SCHEME OF STUDIES
FOR
M.Phil./PhD IN PHYSICS

Department of Physics

Abdul Wali Khan University Mardan

Revision July 2023

Semester wise Scheme for MPhil in Physics

Year 1

Semester-I			
Code	**Title of the Course**	**Cr Hrs**	**Remarks**
PHY-701	Mathematical Methods of Physics	3	Compulsory
PHY-702	Classical Mechanics	3	Compulsory
PHY-703	Quantum Mechanics	3	Compulsory
PHY-704	Electrodynamics	3	Compulsory
	Total	12	
Semester-II			
Code	**Title of the Course**	**Cr Hrs**	**Remarks**
PHY-705	Statistical Physics	3	Compulsory
PHY-7xx	Graduate Level Physics Course	3	Elective I
PHY-7xx	Graduate Level Physics Course	3	Elective II
PHY-7xx	Graduate Level Physics Course	3	Elective III
	Total	12	

Year 2

Semester-II & III			
Code	**Title of the Course**	**Cr Hrs**	**Remarks**
PHY-799	M.Phil. Project (Graduate Level)	6	Compulsory

Semester wise Scheme for PhD in Physics

Year 1

Semester-I			
Code	**Title of the Course**	**Cr Hrs**	**Remarks**
PHY-8xx	Graduate Level Physics Course	3	Elective I
PHY-8xx	Graduate Level Physics Course	3	Elective II
PHY-8xx	Graduate Level Physics Course	3	Elective III
	Total	9	
	Semester-II		
Code	**Title of the Course**	**Cr Hrs**	**Remarks**
PHY-8xx	Graduate Level Physics Course	3	Elective IV
PHY-8xx	Graduate Level Physics Course	3	Elective V
PHY-8xx	Graduate Level Physics Course	3	Elective VI
	Total	9	

Year 2+

Semester-I			
PHY-899	PhD Project	9	Compulsory

Note:

1. Courses can be swapped according to the resources of the university
2. The courses for both M.Phil. and Ph.D. are same but with different codes i.e. a code for a specific M.Phil. course is 7xx then for PhD it will be 8xx (As shown on Page No. 35)

Table of Contents

PHY-701 Mathematical Methods of Physics

Tensor analysis & algebra, General tensors, Vector algebra, Vector derivatives, Vector integrations, Gauss's and Stokes theorems and generalizations & potentials, Gauss's law, Poisson's equation, the Dirac delta function & Helmholtz theorem, Orthogonal coordinates and derivatives therein, Cylindrical and spherical coordinates, Matrices, determinant and matrix algebra, Diagonalization of matrices & eigen system of a matrix, Introduction to group theory, Orbital angular momenta, The Lorentz group, discrete groups, Differential forms in physics, Infinite series, their convergence, algebra of series, Function series, elliptic integrals, Bernuolli numbers , Divergent series, Infinite products, Complex numbers, regular functions and their integrals, Cauchy's Integral, the Laurent series and singularities, Complex mappings, Residues & applications, The Gamma-Function and derivatives, Approximations and generalizations.

Recommended Texts

1. G. Arfken, Mathematical Physics, 2nd ed, Academic Press, 1970.
2. Dass H.K, R. Verma, 2011, 6th Edition, Mathematical Physics, S. Chand& Company Ltd. New Delhi.
3. E. Butkov, Mathematical Physics, Addison-Wesley 1968.
4. Pipes and Harvill, Applied Mathematics for Engineers and Physicists, McGraw Hill, 1971.
5. M. L. Boas, Mathematical Methods in Physical Sciences, John Wiley & Sons, New York (1989)
6. M. R. Speigel, Complex Variables Schaum's Outline Series, McGraw Hill 1979
7. Partial Differential Equations, Epstein B and Malaber Mcgraw Hill 1983.

PHY-702 Classical Mechanics

Survey of the elementary principles, Variational principles and Lagranges's equations, Oscillations, The classical mechanics of the special theory of relativity, Hamiltonian equations of motion, canonical transformations, Hamilton-Jacobi theory and Action angle variable, Classical Chaos, Canonical perturbation theory, Introduction to the Lagrangian and Hamiltonian formulations for continuous systems and fields, Classical mechanics of liquids and deformable solids; stress, deformation and strain flow.

Recommended textbook

1. Herbert Goldstein, "Classical Mechanics". 2nd ed., Addison-Wesley USA, 1989
2. Vernon D Barger, "Classical Mechanics" McGraw Hill, New York, 1973
3. Kibble T. W., "Classical Mechanics" Longman, New York, 1985
4. James H Bartlett, "Classical and Modern Mechanics", Alabama Press, 1985
5. Fetter A.L., "Theoretical Mechanics of Particles and Continua", McGraw Hill, New York, 1989
6. Chow T. L., "Classical Mechanics", John Wiley and Sons, New York, 1995
7. Arya A. P., "Introduction to Classical Mechanics", Allyn and Bacon, USA 1990
8. Bhatia V. B "Classical Mechanics", Narosa Publishing House, 1997

PHY-703 Quantum Mechanics

- Overview of quantum mechanics
- The mathematical tool of quantum mechanics:

One particle wave function space; Structure of the wave function space, Discrete orthonormal basis in wave function space, Introduction of basis not belonging to wave function space, State Space: Dirac notation; introduction, ket vectors and bra vectors, Linear operators, Hermitian conjugation Representation in the state space; Relation characteristic of an orthonormal basis, Representation of kets and bras, Representation of operators, Eigen value equation: Observables; Eigen values and Eigen vectors of an operators, Observables, Sets of commuting observables, Two important example of representation and observables; {lr>} and {lp>} repsentations, The R and P representation.
The Schwartz inequality, Review of some useful properties of linear operator, Unitary operators, A more detail study of {lr>} and {lp>} repsentations, Some general properties of two observables, Q and P, The parity operator.

- The postulates of quantum mechanics:

Description of the state of the system and physical quantaties, the measurement of a physical quantaties, time evolution of a system, Quantization rule, the physical interpretation of the postulates, Postulates concerning observables and their measurements, Quantization of certain physical quantaties, The measurement process, mean value of an observable, The root mean square deviation, Compatibility of observables, The physical implication of the Schrodinger equation; General properties of Schrodinger equation, The case of conservative system, The superposition principle and Physical prediction; Probability amplitudes and interference effects, Case in which several states can be associated with the same measurement result.
Study of the probability current in some special cases, Root mean square deviation of two conjugate observables, measurements bearing on only one part of a physical system, The density operator, The evolution operator, The Schrodinger and Heisenberg picture, The Gauge invariance, Propagator for the Schrödinger equation.

- Application of the postulate to the simple cases: Spin1/2 and two level system.

Spin1/2 particle:

- The one-dimensional harmonic oscillator:

Introduction; Importance of harmonic oscillator in physics, the harmonic oscillator in classical mechanics, General properties of quantum mechanical Hamiltonian, Eigen values of the Hamiltonian; Notation, Determination of the spectrum, Degeneracy of the eigen values, Eigen State of the Hamiltonian; The {lϕn>} representation, Wave function associated with the stationary state, Discussion; Mean value and root mean square deviation of X and P in a state {lϕn>}, Properties of the ground state, Time evolution of mean values.
Some example of harmonic oscillator, Study of the stationary state in the {lr>} representation, Solving the eigen value equation of the harmonic oscillator by the polynomial method, Study of the stationary state in the {lp>} representation, The isotropic three dimensional harmonic oscillator, A charged harmonic oscillator in uniform electric field, Coherent quasi classical state of harmonic oscillator.

General properties of angular momentum in Quantum mechanics: Introduction; The importance of angular momentum, Commutation relation; Orbital angular momentum, Generalization. definition of angular momentum, Statement of the problem, General theory of angular momentum;. Definition and notation, Eigen values of J2 and Jz, Standard {lk, j, m>} representation, Application to the orbital angular momentum; Eigen values and eigen function of L2 and Lz, physical consideration.

- Particle in a central potential: the hydrogen atom:

Stationary state in a central potential; Outline of the problem, Separation of variable, Stationary state of the particle in a central, Motion of the centre of mass and Relative motion for a system of two Interacting particle; Motion of the centre of mass and Relative motion in Classical mathematics, Separation of variable in Quantum mechanics, The hydrogen atom; Introduction, The Bohr model, Quantum mechanical theory of the hydrogen atom, Discussion of the result. Hydrogen like system, a soluble example of the central potential, Probability current associated with the stationary state of the hydrogen atom, the hydrogen atom placed in a uniform magnetic field, Study of some atomic orbitals. Hybrid orbitals, Vibrational –rotational levels of diatomic molecules.

Recommended Textbook

1. Quantum Mechanics (Vol. 1) by Claude Cohen-Tannoudji, Bernard Diu, Frank Laloe, Wiley-VCH, 1992.
2. Modern Quantum Mechanics (2nd Edition) by J. J. Sakurai, Jim J. Napolitano, Addison-Wesley, 2010.
3. Principles of Quantum Mechanics (2nd Edition) by R. Shankar, Plenum Press, 1994.
4. Quantum Mechanics by Dirac, P. A. M (Oxford University Press

PHY-704 Electrodynamics

Coulomb's Law and Electric Field; Gauss's Law; Another Equation of Electrostatics and the Scalar Potential; Surface Distribution of Charges and Discontinuities in the Electric Field (Excluding the part on the Dipole Layer); Poisson and Laplace Equations; Green's Theorem; Uniqueness of the Solution with Dirichlet or Neumann Boundary Conditions; Formal Solution of Electrostatic Boundary-Value Problem with Green Function; Electrostatic Potential Energy and Energy Density

Method of Images; Point Charge in the Presence of a Grounded Conducting Sphere; Point Charge in the Presence of a Charged, Insulated, Conducting Sphere; Point Charge Near a Conducting Sphere at Fixed Potential; Green Function for the Sphere, General Solution for the Potential; Orthogonal Functions and Expansions; Separation of Variables, Laplace Equation in Rectangular Coordinates

Laplace Equation in Spherical Coordinates; Legendre Equation and Legendre Polynomials (Rodrigue's formula, Recurrence relations, Orthogonality - no derivations); Boundary-Value Problem with Azimuthal Symmetry; Associated Legendre Functions and the Spherical Harmonics; Addition Theorem for Spherical Harmonics (no derivation); Expansion of Green Functions in Spherical Coordinates

Multipole Expansion; Multipole Expansion of the Energy of a Charge Distribution in an External Field; Elementary Treatment of Electrostatics with Ponderable Media; Boundary-Value Problems with Dielectrics; Electrostatic Energy in Dielectric Media

Introduction and Definitions; Biot and Savart Law; Differential Equations of Magnetostatics and Ampere's Law; Vector Potential; Magnetic Fields of a Localized Current Distribution, Magnetic Moment; Force and Torque on and Energy of a Localized Current Distribution in an External Magnetic Induction; Macroscopic Equations, Boundary Conditions of B and H; Faraday's Law of Induction; Energy in the Magnetic Field

Maxwell's Displacement Current; Maxwell Equations; Vector and Scalar Potentials; Gauge Transformations, Lorentz Gauge, Coulomb Gauge; Green Functions for the Wave Equation; Retarded Solutions for the Fields: Jefimenko's Generalizations of the Coulomb and Biot-Savart Laws; Poynting's Theorem and Conservation of Energy and Momentum for a System of Charged Particles and Electromagnetic Fields; Transformation Properties of Electromagnetic Fields and Sources under Rotations, Spatial Reflections, and Time Reversal

Recommended Books

1. Jackson J. D, "Classical electrodynamics". 3rd ed., John Willey & Sons, New York, 1998.
2. David K. Cheng, "Fields and Waves Electromagnetic". 2nd ed., Addison Wesley, 1989.
3. Mathew N. O. Sadiku, "Elements of Electrodynamics". 5th ed., Oxford University Press, USA, 2009.
4. Zahn, M, "Electromagnetic Field Theory". 1st ed., Willey New York, 1979.
5. Sander, K. F. and Reed, "Transmission and Propagation of Electromagnetic Waves". Cambridge University Press England, 1986.
6. Kong J. A. "Electromagnetic Wave Theory".1st ed., John Wiley & Sons, New York 1986.

PHY-705 Statistical Physics

1. Intensive and extensive quantities, thermodynamic variables, thermodynamic limit, thermodynamic transformations.
2. Classical ideal gas, first law of thermodynamics, application to magnetic systems, heat and entropy, Carnot cycle. Second law of thermodynamics, absolute temperature, temperature as integrating factor, entropy of ideal gas.
3. Conditions for equilibrium, Helmholtz free energy, Gibbs potential, Maxwell relations, chemical potential. First-order phase transition, condition for phase coexistence. The statistical approach: phase space, distribution function, microcanonical ensemble, the most probable distribution, Lagrange multipliers.
4. Maxwell-Boltzmann distribution: pressure of an ideal gas, equipartition of energy, entropy, relation to thermodynamics, fluctuations, Boltzmann factor.
5. Quantum statistics: thermal wavelength, identical particles, Fermi and Bose statistics, pressure, entropy, free energy, equation of state, Fermi gas at low temperatures, application to electrons in solids and white dwarfs. The Bose gas: photons, phonons, Debye specific heat, Bose-Einstein condensation, equation of state, liquid helium.

Recommended Texts:

1. Introduction to Statistical Physics, Kerson Huang, (Taylor and Francis, 2001).
2. Statistical Mechanics, Raj Kumar Pathria, 2nd edition (India, 1996).

PHY-706 Materials Science

Objective

The main objectives of the course is to familiarize the students with key materials; ceramics, polymers and composites. This content of this course will be used as background knowledge for the understanding of specialized courses in the field of Materials Science

Contents

Materials Selection and Design Considerations: Discusses materials selection issues in several contexts and from various perspectives

Structures and Properties of Ceramics: Crystal Structures, Silicate Ceramics, Carbon, Imperfections in Ceramics, Diffusion in Ionic Materials, Ceramic Phase Diagrams, Brittle Fracture of Ceramics, Stress–Strain Behaviour, Mechanisms of Plastic Deformation, Miscellaneous Mechanical Considerations

Applications and Processing of Ceramics: Glasses, Glass–Ceramics, Clay Products, Refractories, Abrasives, Cements, Advanced Ceramics, Fabrication and Processing of Glasses and Glass–Ceramics, Fabrication and Processing of Clay Products, Powder Pressing, Tape Casting

Polymer Structures: Hydrocarbon Molecules, Polymer Molecules, The Chemistry of Polymer Molecules, Molecular Weight, Molecular Shape, Molecular Structure, Molecular Configurations, Thermoplastic and Thermosetting Polymers, Copolymers, Polymer Crystallinity, Polymer Crystals, Defects in Polymers, Diffusion in Polymeric Materials

Characteristics, Applications, and Processing of Polymers: Stress–Strain Behaviour, Macroscopic Deformation, Viscoelastic Deformation, Fracture of Polymers, Miscellaneous Mechanical Characteristics, Deformation of Semicrystalline Polymers, Factors That Influence the Mechanical Properties of Semicrystalline Polymers, Deformation of Elastomers, Crystallization, Melting, The Glass Transition, Melting and Glass Transition Temperatures, Factors That Influence Melting and Glass Transition Temperatures, Plastics, Elastomers, Fibers, Miscellaneous Applications, Advanced Polymeric Materials. Electrical and Optical Properties of Polymers.

Composites: Large-Particle Composites 580 16.3 Dispersion-Strengthened Composites, Influence of Fiber Length 585 16.5 Influence of Fiber Orientation and Concentration, The Fiber Phase, The Matrix Phase, Polymer-Matrix Composites, Metal-Matrix Composites, Ceramic-Matrix Composites, Carbon–Carbon Composites, Hybrid Composites, Processing of Fiber-Reinforced Composites, Laminar Composites, Sandwich Panels.

Economic, Environmental, and Societal Issues in Materials Science and Engineering: Component Design, Materials, Manufacturing Techniques, Recycling Issues in Materials Science and Engineering.

Text / Reference Books:

1. Materials Science and Engineering an Introduction, by W. D. Callister, Jr., publisher John Wiley & Sons Inc (2007)

2. The Physics and Chemistry of Materials, by J. I. Gersten and F. W. Smith, publisher John Wiley & Sons Inc (2001)
3. Fundamentals of Ceramics, by M. W. Barsoum, IOP Publishing Ltd (2003)
4. The Physics of Amorphous Solids, by Richard Zallen, publisher John Wiley & Sons Inc. (1998).
5. Solid State Physics, by J.S. Blakemore (2nd Edition), publishers Cambridge University Press (1995)

PHY-707 Nanoscale Physics

Course Objective:

This course provides the physics of nanomaterials, in conjunction with quantum-size phenomena and matter-photon interactions, as well as their applications. After successful completion of the course students will acquire the following skills:

- Deepen understanding of physical principles and methods necessary to master nanomaterials' science & technology.
- To be able to combine quantum physics, solid state physics and atomic molecular physics to analyse, simulate the properties of nanomaterials.
- To be familiarized with the basic theoretical models pertaining with the interpretation of electronic, photophysical, interfacial physicochemical properties of nanomaterials within the broader context of applicability of nanomaterials & nanotechnology.

Course Outlines:

Introduction to Nanophysics: An overview

Introductory review of the principles and mathematical tools of quantum physics from the atom to nanoparticle, Density of states for 0D, 1D and 2D nanomaterials.

Classification of Nanomaterials:

Quantum Dots/Nanocrystals, Quantum Wires and Quantum Well/Superlattices structure, synthesis, properties and applications

Electrons in Nanostructures:

Variation in electronic properties, Electronic Phase Coherence: The Aharonov-Bohm effect, weak localization, resonant tunneling, Quantum transport in nanostructures: Ballistic electron transport, quantized conductance, Single-Electron Tunneling: Coulomb blockade, single-electron tunneling devices, electron pumping

Magnetic Molecules:

Intermezzo: Ferromagnetism and Antiferromagnetism, Examples of Magnetic Molecules, Magnetic Relaxation and Magnetization Tunneling, Properties of Magnetic Molecules, Application Possibilities of Magnetic Molecules

Photonic Crystals and Nanophotonics:

Photons and Electrons; Similarities and Differences, Nanoscale optical interactions, Photonic Crystals, Properties of photonic crystals, Generation of Photonic Crystals, Application of photonic crystals

New Directions in Electronics:

Spintronics, Molecular Electronics, Devices for Quantum Computation

Recommended Books:

1. "Introduction to nanotechnology", Ch. Poole Jr., F. J. Owens, John Wiley & Sons E, 2003.
2. "Nanoscale science and technology" R. W. Kelsall, I. W. Hamley and M. Geoghegan, John Wiley & Sons, 2005.
3. "Nanophysics & Nanotechnology: An introduction to modern concepts in nanoscience", Edward L. Wolf, WILLEY-VCH Verlag GmbH and Co, 2004.
4. "Introduction to Nanoscience", S. Lindsay, Oxford University Press, 2009.
5. "Introduction to Nanoscience and Nanotechnology", C. Binns, Willey, 2010.

PHY-708 Semiconductor Devices

Overview

The Semiconductor Devices preliminary examination will cover basic properties of semiconductors, physical principles and operational characteristics of semiconductor devices, and advanced device issues relevant to state-of-the-art integrated-circuit technologies. The primary emphasis will be on silicon devices. The syllabus is roughly equivalent to the material in the present EE 230A, 230B, and 230C course descriptions.

Course Contents

Physics and Properties of Semiconductors: crystal structure, energy bands, statistics, Fermi level, carrier concentration at thermal equilibrium, carrier transport phenomena, Hall effect, recombination, optical and thermal properties, basic properties for semiconductor operation.

P-N Junction: depletion region, diffusion, generation-recombination, current-voltage characteristics, junction breakdown, charge storage and transient behavior. metal-semiconductor junctions.

Diodes and Photovoltaics: diodes, light-emitting diodes (LED), laser diodes (LD), photodiodes, and photovoltaic solar cells

Bipolar Transistor: transistor action and dependence on device structure, charge control switching model, Ebers-Moll Model, current-voltage characteristics, non-ideal and limiting effects at extremes of bias.

State-of-the-Art Bipolar Transistor Technology: poly-Si emitters, narrow base, structural tradeoffs in optimizing performance.

Metal-Semiconductor Contacts: equilibrium, idealized metal semiconductor junctions, nonrectifying (ohmic) contacts, Schottky diodes, tunneling.

Metal-Oxide-Silicon System: MOS structure, capacitance, oxide and interface charge (charging of traps, tunneling through oxide).

MOS Field-Effect Transistor: threshold voltage, derivation of current-voltage characteristics, dependence on device structure.

State-of-the-Art MOS Technology: small-geometry effects, fin-FETs, ultrathin body FETs, mobility degradation due to channel and oxide fields, velocity saturation, ballistic transport, hot-electron effects, device wearout mechanisms, introduction of new semiconductors.

References

1. C.C. Hu, Modern Semiconductor Devices for Integrated Circuits, Pearson, 2010
2. R. F. Pierret, Semiconductor Device Fundamentals, Addison-Wesley, 1996.
3. Y. Taur and T. H. Ning, Fundamentals of Modern VLSI Devices, Cambridge, 2013.
4. S. Wolf, The Submicron MOSFET, volume 3 of Silicon Processing for the VLSI Era, Lattice Press, 1995.

PHY-709 Materials Synthesis and Characterization

Description:

The course is focused on the synthesis and experimental techniques used for characterization of functional materials to study structure-property relation. The topics treated include basic characterization, electrical characterization and magnetic characterization techniques.

Contents to be covered:

- Synthesis by physical and chemical routes (Experimental work)
- Thermal Analysis using TGA, DTA and DSC
- Phase Identification using Powder Diffraction Techniques, Quantitative Phase analysis, Lattice Constant Prediction and Indexing, Stress and Strain in Polycrystalline materials
- Fourier Transform Infra-Red Spectroscopy (FTIR)
- Raman Spectroscopy
- Microstructural analysis using microscopy techniques
- Quantitative Compositional analysis using EDS
- Data analysis of the UV-Vis spectroscopy
- Data Analysis of Impedance Spectroscopy

References

1. J. Guo, A. L. Baker, H. Guo, M. Lanagan, C. A. Randall, Cold sintering process: A new era for ceramic packaging and microwave device development. Journal of the American Ceramic Society 100, 669-677 (2017).
2. J. P. Syvitski, Principles, methods and application of particle size analysis. (Cambridge University Press, 2007).
3. S. Gaisford, V. Kett, P. Haines, Principles of thermal analysis and calorimetry. (Royal society of chemistry, 2016).
4. R. Jenkins, R. L. Snyder, Introduction to X-ray Powder Diffractometry (Volume 138). (Wiley Online Library, 1996).
5. E. Smith, G. Dent, Modern Raman spectroscopy: a practical approach. (John Wiley & Sons, 2013).
6. B. C. Smith, Fundamentals of Fourier transform infrared spectroscopy. (CRC press, 2011).
7. E. Meyer, H. J. Hug, R. Bennewitz, Scanning probe microscopy: the lab on a tip. (Springer Science & Business Media, 2013).
8. D. B. Williams, C. B. Carter, in Transmission electron microscopy. (Springer, 1996), pp. 3-17.

PHY-710 Dielectric Physics

Objective:

The course is devoted to the study of dielectric polarization and relaxation phenomena in condensed matter. A basic theory of dielectrics is given. Different experimental technique of dielectric spectroscopy is presented.

Contents:

Electric Field in Composite Dielectrics, Lorentz effective electric field and Clausius–Mossotti relation, Onsager Effective Electric Field, Electronic Elastic Displacement Polarization, Dielectrics in Electrostatic Fields, Polarization and permittivity of various practical dielectrics, Polarization and Permittivity of Various Real Dielectrics, Dielectric Polarization Process and Dielectric Polarization Time Domain Response, Complex Permittivity and Frequency Response of Dielectrics, Kramer-Kronig Relation, Equivalent Circuit of Dielectric, Debye Relaxation and the Micromechanism of Relaxation Polarization, Debye relaxation, Relation between Complex Permittivity, Frequency and Temperature, Deviation and Amendment of Debye Relaxation Theory, Universal Relations of Polarization Relaxation and Multibody Models and Resonant Polarization of Dielectrics, Breakdown of Gas Dielectric, Conductance and breakdown of liquid dielectric, Conductance of Solid Dielectrics, Breakdown of Solid Dielectrics, Crystal Anisotropy, Electromechanical Coupling Effect of Crystals, Crystal Elasticity and Piezoelectricity, Mechanical-electrical interaction and piezoelectric equations, Electromechanical Coupling and Piezoelectric Oscillator, Spontaneous Polarization and Pyroelectric Effect, Ferroelectrics and Domains, Phase Transformation of Ferroelectric Structure, Antiferroelectricity, Optical Properties of Dielectrics.

Recommended Books

1. Kao, Kwan Chi. Dielectric phenomena in solids. Elsevier, 2004.
2. Coelho, Roland. Physics of Dielectrics for the Engineer. Vol. 1. Elsevier, 2012.
3. Bunget, Ion, and Mihai Popescu. "Physics of solid dielectrics." *Materials science monographs* 19 (1984).

PHY-711 Surface Physics

Objective(s)
To understand the basics of surface physics. Strengthen the previous knowledge of Solid State Physics and Quantum Mechanics.

Contents
Basics of Surface Science: Surface reactions, Heterogeneous catalysis, Semiconductor technology, Corrosion, Nanotechnology, Surface Structure and Reconstruction: Electronic Structure of Surfaces: Band structure of metals, insulators and semiconductors, Fermi level, Screening, Work Function, Surface States, Electron Affinity, Ionization Potential, Surface Chirality, Thermodynamics of Surfaces, Equilibrium Crystal Shape.

Quantum confinement of Electrons at Surfaces: Interference of Electron Waves, Quantum size effects, Quantum wells, Mechanical Quantum Wells, Quantum Wires, Chemist's Approach, Bonds to Bands.

Surface Dynamics: Nucleation and growth of nanostructures and films, Surface Magnetism and magnetic imaging, Diamagnetism, Paramagnetism, Anti-Ferromagnetism, Magnetism in thin films, Kerr microscopy (MOKE), Spin Polarized Photoemission (SP-PEEM), Magnetic Force Microscopy (MFM).

Surface Study Techniques: Surface Sensitivity and specificity, Explanation and comparison of Low-Energy Electron Diffraction (LEED) and Reflection High-Energy Electron Diffraction (RHEED), Explanation of Near-Edge X-ray Absorption Fine Structure (NEXAFS), High-Resolution Electron Energy Loss Spectroscopy (HREELS), Introduction to Desorption Techniques, Thermal Desorption Spectroscopy (TDS), Electron Stimulated Desorption (ESD), Electron Stimulated Desorption Ion Angular Distribution (ESDIAD), Photon Stimulated Desorption (PSD), Electron Spectroscopy, Theory: Mean free path, Koopman's Theorem, Spin orbit coupling effects, chemical shifts, binding energy, Auger Electron Spectroscopy (AES), X-Ray Photo-electron Spectroscopy, Electron Analyzer, Electron optics, Scanning Tunneling Microscopy (STM), History, Theory, Electronics and applications.

Case Studies: Silicon Surfaces: Geometric and Electronic Structure, Molecular Adsorption on Semiconductor Surfaces, Adsorption Properties of CO on Metal Single-Crystal Surfaces, Molecular or dissociative adsorption, Chemical bonding and Orientation, Adsorption Site as a function of coverage, Over layer long-range order, Ammonia Synthesis, Oxide Surfaces.

Photovoltaic and Organic Electronics: Different types of semiconductors (organic, inorganic, conjugated polymers), Prototypes (OLEDs etc), intramolecular bonding, Van der Waals, electronic properties, polarization effects, Field effect Transistors, basics of excitonic solar cells.

Recommended Books:

1. A. Zangwill, “Physics at Surfaces”, Cambridge University Press, 1988.
2. D. P. Woodruff and T. A. Delchar, “Modern Techniques of Surface Science”, Cambridge University Press, 2nd ed. 1994.
3. D. Briggs and M. P. Seah, “Practical Surface Analysis”, Vol-I, John Wiley, 2nd ed. 1990.
4. J. B. Hudson, “Surface Science, an Introduction”, Wiley-Interscience, 1998.
5. H. Luth, “Surfaces and Interfaces of Solids”, Springer-Verlag, 2nd ed. 1993.
6. M. Prutton, “Introduction to Surface Physics”, Oxford University Press, 1994.

PHY-712 Functional Materials and Devices

Description:
The course is focused on the properties of smart/functional materials used in modern electronic devices. The contents of this course include crystal structures, bonding, and physical properties (electrical, magnetic, optic etc) of materials, devices and their applications. Special focus is given to the relationship between properties and crystal structure.

Contents

- **Trends in Periodic Table and Basic Concepts**: Physical and Chemicals Properties of Cations and Anions, Coordination Chemistry, Atomic Radius, Ionic Radius
- **Bonding**: Mixed Ionic-Covalent Bonding in Functional Oxides, Binding Energy
- **Classification of Functional Oxides by Function**
- **Dielectrics and Polarization**: Electrostatics, Permanent and Induced Dipoles, Linear and Non-Linear, Polar and Non-Polar Molecules, Polarization Mechanisms
- **Dielectric Properties:** Dielectric Constant, Dielectric Loss/Dissipation Factor, Time Constant, Spontaneous Polarization, Clausius-Mossotti Expression for Permittivity Prediction
- **Strength and Breakdown:** Strength and Breakdown Mechanisms, Aging
- **Crystal Chemistry of Perovskites:** Centrosymmetric and Non-Centrosymmetric Structures, types of Perovskites, Tolerance Factor, Cation Ordering in Perovskites, Anti-perovskites, Octahedral Tilting Schemes, Corner Shared and Face Shared Octahedron, and Ionic Radii Rules
- **Other Structures:** Forsterite, Willemite, Corundum, Spinals and Apatites
- **Paraelectric Material:** Paraelectricity, Microwave dielectrics and their properties, Microwave Telecommunication, Resonators, Current and Future Trends
- **Ferroelectric Materials:** Ferroelectricity, Relaxor Ferroelectrics, Dielectric response with respect to temperature, Curie Point, Domains and Hysteresis, MLCC, High Energy Density Storage Applications
- **Piezoelectric Materials:** Piezoelectricity/Piezoelectric Effect, Polarization and strain vs. electric field (E), Piezoelectric Coefficients, Electromechanical Coupling, Piezoelectrics for Energy Harvesting, Piezoelectrics for sensors and actuators
- **Pyroelectric Materials:** Pyroelectric effect, pyroelectric coefficients, Infrared detection, Johnson noise, Thermal Fluctuations, PFN and its applications
- **Electro-Optics:** Background, PLZT, applications.
- **Magnetic Materials:** Background, ferrites, magnetic properties, applications.
- **Thermoelectric Materials:** Thermoelectricity, Seabeck effect, Pelteir Effect, Thermoelectric power generation and cooling, Defects versus Thermoelectric Properties and Applications
- **Other Topics:** Conducting Oxides, Electrides, Solid Oxide Fuel Cells, Oxygen Ion Conductors and Batteries

Recommended Books

1. K.M. Nair, A. Bhalla, l. K. Gupto, S. Hirano, B. V. Hiremath, l. Jean, R. Pohanka, Dielectric Materials and Devices, 1999, The American Ceramics Society.
2. K. C. Kao, Dielectric phenomena in solids, 2004, Elsevier
3. M. T. Sebastian, Dielectric Materials for Wireless Communications, 2007, Springer
4. Moulson A. J. and J.M. Herbert J. M., “Electro ceramics: Materials, Properties, and Applications”. 2nd ed. John Wiley & Sons Ltd, England, 2003
5. Richard J. D. Tilley, Perovskites: Structure–Property Relationships, 2016 John Wiley & Sons, Ltd
6. Julian Goldsmid, The Physics of Thermoelectric Energy Conversion, Morgan & Claypool Publishers, 2017

PHY-713 Electrochemistry and Electrocatalysis

Course Outline

Equilibrium Electrochemistry: Electrodes and half-reactions, Complete electrochemical cells and electrochemical reactions, Types of electrochemical cells (galvanic and electrolytic), Reactions quotient and the Nernst equation; Gibbs energy of half-cell and complete cells; application of the Nernst equation, Cell potential (electromotive force); standard and non-standard cell potentials, Application of cell potentials, Reference Electrodes

Electrode-Electrolyte Interface: Components of the electric double layer, Inner and outer Helmholtz layer, Gouy-Chapmann, Stern and Grahame models, Potential distribution at the electrode-electrolyte interface

Dynamic Electrochemistry: Rate of charge transfer and the activation energy of the charge transfer, Derivation of the Butler-Volmer equation, Low and high overpotential limiting cases of the Butler-Volmer equation, Tafel relation

Electrocatalysis: Hydrogen oxidation and oxygen reduction reactions, Rechargeable and non-rechargeable batteries, Corrosion reactions, Water electrolysis, Metal electrodeposition, Electrocatalytic hydrogenation, Electrosynthesis

Laboratory Procedures in Electrochemistry and Electrocatalysis: Components of an electrochemical setup and their roles, Cleanliness in electrochemical measurements, Electrodes, Electrochemical cells and the two-electrode and three-electrode configurations, Reference electrodes, Safety in electrochemistry and electrocatalysis research

Electrochemical Experimental Techniques: Chrono-amperometry, Coulometry, Cyclic voltammetry, Polarization curves, Tafel plots, Electrochemical quartz-crystal nanobalance

Recommended Books

1. P. Atkins, J. de Paule, Physical Chemistry, 8th or 9th Edition, W. H. Freeman & CO, New York (2006 or 2010).
2. E. Gileadi, Physical Electrochemistry, Wiley-VCH, Weinheim (2011).
3. A. J. Bard, G. Inzelt, F. Scholtz, Eds., Electrochemical Dictionary, 2nd Edition, Springer, Heidelberg-New York (2012).
4. C.H. Hamann, A. Hamnett, W. Vielstich, Electrochemistry, 2nd edition", Wiley-VCH (2007).

PHY-714 Piezoelectric Materials and Devices

Summary

The students acquire knowledge on structure-property relations of piezoelectric and related materials (ferroelectrics, relaxors). Different material classes (ceramics, crystals, composites, polymers) are discussed in view of applications in sensors, actuators, high frequency transducers and others.

Content

1. Piezoelectric effect. Thermodynamic relations. Electromechanical coupling coefficients. Constitutive equations. Boundary conditions.
2. Piezoelectric materials: single crystals, ceramics, polymers and composites. New piezoelectric materials.
3. Piezoelectric anisotropy. Symmetry and piezoelectricity.
4. Concept of morphotropic phase boundary. Soft and hard piezoelectrics
5. Piezoelectric resonance.
6. Equivalent circuits
7. Physical phenomena that can contribute to the piezoelectric effect. Piezoelectric hysteresis, nonlinearity, creep and relaxation.
8. Piezoelectric actuators and motors.
9. Piezoelectric sensors. Quasistatic and resonance mode of operation.
10. High frequency piezoelectric transducers for medical imaging. Concept of matching layers. Ultrasonic arrays. Doppler probes.
11. Surface acoustic wave effect and devices.
12. Other types of electro-mechanical and magneto-electro-mechanical coupling (electrostriction, flexoelectricity, strain mediated magneto-electric effect)

Recommended Books

1. Vijaya, M.S., 2016. Piezoelectric materials and devices: applications in engineering and medical sciences. CRC Press.
2. Uchino, K. ed., 2017. Advanced piezoelectric materials: Science and technology. Woodhead Publishing.
3. Nelson, W.G., 2010. Piezoelectric Materials: Structure, Properties and Applications. Nova Science Publishers, Incorporated.

PHY-715 Physics of Thin Film

Objective

1. To provide students with a comprehensive overview on the fundamentals of thin film preparation and characterization.
2. To enable the students to develop a thorough understanding of how core physics can be used to understand thin film deposition processes.
3. To establish the correlation between processing variables, materials characteristics and performance within the framework of nanotechnologies.
4. To allow students to develop a sense of teamwork, communication skills and research methodologies through team project.

Contents

Physics of Thin Film: Overview of the thin film for various industrial application, crystal structures of thin films, Defects in thin films(vacancies and interstitials, dislocations, grain boundaries, etc.), Nanocrystaline, polycrystalline and epitaxial thin films, interface and surface of thin films, thin film nucleation and growth model(2D,3D and 2D-3D combinations), Epitaxial growth of thin film, Homoepitaxial and heteropitaxial.

Deposition Methods of Thin Films: Choosing a deposition method. Classification of deposition technologies. Thin-film nucleation and growth. Thermal vacuum evaporation. Apparatus. Applications. Magnetron sputtering. Apparatus. Applications. Chemical methods. Chemical Vapor Deposition (CVD). Apparatus. Applications. Electrochemical and electroless methods. Molecular beam epitaxy (MBE). Apparatus. Applications. Pulsed laser deposition (PLD). Apparatus. Applications. Thin film applications in Nanoelectronics (optoelectronic devices, photodetectors, solar cells, sensors and actuators), Nanotechnologies.

Recommended Books:

1. Handbook of Thin-Film Deposition Processes and Techniques Principles, Methods, Equipment and Applications, Krishna Seshan ,Second Edition William Andrew Publishing Norwich, New York, U.S.A.
2. An Introduction to Physics and Technology of Thin Films, Alfred Wagendriste1, Yuming Wang, World Scientific Publishing Co. Pte. Ltd.
3. Handbook of Deposition Technologies for Films and Coatings: Peter M. Martin, , Third Edition: Science, Applications and Technology, Elsevier, Amsterdam-Boston, 2010.
4. Handbook of Nanoscience, Engineering, and Technology: William A. Goddard, III, Donald W. Brenner, Sergey E. Lyshevsky, Gerald J. Iafrate (Eds.), CRC Press, Boca Raton, London, New York, 2007.
5. Thin Film Physics and Applications, I. Spînulescu, Scientific Publishing House, Bucharest, 1975 (in Romanian).
6. Thin Film Materials (Stress, Defect Formation and Surface Evolution), S. Suresh, L. B. Freund Division of Engineering Brown University, Department of Materials Science and Engineering MIT USA.

PHY-716 Advanced Scintillation Materials

Objectives:

1. To learn basics of scintillation materials
2. To learn the basic scintillation mechanism in the scintillators
3. To understand the different properties of scintillators

Contents

Historical background of scintillators, Types of scintillators, Scintillator and Scintillations, Growth of single crystal scintillators, Luminescence and types of luminescence, Radiation detection mechanism, Basic Principles and Processes, Physical mechanism of scintillation, Creation of electron hole pairs, Excitation and emission of luminescence centers, Intrinsic luminescence of Inorganic Scintillators, Excitonic luminescence, Core to valance transition, Scintillation Materials, Halides, Oxides and Oxides systems, Interaction of ionization radiation with scintillators, High energy photons, Charged particles, Neutral particles, General characteristics of inorganic scintillators, Light yield, Duration of scintillation pulse, Afterglow, Low temperature effects on scintillation mechanism, Defect formation by ionizing Radiation, Mechanism of defect formation, Efficiency of defect production, Formation time of F-H pairs. Effects of defects on scintillation mechanism i.e. light yield, decay time, energy resolution, optical emission.

Recommended Books:

1. Physical Process in Inorganic Scintillators, Piotr, A. Rodnyi, CRC Press, Boca Raton New York 1997.
2. Inorganic Scintillators for Detector Systems, Springer-Verlag Berlin Heidelberg 2006.
3. Inorganic Scintillators for Modern and Traditional Applications, M. Globus, B. Grinyov, J. K. Kim, Institute for single crystals Ukrain-Kharkiv, 2005.
4. Radiation Detection and Measurements, 4th Ed., Glenn F. Knoll, John Wiley & Sons, Inc. Techniques for Nuclear and Particle Physics Experiments, William R. Leo, Springer Verlag, Inc. 1994.

PHY-717 Advance Laser Optics

This is a lecture and laboratory course. including Spontaneous Raman scattering, the physical origin of non-linear polarization, propagation in anisotropic and non-linear media, birefringence, parametric generation and parametric amplification, electro-optic effects in crystals, non-linear optics, including second harmonic generation (SHG), third harmonic generation (THG), Pump probe technique, phase conjugate optics, four-wave mixing (FWM), Coherent-Anti Stokes Raman scattering (CARS), Stimulated Raman scattering (SRS).

Recommended Books:

1. C. Rulliere, Femtosecond laser pulses, Springer, 2005
2. H. Abramczyk, Introduction to laser spectroscopy, Elsevier, 2005
3. Rosencwaig A. Photoacoustic spectroscopy, John Willey and Sons, New York, 1980.
4. Gusev V.E., Karabutov. A.A. Laser Optoacoustics. AIP, N.-Y., 1993.
5. Almond D.P. Patel J. Photo thermal science and techniques, London, Chapman and Hall, 1996. 450 p.
6. Tam A.C. Application of photo acoustic sensing techniques. Rev. Mod. Phys., 1986,v.58, N2, pp.381-431.
7. Phys. Acoustic (Ed. Mason W.P., Thurston R.N.), 1988, v.18, Acad. Press., P.168-277.
8. Vargas H., Miranda L.C.M. Photoacoustic and Related photothermal techniques. Phys. Rep., 1988, v.163, 43.
9. Malkin S., Canani O. The use and characteristics of the photoacoustic method in the study of photosynthesis. Annu. Rev. Plant Physiol. Plant Mol. Biol. 1994, 45:493-526.
10. Rogers J.A., Maznev A.A, Matthew J.B., Keith A.N. Optical generation and characterization of acoustic waves in thin films: Fundamentals and Applications. Annu.Rev. Matter. Sci., 2000, 30: 117-157.

PHY-718 Optoelectronics and Photonics

Wave Nature of light, Dielectric wave guide and optical fibres, Semiconductor Science and light emitting diodes, Stimulated emission devices lasers, Principle of laser diode, modes in laser and the optical cavity length, photodetectors, Photovoltaic devices, Polarization and modulation of light, Light propagation of light in anisotropic medium. quartz half wave plate, magneto optic effects, Kerr effect, Nonlinear optics and second harmonic generation.

Recommended Books

1. C. Rulliere, Femtosecond laser pulses, Springer, 2005
2. S. O. Kasap, Optoelectronics and Photonics Principles and practices, PEARSON
3. H. Abramczyk, Introduction to laser spectroscopy, Elsevier, 2005
4. Rosencwaig A. Photoacoustic spectroscopy, John Willey and Sons, New York, 1980.
5. Gusev V.E., Karabutov. A.A. Laser Optoacoustics. AIP, N.-Y., 1993.

PHY-719 Particle Physics

- Relativistic quantum mechanics, Klein Gordon and Dirac equations. Pauli and Weyl representations of gamma matrices, antiparticles, Majorana representation, left and right handed particles, zitterbewung.
- 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.
- Minimal coupling to electromagnetic field, diagrammatic perturbation theory, Ruther, Moller, and Bhabha scattering.
- Introduction to the gauge principle, non-abelian transformations, examples of SU(2) and SU(3) gauge theories.
- The parton model, deep inelastic scattering, running of the coupling constant, beta function, limitations of the perturbative approach.
- V-A Theory of weak interactions, beta decay, tests of C and P-violation, time reversal invariance, leptonic and semileptonic decays.
- Spontaneous symmetry breaking, Goldstone theorem, Higgs mechanism, standard model, experimental tests of standard model of particle physics.
- Neutrino oscillations, mass matrices and mixing, tests for generations beyond three.

Recommended Texts:

1. Quarks and Leptons, An Introductory Course in Modern Particle Physics" by F. Halzen and A.D. Martin, Publisher: Wiley; 1st edition (January 6, 1984)
2. An Introduction to Quantum Field Theory, by M.E. Peskin and D.V. Schroeder, Publisher: Addison Wesley Publishing Company, 1995.
3. Collider Physics, by V.D. Barger, R.J.N. Phillips, Publisher: Westview Press; Upd Sub edition (December 17, 1996)
4. A Modern Introduction to Particle Physics, Fayyazuddin and Riazuddin, Publisher: World Scientific Pub Co Inc. 2nd Edition, September 29, 2000.

PHY-720 Quantum Field Theory

Objective :

1. To understand the application of QFT
2. To understand the quantization of electromagnetic field

Contents

- Relativistic Mechanics, Relativistic wave equations: Klein-Gordon, Dirac, Maxwell and Proca equations. Dirac algebra, Dirac spinors
- Classical Lagrangian dynamics, Lagrangian field theory, global and local symmetries, Noether's theorem, canonical quantization, from Classical to quantum mechanics, quantum fields and causality, canonical quantization of scalar field theory, complex fields and anti-particles, second quantization
- The S-Matrix in quantum field theory, time evolution of quantum states and the S-Matrix, Wick's theorem, path integrals, propagators. Feynman diagrams and Feynman rules.
- Particle decays and cross-sections, calculation of scattering processes.

Recommended Books:

1. A. Zee, Quantum Field Theory in a Nutshell, Princeton University Press.
2. M. E. Peskin and D. V. Schroeder, Quantum Field Theory, Perseus Books Group, 1995.
3. Greiner, Walter, Relativistic Quantum Mechanics. Wave Equations, Springer-Verlag Berlin Heidelberg

PHY-721 Group Theory

Finite Groups: groups and representations, the regular representations, irreducible representations, transformation groups and applications, Schur's lemma, orthogonality relations, characters, eigenstates, tensor products.
Lie groups: generators, Lie algebras, Jacobi identity, the adjoint representation, simple algebras and groups, states and operators.
SU(2): eigenstates of J3, raising and lowering operators, tensor products.
Tensor operators: orbital angular momentum, Wigner Eckart theorem and examples, product of tensor operators.
Isospin: charge independence, creation operator, number operators, isospin generators, symmetry of tensor products, the deuteron, supers election rules.
Roots, weights and SU(3): Gellmann matrices, weights and roots of su(3), positive weights, simple roots, constructing the algebra, Dynkin diagrams and examples, the Cartan matrix, the trace of generator, fundamental representation of SU(3), constructing the states, the Weyl group, complex conjugation and example of other representation.
Tensor method: lower and upper indices, tensor components and wave functions, irreducible representation and symmetry, invariant tensor, Clebsch-Gordon decomposition, triality, matrix elements and operators, normalization, tensor operators.
Hypercharge and strangeness: the eight-fold way, the Gellmann-Okubo formula, hadron resonances, quarks.
Young tableaux and SU(n): raising and lowering indices, Clebsch-Gordan decomposition, U(1), generalization of Gell-mann matrices, SU(N) tensors, dimensions, complex representations
The Lorentz and Poincare groups and space-time symmetries: generators and the Lie algebra, irreducible representation of the proper Lorentz group, unitary irreducible representation of the Poincare group, relation between representation of the Lorentz and Poincare groups, relativistic wave functions, fields and wave equations.

Recommended Textbooks:

1. Lie algebras in Particle Physics: From Isospin to Unified
Theories, Westview Press; 2nd Edition, 1999.
2. Group Theory in Physics, Wu-Ki-Tong, World Scientific, 1985.

PHY-722 Heavy Ion Physics

Course Objectives

This course is about the collision of particles that include light as well as heavy particles/nuclei. After this course, the students will be able to understand about particles production, their sources, collisions and cross-sections and analyses of end products.

Course Contents

Basic properties of atomic nuclei, sources of relativistic and ultra-relativistic particles, four-vectors, Energy and momentum, classical collisions, relativistic collisions, Detection techniques, Fixed target experiments, Experiments at colliders, Cross-section and collision geometry, Interaction cross section, Geometrical picture of the collision, Fragmentation process, Electromagnetic dissociation, Nuclear fragmentation, Fragmentation in its extended meaning, Multiplicities and relative abundances of secondary particles, Mean multiplicities, Multiplicity distributions, Particle abundances, longitudinal distributions of secondary particles, transverse spectra of secondary particles, Electromagnetic effect on charged meson spectra. Production of strangeness and heavy flavors, Emission of light nuclei anti-nuclei and hyper-nuclei.

Recommended Books

1. Introduction to relativistic Heavy Ion Physics, by J. Bartke, World Scientific Publishing Co. 2008.

2. Collider Physics, by V.D. Barger, R.J.N. Phillips, Publisher: Westview Press; Upd Sub edition (December 17, 1996)

3. Introduction to elementary particles, 2nd Revised Edition, by David J. Grifth, Wiley-VCH Verlag GmbH & Co. DGaA.

PHY-723 Radiation Detection & Measurement

Objectives

1. To learn basics of radiation interaction with matter.
2. To learn the basics of radiation detector design and their working principle
3. To learn the various detection techniques about radiation.

Contents

Radiation Sources

1. Units and Definitions
2. Fast Electron Sources
3. Heavy Charged Particle Sources
4. Sources of Electromagnetic Radiation
5. Neutron Sources

Radiation Interactions

1. Interaction of Heavy Charged Particles
2. Interaction of Fast Electrons
3. Interaction of Gamma Rays
4. Interaction of Neutrons

Gas filled Detectors

1. Principle and operating characteristics of ionization chambers
2. Proportional Counter
3. Geiger Mueller Counter

Scintillation Detector Principles

1. Scintillation mechanism in organic scintillators
2. Scintillation mechanism in inorganic scintillators

Photomultiplier Tubes and Photodiodes

1. Introduction
2. The Photocathode
3. Electron Multiplication
4. Photomultiplier Tube Characteristics

Radiation Spectroscopy with Scintillators

1. General Considerations in Gamma-Ray Spectroscopy
2. Predicted Response Functions
3. Properties of Scintillation Gamma-Ray Spectrometers
4. Relationship between Pulse Height and Energy and Type of Incident Particle

Semiconductor Diode Detectors

1. Semiconductor Properties
2. The Action of Ionizing Radiation in Semiconductors
3. Semiconductors as Radiation Detectors
4. Different Types of Semiconductor Detectors

Recommended Books:

1. Radiation Detection and Measurements, 4th Ed., Glen F Knoll, John Wiley & Sons.
2. Measurement & Detection of Radiation, 4th Ed., Nicholas Tsoulfanidis Sheldon Landsberger, CRC Press, Taylor & Francis Group, 2015.
3. Physics and Engineering of Radiation Detection, 2nd Ed. Syed Naeem Ahmed, Elsevier Amsterdam, Netherlands, 2015

PHY-724 Advanced Magnetic Resonance Imaging

Objectives

- To enhance student's skills and understanding of the physics of Nuclear Magnetic Resonance.
- Understanding of underlying principles in Magnetic Resonance Imaging
- Ability to apply the principles for analysis of MR images and contrast agents.

Contents

Unit 1: A Preview, Nuclear Magnetization, and the Bloch Equation, The Quantum Mechanical Basis of Precession and Excitation, The Quantum Mechanical Basis of Thermal Equilibrium and Longitudinal Relaxation
Unit 2: Signal Detection Concepts, Introductory Signal Acquisition Methods, Free Induction Decay, Spin Echoes, Inversion Recovery and Spectroscopy
Unit 3: One Dimensional Fourier Imaging, k Space and Gradient Echoes, Multi-Dimensional Fourier Imaging and Slice Excitation
Unit 4: NMR Signal, Continuous and Discrete Fourier Transforms, Sampling and Aliasing in Image Reconstruction, Filtering and Resolution in Fourier Transform Image Reconstruction, Projection Reconstruction of Images
Unit 5: Signal, Contrast and Noise, Fast Imaging in the Steady State, Spin Density, T-1 and T-2 Quantification Methods in MR Imaging
Unit 6: Introduction to MRI Coils and Magnets.

Recommended Books:

1. Magnetic Resonance Imaging: Physical Principles and Sequence Design, E. Mark, Robert W. Brown, Michael R. Thompson, Ramesh. V. Willy, 1999.
2. Functional Magnetic Resonance Imaging, Second Ed., S. A. Huettel, A. W. Song, G. McCarthy, Sinauer Associates Inc., 2008.
3. Handbook of MRI Pulse Sequences, 1st ed., Bernstein, K. F. King, X. J. Zhoa, Academic press, 2004
4. MRI: The Basics, Rah H. ashemi, William G. Bradley, ChristopherJ. Lisanti, 2nd edition.
5. Lippincott Williams & Wilkins

PHY-725 Particles Collision

Objectives

This course is about the collision of particles that include light as well as heavy particles/nuclei. After this course, the students will be able to understand about particles production, their sources, collisions and cross-sections and analyses of end products.

Contents

Basic properties of atomic nuclei, sources of relativistic and ultra-relativistic particles, four-vectors, Energy and momentum, classical collisions, relativistic collisions, Detection techniques, Fixed target experiments, Experiments at colliders, Cross-section and collision geometry, Interaction cross section, Geometrical picture of the collision, Fragmentation process, Electromagnetic dissociation, Nuclear fragmentation, Fragmentation in its extended meaning, Multiplicities and relative abundances of secondary particles, Mean multiplicities, Multiplicity distributions, Particle abundances, longitudinal distributions of secondary particles, transverse spectra of secondary particles, Electromagnetic effect on charged meson spectra. Production of strangeness and heavy flavors, Emission of light nuclei anti-nuclei and hyper-nuclei.

Recommended Books:

1. Introduction to relativistic Heavy Ion Physics, by J. Bartke, World Scientific Publishing Co. 2008.
2. Collider Physics, by V.D. Barger, R.J.N. Phillips, Publisher: Westview Press; Upd Sub edition (December 17, 1996)
3. Introduction to elementary particles, 2nd Revised Edition, by David J. Grifth, Wiley-VCH Verlag GmbH & Co. DGaA.

PHY-726 Relativistic Quantum Mechanics

Objectives

- The course is given to understand the effect of special relativity in quantum mechanics
- Students will be able to explain the Klein-Gordon and Dirac equation and its solutions
- Students will be able to explain the existence of anti-particles and quantization of fields

Course Contents

Relativistic Kinematics

Lorentz transformations, Four vector, Lorentz transformations in four vector notation, Energy-momentum, Collisions, Classical and relativistic collisions, Example and applications

Relativistic wave equation for Spin-0 particles – Klein-Gordon Equation

The notation, Schrödinger wave equation, The Kelin-Gordon wave equation, The non-relativistic limit, Free spin-0 particles, Energy-momentum tensor of the Klein-Gordon field, Charge conjugation and the current

A wave equation for Spin-1/2 particles – Dirac Equation

Failures of Klein-Gordon equation, The Dirac equation, Free motion of a Dirac particle, Single particle interpretation of the plane (free) Dirac waves, Non-relativistic of Dirac equation, Lorentz covariance of Dirac equation

Recommended Books:

1. Walter Greiner, Relativistic Quantum Mechanics, 3rd Edition, Springer-Verlag Publisher
2. Tommy Ohlsson, Relativistic Quantum Physics, Cambridge University Press
3. David Griffith, Introduction to Elementary Particles, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

PHY-727 Advanced Materials Processing and Design

Objectives:
General objective of the course is to enhance students' skills use and understanding of the joining methods. Specific objectives are as under

1. Understanding of underlying principles in welding and joining techniques of different materials
2. Ability to analyze the effect of different joining methods on the properties of advanced materials.

Course Learning Outcomes (CLOs):

Students will be able to:

- Understand the theory of joining of metals and non-metals
- Gain knowledge about the science of different joining techniques available
- Select an appropriate joining method for a specific material combination
- Asses the influence of different joining methods on the structure property relation of different materials.

Course Outline:

Unit-1: Arc welding process: Fundamentals of arc voltage, polarity, heat input, filler metals and electrodes, shielding gas, joint types, defects in arc welding, different types of arc welding processes.

Unit-2: Resistance welding, fundamentals, resistance spot welding, resistance seam welding, resistance projection welding, high frequency welding, flash welding.

Unit-3: Solid State welding: fundamentals, roll bonding, different types of friction welding (inertia, continuous drive, linear), diffusion welding, explosion welding, and ultrasonic welding.

Unit-4: High energy density welding, fundamentals, keyhole and conduction mode, laser beam welding, electron beam welding.

Unit-5: Brazing, soldering, hybrid welding, adhesive bonding, welding, welding of plastics through vibration welding, implant induction, hot tool, hot gas

Unit-6: Welding metallurgy, fusion zone, heat affected zone, phase diagrams, welding of ferrous and non-ferous alloys. Characterization of weldments though tensile, fatigue, impact strength and residual stresses and distortions, welding codes.

Textbook:

1. Welding engineering: An introduction by David H. Phillips, 1st edition, 2016
2. Fabrication and Welding Engineering by Roger Timings, 2008, Elsevier

PHY-728 Advanced Stress Analysis

Objectives:
General objective of the course is to enhance students' skills use and understanding of the stress measurement methods. Specific objectives are as under

3. Understanding of underlying principles in experimental stress analysis
4. Ability to apply the principles for analysis of stress distribution in different type of structures.

Course Learning Outcomes (CLOs):
Students will be able to:

- Apply the theory of stress-strain transformation and strain gauges to measure the stresses in different members.
- Apply the theory of photo elasticity to determine stress distribution in transparent and opaque bodies

Course Outline:
Unit-1: Stresses on planes, transformation of stresses, principle stresses Transformation of Stress, Principal Stresses, Principal Values and Directions, Plane stress, Mohr's Circle in Two Dimensions
Unit-2: Dimensional analysis, Stress analysis techniques, strain gauges (general description, configuration, instrumentation, commercial indicators
Unit-3: Strain measurement characteristics: linearity of grid, gage sensitivity, temperature effects, lead wire connection, strain gradient, zero shifts, dynamic response, noise effects
Unit-4: Photo elasticity: Electromagnetic waves, polarization, refraction, birefringence, fringe analysis, stress freezing, brittle coatings
Unit-5: Experimental tools for stress analysis: X-ray diffraction, contour methods, residual stresses, hole drill strain measurement. Laser speckle interferometry
Unit-6: Practical case studies or Problem Based Learning (PBL) to enhance application skills.

Recommended Books

1. Advanced strength and applied stress analysis, 2nd edition, Richard G Budynas, 1999
2. Modern experimental stress analysis by James F Doyle, 2004
3. Advanced mechanics of materials Arthur P. Boresi, Schmidt, 6th edition, 2003

PHY-729 Optical Materials

Objectives:
The objective of the course is to get insight into the optical properties of materials. The student will be exposed to a quantitative interpretation of the fundamentals of the interaction of light with passive and active optical materials as well as general information on the applications of optical materials in applied sciences.

Contents
Introduction to Light-Matter Interactions
Introduction; passive & active optical materials; Electromagnetic radiation; Maxwell's Equations; Lorentz Model Dispersive optical constants Absorption, transmission, reflection (Fresnel Equations), refraction, diffraction, emission, scattering (phonons, elastic, Raman, Brillouin), polarization measurement and simulation of the optical properties of materials
Passive Optical Materials
Glasses: oxides, origin of color in glasses: optical constants, specialty optical applications, polarization Crystals: polarization, birefringence, waveplates, liquid crystals Passive optical components: lenses; optical coatings; mirrors; gratings, photonic bandgap materials Optical waveguides: thin films (slab); optical fibers; mode equations and profiles.
Active Optical Materials
Semiconductors: interband absorption; direct, indirect bandgap; Si, III-V; II-V Semiconductors: excitons, Applications of active semiconductor optical materials: photodetectors, amplifiers (lasers), lighting, displays. Nonlinear optical materials: Nonlinear optical properties; gain materials; upconversion; harmonic generation, electro-optic materials.

Recommended Books
1. Optical Properties of Solids by Mark Fox, Oxford University Press, New York 2001.
2. Photonics by Amnon Yariv & Pochi Yeh, Oxford University Press, 6th Edition, New York, 2007.
3. Introduction to Modern Optics by Grant R. Fowles, Dover Publications, 2nd Edition, New York 1989.
4. Materials Chemistry by Bradley D. Fahlman, Springer, 2nd Edition, New York, 2011.

PHY-730 Organic Semiconductor Devices

Objectives:
To introduce the organic electronics and optoelectronics in terms of basic theory, applications, recent developments, etc.

Course Contents:
Organic Molecules
Electronic structure of atoms, Atomic and Molecular Orbitals, LCAO, Bonding and antibondig orbitals, Covalent Bond, Sigma and Pi Bonds, Energy Levels, Spectroscopic
Photophysics of Molecules and Aggregates
Excited states: Absorption and emission, Singlet and triplet states, Radiative and non-radiative transitions, Aggregates, Van der Waals Bonding, Hydrogen Bonding, Dimer, Eximers.
Excitons (Wannier Exciton, Charge-transfer Exciton, Frenkel Exciton), Exciton Diffusion, Excitonic Energy Transfer.
Conduction in Organic Solids
Conductivity: carrier concentration versus mobility, Carrier generation, Hopping transport, Mobility measurements, Traps. Photovoltaics and Photodetectors: Photovoltaic Devices: Organic Heterojunction Photovoltaic Cells, Organic/Nanorod hybrid Photovoltaics, Gratzel Cells (Dye sensitized solar cells), Photodetector Devices
Organic Light Emitting Devices
Basic OLED Properties, Charged Carrier Transport, Organic LEDs, Quantum Dot LEDs.
Organic Thin Film Transistors: OFETs
Materials, Contacts, Applications, Nanotube Transistors.

Recommended Books:
1. Essentials of Molecular Photochemistry, Gilbert &Baggott, CRC Press, 1991.
2. Fundamentals of Photochemistry, K. K. Rohatgi- Mukherjee, NewAge International, 1978.
3. Electronic Processes of Organic Crystals and Polymers", Pope & Swenberg, Oxford University press, 2nd edition (1999).
4. Organic Semiconductors" H. Meier, Verlag Chemie GmbH, 1974
5. Physics of Organic Semiconductors, Wolfgang Brütting, John Wiley & Sons Canada; 1 edition (2005)

PHY-731 Advanced Computational Physics

Objective(s)

To enable students to get data from the repositories developed for material scientists and physicists, and process and analyze it.

Course Contents

Nested Data and Nested Iteration: Introduction: Nested Data and Nested Iteration; Nested Dictionaries; Processing JSON results

Nested Iteration: Nested Iteration; Structuring Nested Data; Deep and Shallow Copies; Extracting from Nested Data

Map and Filter: Introduction: Map, Filter, List Comprehensions, and Zip; Map; Filter

List Comprehensions and Zip: List Comprehension, Zip

Requesting Data from the Internet: The Internet: Behind the Scenes; Anatomy of URLs; The HTTP protocol; Using REST APIs; Fetching a page

Using REST APIs: Figuring Out How to Use a REST API; Debugging calls to requests.get(); Caching Response Content

Practice with REST APIs: Searching for Media on iTunes; Searching for tags on flickr; Unicode for non-English characters

Recommended Book(s)

1. Python: The Fundamentals of Python Programming, by Paul Jones
2. Python Crash Course: A hands Project-based Introduction to Programming, by Eric Matthes
3. How to Think Like a Computer Scientist: Learning with Python, by Allen Downey, Jeffrey Elkner, Chris Meyers

PHY-732 Machine Learning in Physics

Objective(s)

To introduce the fundamental of machine learning as applied to problems in Physics.

Intended Learning Outcomes

Upon completion of the subject, students will be able to (a) extract, visualize and process data from online database dedicated to materials scientist and physicists; (b) select machine learning models to solve specific problems; (c) implement various machine learning models in Python; and (d) evaluate and improve the performance of a model.

Course Contents

- Supervised/Unsupervised learning
- Data for machine learning
- Univariate linear regression
- Multivariate linear regression
- Logistic regression
- Overfitting, validation, and regularization
- Neural networks
- Back propagation algorithm
- Clustering
- Advanced methods

<u>Recommended Books:</u>

1. Physics of Data Science and Machine Learning by Ijaz A. Rauf, 2021, CRC Press.
2. Deep Learning for Physics Research by Martin Erdmann, Jonas Glombitza, Gregor Kasieczka, Uwe Klemradt, 2021, World Scientific.
3. Deep Learning and Physics by Akinori Tanaka, Akio Tomiya, Koji Hashimoto, 2021, Springer Nature.

PHY-733 Physics of Glasses

Objective(s): To understand the glass' nature and structure using different models. To understand the properties of glasses (amorphous inorganic solids).

Contents

Nature and Structure of Glass/ Principles of Glass Formation

Introduction, Structural Theories of Glass Formation, Kinetic Theories of Glass Formation, Introduction to glass, Glass transformation behavior (Enthalpy vs. temperature diagram, glass transition), Principles of glass formation, Structures of glasses, Phase transformations and microstructure development in glass, Crystallization of glasses, Phase separation in glasses, Glass manufacturing: Principles and processes, Viscosity of glass forming melts, Viscoelasticity, Thermal shock and annealing of thermal stresses: Laboratory visits: Practical experience of glass melting: Characterization of glass

Density: Density: Experimental Background and Theory, Experimental Methods and Theory, Instrumentation Used for Determining Density, Analysis of Data, Extraction of Useful Information, and Other, Ways to Express Density, Case Studies from Some Glass Systems

Index of Refraction: Methods of Measurement, Dependence on Composition, Calculation Based on Composition, Methods of Measurement, Transparency in the Ultraviolet Range, Transparency in the Visible Range, Transparency in the Infrared Range, Dependence on Temperature

Photoluminescence (PL) spectroscopy OF GLASSES: Instrumentation, analysis of data, Bulk Glasses**;** Special glass and glass materials

Recommended Books

1. Introduction to Glass Science and Technology Second Edition, James E. Shelby New York State College of Ceramics at Alfred University School of Engineering, Alfred, NY, USA, Published by The Royal Society of Chemistry, Thomas Graham House, Science Park, Milton Road, Cambridge CB4 OWF, UK
2. Glass Nature, Structure, and Properties, Horst Scholze; translated by Michael Lakin. 1991 Springer-Verlag New York, Inc.
3. MODERN GLASS CHARACTERIZATION, Edited by Mario Affatigato, The American Ceramic Society and John Wiley & Sons, Inc. 2005

PHY-734 Photophysics and Photocatalysis

Objective (s)
The objective of the course is to get insight into the optical and photocatalytic properties of materials. The student will be exposed to a quantitative interpretation of the fundamentals of photocatalysis.

Basic principles: Introduction, Laws of light absorption, Radiation and molecular orbitals, Selection rules, Light absorption by solids
Molecular photophysics: Excited state's deactivation pathways, Kinetics of photochemical processes, Intermolecular energy transfer
Molecular Photophysics: Excited state's deactivation pathways, Kinetics of photochemical processes, Intermolecular energy transfer
Natural photochemical processes: Atmospheric reactions, Photochemistry of waters and soils, Natural photosynthesis, Mechanisms of vision
Principles of photo-induced electron transfer: Thermodynamics of photoredox reactions, Dynamics of electron transfer processes, Examples of homogeneous and nano-heterogeneous systems
Photo-electrochemistry of semiconductors: Energetics at the surface of semiconductors, Case of thin semiconductor layers, Potential-controlling ions, Light-induced charge separation at liquid junction, Dye-sensitization of wide-bandgap semiconductors
Photo-electrochemical conversion of solar energy: Introduction, Thermodynamic limitation of power conversion efficiency, Photovoltaic solar cells, Artificial photosynthesis Semiconductor-assisted photocatalysis (Advanced oxidation processes)

Recommended Books
1. Photochemistry and Photophysics (concepts, research and applications) V. Balzani, P. Ceroni & A. Juris Wiley-VCH Weinheim, 2014
2. Principles of photochemistry (An introduction) N. J. Turro, V. Ramamurthy & J. C. Scaiano University Science Books Dulles VA (USA), 2010

PHY-735 Magnetism and Magnetic Materials

Course Contents

- Review of concepts in magnetism
- Classification of magnetic materials
- Diamagnetism etc
- Main families of magnetically hard materials (Alnico, Fe-Cr-Co, Sm-Co, Nd-Fe-B, ferrites)
- Main families of magnetically soft materials (silicon iron, Fe-Ni, Fe-Co, Fe-Al, ferrites, amorphous and nanocrystalline alloys)
- Other magnetic materials (magneto-resistive materials, magneto-electric materials, magneto-elastic materials, materials with shape memory, materials for magnetic recording)
- Application of magnetic materials
- Measurements techniques, Production and measurement of field, magnetic shielding, Vibration sample magnetometer, SQUID magnetometer, Nuclear magnetic resonance of paramagnetic systems. Neutron diffraction.

Recommended Books:

1. Chikazumi, S. Physics of Ferromagnetism. New York: Oxford University Press, 1997. ISBN: 9780198517764.
2. C.Kittel. Introduction to Solid State Physics, 8th edn. (Wiley, 2005).
3. Magnetism in Condensed Matter (Oxford Master Series in Physics) 1st Edition by Stephen Blundell
4. . B. D. Cullity and C. D. Graham, Introduction to magnetic materials. John Wily & Sons, Inc, 2011 2. D. Jiles, Introduction to magnetism and magnetic materials. Taylor and Francis, CRC Press 1998.
5. B. D.Cullity and C. D. Graham. Introduction to Magnetic Materials. New York, NY: Wiley-IEEE Press, 2008.
6. N.A.Spaldin. Magnetic Materials: Fundamentals and Device Applications. Cambridge University Press, 2003.
7. J.M.D.Coey. Magnetism and Magnetic Materials. Cambridge University Press, 2010.

PHY-736 Luminescence of Solid Materials

Fundamentals of luminescence, Characteristics of Luminescence, Theoretical model and mechanism of luminescence, Experimental techniques of luminescence measurements, Absorption and luminescence spectroscopy, Spectroscopic components, radiative and nonradiative processes, Cross Relaxations and Resonant Energy transfer, Photoluminescence, Classification of photoluminescence in solids, Band to band luminescence, Wannierexciton luminescence, Characteristics of localized center luminescence, Extrinsic luminescence of unlocalized type, Extrinsic luminescence of localized type, luminescence of rare earth/lanthanides(RE/Ln^{3+}) doped materials, Thermoluminescence, Thermoluminescence model, Thermoluminescence mechanism, Methods of analysis, Applications.

Recommended Books:

1. Luminescence Materials, G. Blasse, B. C. Grabmaier, Springer-Verlag, 1994.
2. Luminescence of Solids, D. R. Vij, Plenum Press New York, 1998.
3. Luminescence, From Theory to Applications, R. Ronda (WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany, 2008.

List of PhD Courses and Their Codes