics*, Creative Media Partners, LLC
4. Robinson, D. Garratt C. (2008). *Introducing Ethics-a Graphic Guide*, Icon Books Ltd.Uk.
5. اخلاق اور فلسفہ اخلاق، سیوہاروی، حفظ الرحمن، ندوة المصنفین، دہلی، ۱۹۷۶

6. دنیا کے بڑے مذاہب، فاروقی، عماد الحسن، مکتبہ جامعہ لمیٹڈ، دہلی، ۱۹۸۶

Websites & Articles

1. Articles on Ethics www.infotrak-college.com
2. Brown. (2017). The ethical dimensions of Global Environmental Issues. American Academy of Arts and Sciences. Retrieved July 7 ,2017 from amacad.org
3. Business Ethics Magazine www.business-ethics.com/annual.htm
4. Bussmann, J. (2016). Top 9 ethical Issues in artificial intelligence. Retrieved 7 July2017 from world Economic Forum weforum.org
5. Ethics and Religion, Shefali Narange <http://www.paperpublications.org/>
6. <http://www.jstor.com/stable/resrep12025.7>
7. <http://www.learnwell.org/ethicalproblems.htm>
8. Institute for Global Ethics www.globalethics.org
9. Klimes, Rudolf e. (2000). Ethical Problems.
10. Ten Ethical Problems of the Present World [https://www.lifepersona.com/10- ethical-problems-of-the-present-world](https://www.lifepersona.com/10-ethical-problems-of-the-present-world)

Ward, Stephen J.A (March 2005). “Philosophical Foundations for Global Journalism Ethics” Journal of Mass Media Ethics:20(1)