Syllabus

Postgraduate

Phy 6001: Advanced Quantum Mechanics **Credit: 3**

Mathematical Introduction: State vector in Hilbert spaces, Bra and Ket notations, Linear vector spaces, Inner product spaces, Dual spaces and Dirac notation, Operators and their representation.
Theory of Angular Momentum: Eigenvalues of angular momentum. Addition of angular momenta, Clebsch-Gordon coefficients, Pauli exclusion principle and spin matrices. Many electron system-Hatree & Hatree-Fock approximation.
Variational Method: Expectation value of the energy, Application to excited states, Linear variation function, Application to harmonic oscillator, hydrogen and helium atoms.
Relativistic Wave Equation: Klein-Gordon and Dirac's relativistic wave equations, Solution of free particle equation, Negative energy states and hole theory.

Books Recommended:

1. Principles of Quantum Mechanics – R. Shankar
2. Introduction to Quantum Mechanics – David J. Griffiths
3. Text Book of Quantum Mechanics – Mathews and Venkatesan
4. Modern Quantum Mechanics – J.J. Sakurai
5. Quantum Mechanics – L.I. Schiff
6. Quantum Mechanics – A. Messiah
7. Quantum Mechanics – Merzbacher
8. Basic Quantum Mechanics – C. Ziock

Phy 6101 Advanced Solid State Physics **Credit: 3**

Basic Concepts: Geometry of lattices; Lattice vibrations; Electrons in a lattice: Tight binding approximation, dynamics of Bloch electrons, Second quantization of Bosons and electrons, Symmetry operations; Groups; Fermi surface construction.
Electron States and Energy Bands Calculations: Muffin-Tin potentials; Orthogonalized plane wave method; Pseudopotentials; The Hartree equation; The Hartree-Fock equation: The Hartree-Fock theory of free electrons.
Classical dc Transport: The Boltzmann equation of electrons, Conductivity and thermoelectric phenomena, energy transport, electron-electron scattering, Shubnikov-de Hass effect.
Semiconductors: Optical Processes: Introduction, Photon-material interaction, microscopic single electron theory, selection rules, intraband transitions. **Excitons:** Excitonic states, Excitonic effects in optical properties. **Doped Semiconductors:** impurity states, Localized electronic states, impurity band for lightly doped semiconductors, AC conductance due to localized states.
Quantum Transport: Preliminary Concepts: Two-Dimensional Electron Gas, Basic Properties, Degenerate and non-degenerate electron gas. **Ballistic Transport:** Landauer

formula, Application of Landauer formula, Additional aspects of ballistic transport, e-e interaction in ballistic systems.

Tunneling and Coulomb blockage: Tunneling, Coulomb blockade. **Quantum Hall Effect**: Ordinary Hall effect, Integer Quantum Hall effect General Picture, Edge Channels and Adiabatic Transport, Fractional Quantum Hall Effect.

Books Recommended:

1. Introduction to Modern Solid State Physics: Galperin, Yuri M.
2. Introduction to Solid State physics: C. Kittel.
3. Solid State Physics: Ashcroft, Mermin.
4. Elementary Solid State Physics: Ali Omar.
5. Principle of Condensed Matter Physics: Chaikin, Lubensky.
6. Advanced Solid State Physics: Philips, Phillips.

Phy 6102 Surface Science **Credit: 3**

Ultra-High Vacuum Techniques, Surface Cleaning Procedures and Deposition Techniques:
Designing a UHV chamber; Vacuum concepts; UHV hardware: pumps, tubes, materials and pressure measurement; Types of pumps: Rotatory, Turbomolecuar, Ion pump, Ti sublimitation pump; Pressure measurement and gas composition; Surface preparation and cleaning procedures: in-situ experiments; Deposition procedures: Thermal evaporation and the uniformity of deposits; Molecular beam epitaxy and related methods; Sputtering and ion-beam assisted deposition; Chemical vapor deposition techniques

Surface Processes:
Elementary thermodynamic ideas of surfaces; Thermodynamic potentials and the dividing surface; Surface tension and surface energy; Surface energy and surface stress; Surface energies and the Wulff theorem; Thermodynamics versus kinetics; Thermodynamics of the vapor pressure; The kinetics of crystal growth.

Introduction to Surface and Adsorbate Reconstructions:
Overview: General comments and notation; Examples of (1×1) structures, Si(001) (2×1) and related semiconductor structures; The famous 7×7 structure of Si(111); Various $\sqrt{3}\times\sqrt{3}$ structures; Polar semiconductors: GaAs (111); Ionic crystal structures: NaCl, CaF2, MgO or alumina.

Introduction to Surface Electronics:
Work function, Electron affinity and ionization potential, Surface states and related ideas, Surface Brillouin zone, Band bending due to surface states.

Surface, Interface and Thin Film Analysis Techniques Based on Interactions Between Light/Ion/Electron Beams With Surfaces:
Classification of surface and microscopy techniques; Surface sensitivity; Microscopic examination of surfaces. Diffraction techniques: LEED, RHEED. Inelastic scattering techniques: Chemical and electronic state information; Electron spectroscopic techniques; Photoelectron spectroscopies: XPS and UPS; Auger electron spectroscopy (AES). Microscopy-

spectroscopy: Secondary Electron Microscopy (SEM). Scanning Probe Microscopes (SPM): Scanning Tunneling Microscopy (STM), AFM, MFM, etc .

Adsorption Phenomena at Surfaces

Chemi- and physi-sorption; Chemisorption: quantum mechanical models and chemical practice.

Surface Processes on Nucleation and Epitaxial Growth:

Introduction: growth modes and nucleation barriers, Epitaxial growth, Growth modes and adsorption isotherms, Nucleation barriers in classical and atomistic models. Atomistic models and rate equations: Rate equations, controlling energies, and simulations. Steps, ripening and inter diffusion: Steps as 1-dimensional sinks, Steps as sources: diffusion and Ostwald ripening.

Magnetic Study on Surfaces

Introduction; X-ray Magnetic Circular Dichroism (XMCD) and Magnetic Force Microscopy (MFM)

Looking Below the Surface

Non destructive: Angle resolved XPS, Bias dependent STM. Destructive: SIMS, TOF SIMS, Sputtering.

Books Recommended:

1. Physics at Surfaces : A. Zangwill, Cambridge University Press, 1988
2. Electronic Properties of Surfaces : M. Prutton (editor), Adam Hilger Ltd., 1984
3. Introduction to Surface Physics: M. Prutton, Oxford Science Publications, 1994
4. The Chemical Physics of Surfaces: S. Roy Morrison, Plenum Press, 1990 (2nd edition)

Phy 6103 Semiconductor and Insulator Physics **Credit: 3**

Types of Semiconductors: Intrinsic, Extrinsic, Degenerate and Nondegenerate semiconductors, Fermi energy, carrier density;

Phenomena of Doping Impurity: in semiconductors and insulators, Defects in semiconductors and insulators, Incorporation of defects. Dielectric properties of Insulator.

Density of States: Different type of bonding; Energy bands, energy levels of band, carrier concentrations, activation energy; transport properties of semiconductors and insulators; temperature dependence conductivity, Brillouin Zones, Effective mass of electrons and holes.

DC and AC Electrical Conduction Mechanism: in low and high field; conductivity; composition, thickness, temperature and frequency dependence conductivity; Field effect on conductivity, Fuch-Sondheimer theory;

Thermoelectric Effect: Thermo e.m.f., Temperature gradient, Diffusion process, Thermopower, Seebeck, Thomson and Peltier effect.

Hall Effect: Hall theory, mobility, concentration, Hall coefficients, Identification of carriers.

Contact Phenomena: work function, vacuum level; Ohmic, neutral and blocking contacts of metal-semiconductor, Solar cell, Photovoltaic cell, p-n junction etc.;

Optical and Photoconduction Phenomena (Semiconductors and Insulator): light absorption (transmission and reflection) by free charge, charge carriers, lattice and electrons in a localized states, Scattering modes, optical constants, photovoltaic effect, selective surface.

Books Recommended:

1. Basic semiconductor Physics: Hamaguchi, Chihiro (Second edition)
2. Fundamentals of Semiconductor Physics and Devices: R Enderlein, njm Horing
3. Solid State Physics: Ashcroft, Mermin.
4. Advanced Solid State Physics: Philips, Phillips.
5. Amorphous and Liquid Semiconductors: H. Fritzsche

Phy 6104: Thin Film Growth Technology and Analysis **Credit: 3**

Vacuum Technique: Production of vacuum, Exhaust pump, Rotary pump, diffusion pump, Ion pump, Measurement of vacuum and Vacuum gauges, Vacuum leaks and their detection.
Film Preparation Techniques: Thermal evaporation, Evaporation theory and mechanism, E-beam evaporation, Molecular beam epitaxy (MBE), Chemical vapor deposition (CVD) and different types of CVD, Different types of sputtering, Electroplating, Spray pyrolysis, Sol-gel technique.
CVD and Spray Pyrolysis Materials: CVD technique and measurements, materials for CVD, Spray pyrolysis technique and measurements, materials for spray pyrolysis, Sol-Gel technique and measurements, materials for sol- gel.
Growth of Thin Films: Thermodynamic concept of nucleation, Atomistic theory of nucleation, Coalescence, Effect of deposition parameters on grain boundary, Growth structure of thin films, Epitaxial growth phenomena, and Different types of defects in thin films.
Thickness Measurement: Optical ineterferometry method, Quartz crystal monitor, Ellipsometry, Spectrophotometry method, Electrical & Mechanical methods.
Film Analysis: Surface morphology-Scanning electron microscopy (SEM), Chemical composition-energy dispersive analysis of x-rays (EDAX), Auger electron microscopy, X-ray photoelectron spectroscopy etc., Structural-X-ray diffraction (XRD), Transmission electron microscopy (TEM), etc.
Transport Phenomena: Electrical conduction in discontinuous and continuous films, Temperature effects, Field effect, Hall effect, Thermoelectric effect, Size effect, Activation energy and activation process,
Optical Parameters: absorption, transmission, reflection and photoconduction mechanisms,
Insulating and Cermet films: Bridgman theory, Tunneling, Space-charge-limited-current, Scottky effect and Pool-Frenkel effect.

Books Recommended:
1. Thin-Film Deposition: Principles and Practice: Donald Smith
2. Thin Film Materials: Stress, Defect Formation and Surface Evolution: L. B. Freund , S. Suresh
3. Materials Science of Thin Films: Milton Ohring
4. Thin Film Phenomena: K. L. Chopra
5. Thin Film Fundamentals: A. Goswami

Credit: 3

Phy 6105: Magnetism

Current and Magnetism, Technical magnetic materials.
Classification of Magnetic Materials, Demagnetizing field and factors, Magnetostatic energy.
Quantum Theory of Diamagnetism, Para magnetism and Ferromagnetism, Pauli Paramagnetism.
Properties of Magnetically Ordered Solids, Wesis theory of ferromagnetism, Interpretation of exchange interaction in solids, Ferromagnetic domains, Technical magnetization, Intrinsic magnetization of alloys.
Theory of antiferromagnetic and ferromagnetic ordering, Ferromagnetic oxide and compounds.
Phenomenology of Anisotropy, Physical origin of anisotropy, Temperature dependence and measurement of anisotropy, Electronic transport in magnetic materials, Magnetic recording and reproduction.

Books Recommended:

1. Physics of Magnetism and Magnetic Materials: K. H. J. Buschow, F. R. Boer, Boer F. R. de, F. R. De Boer Publisher: Springer-Verlag New York
2. Physics of Ferromagnetism: Sōshin Chikazumi, Chad D. Graham, Publisher Clarendon Press, 1997, ISBN 0198517769, 9780198517764
3. Introduction to Magnetism and Magnetic Materials: David Jiles, Publisher: CRC Press

Phy 6106: Material Characterization Techniques **Credit: 3**

Structural Measurement: X-ray diffraction method (XRD), Transmission electron microscopy (TEM), etc.
Surface Morphology Measurement: Scanning electron microscopy (SEM).
Compositional Analysis: Energy dispersive analysis of X-ray (EDAX).
Measurement of Film Thickness: Optical interferometry methods, spetrophotometry method.
DC Conductivity Measurement: I-V measurement method, Van der Paw method, Sandwich method.
Measurement of AC Conductivity: Conductance, Capacitance, dielectric constant and dielectric loss as a function temperature and frequency.
Measurement of Optical Parameters: Optical absorption, Transmittance, Reflectance (UV-VIS-IR Spectra) with spectrophotometer, Photovoltaic measurement: Optical parameters analysis.
Measurement of Thermopower: Thermo e.m.f., Thermopower (Seebeck, Peltier) by differential and integral methods.
Hall effect measurement: Annealing, magnetic and non-magnetic annealing measurements.
Magnetization Measurement Methods (Faraday, VSM and SQUID), magnetic anisotropy and magnetostriction measurements, magnetic domain observation, Electron spin resonance (ESR), Ferromagnetic resonance (FMR) and Nuclear magnetic resonance (NMR).

Books Recommended:

1. X-Ray Diffraction- B. E. Warren
2. X-Ray Diffraction: In Crystals, Imperfect Crystals, and Amorphous Bodies-A. Guinier
3. Introduction to Crystallography -Donald E. Sands
4. Elements of X-Ray Diffraction (1956) - Cullity, B. D. Publisher: Addison-Wesley Publishing Company, Inc.
5. Scanning Electron Microscopy and X-ray Microanalysis- Joseph Goldstein, Dale E. Newbury, David C. Joy, Charles E. Lyman, Patrick Echlin, Eric Lifshin, Linda Sawyer, J.R. Michael
6. Modern Infrared Spectroscopy - Barbara H. Stuart, Bill George, Peter McIntyre
7. NMR-MRI, [mu]SR, and Mössbauer spectroscopies in molecular magnets- Pietro Carretta, Alessandro Lascialfari, Publisher: Springer

Phy 6107: Nanotechnology **Credit: 3**

Fabrication of nanostructured materials:
Self assembly: self assembled monolayers, guided assembly using templates. Top down and Bottom up approach of fabrication.

Confinement and transport in nanostructured materials:
Electron channels, conductance formula for nanostructures, quantized conductance. Local density of states. Ballistic transport, Coulomb blockade, Diffusive transport. Example: Single electron transistor.

Buckyballs, Nanotubes and Nanowires:
Introduction; Fullerenes, C60 and nanostructures; Properties & Applications (mechanical, optical and electrical). Single and multiple wall carbon nano tubes: Synthesis, characterization and application. Nanowires: Fabrication, applications, quantum conductance effects in semiconductor nanowires,

Molecular electronics:
Molecules as building blocks, Examples: Molecular rectifying diode switches.

Nanostructure Magnetism:
Giant and colossal Magnetic resistance; Super Para Magnetism in metallic nanoparticle; Super para magnetism / FM in Semi-conduction quantum dots.

Spintronics:
Introduction, Overview, History & Background, Generation of Spin Polarization, Theories of spin Injection, spin relaxation and spin dephasing, Spintronic devices and applications, spin filters, spin diodes, spin transistors. Spin polarized Scanning tunneling microscopy (SP STM).

Nano Clusters and Quantum dots:
Different growth modes and applications.

Electronic Transport in low dimensional structures:
Transport properties of electrons in 2-, 1- and 0-dimensional systems.

Books Recommended:

1. Selected Topics in NanoScience and Nanotechnology - Edited by: Andrew TS Wee, Published by: World Scientific Publishing Co. Pvt. Ltd., Year: 2009. 5 Toh Tuck Link, Singapore 596224, ISBN-13 978-981-283-955-8; ISBN-10 981-283-955-0
2. Scanning Probe Microscopy: Analytical Methods (NanoScience and Technology)- Roland Wiesendanger
3. Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM - Ray F. Egerton
4. Nanoscale materials -Liz Marzan and Kamat.
5. Physical properties of Carbon Nanotube-R Satio.
6. Applied Physics Of Carbon Nanotubes : Fundamentals Of Theory, Optics And Transport Devices
- S. Subramony & S.V. Rotkins.
7. Carbon Nanotubes: Properties and Applications- Michael J. O'Connell.
8. Nanotubes and Nanowires- CNR Rao and A Govindaraj RCS Publishing.
9. Nanoelectronics & Nanosystems: From Transistor to Molecular & Quantum Devices: Karl Goser, Jan
Dienstuhl and others.
10. Concepts in Spintronics – Sadamichi Maekawa
11. Spin Electronics – David Awschalom

Phy 6201: Advanced Nuclear Physics **Credit: 3**

Optical Model of Elastic Scattering:
Complex potential; Collision in nuclear matter and mean free path; Giant resonance, Microscopic and macroscopic optical-model.

Nuclear Shell Model:
Single Particle Shell model; Iso-spin formalism; Two-particle system; Shell model Hamiltonian; Perturbation theory and configuration mixing, Allowed states; Anti-symmetric wave functions, More than two particles in one orbit; Coefficient of fractional parentage, Double parentage coefficients; Spectroscopic factors; Spectroscopic factors for particles in two active shells; Spectroscopic factors for mixed configurations; Sum rules for single particle transfer reactions.

Collective Model:
Shortcomings of the shell model and the nuclear collective models; Nuclear rotational motion; Rotational energy spectra and nuclear wave functions for even and odd A nuclei. Nuclear deformation; Collective oscillation; Liquid drop model; Quadrupole deformation; Electromagnetic properties, Reduced transition probability and expression for B(E2) value in the case of a symmetric rotor for Coulomb excitation.

Books Recommended

1. Nuclear Physics-Hodgson and Gladioli, Roy R.R. and Nigam B.P.
2. Structure of the Nucleus -Preston M.A. and Bhadury R.K.
3. Direct Nuclear Reactions-Satchler G.R.
4. Theoretical Nuclear Physics-Feshbach Herman
5. Shell Model Applications in Nuclear Spectroscopy -Brussard P.J. and Glaudemans P.W.M

Phy 6202: Theory of Nuclear Reactions **Credit: 3**

Compound Nucleus and Statistical Model:
Resonance reaction; Breit-Wigner dispersion formula; Bohr Compound nuclear model; Continuum theory of cross-section.

Direct Nuclear Reactions:
Types of direct reactions and selection rules; Reaction kinematics: non-relativistic and relativistic; Theory of inelastic scattering; Theory of transfer reactions: one nucleon transfer, two nucleon transfer, multinucleon transfer reactions and their selection rules; Importance of direct reactions; Multi-step nuclear reactions.

Electromagnetic Interactions with Nuclei: Infinitesimal rotations in vector fields; Intrinsic angular momentum of vector fields; Total angular momentum of vector fields and vector spherical harmonics; Multipole fields; Sources of multipole fields; Transition probability of a multipolar radiation; Multipole moments; Selection rules in a gamma transition; Angular distribution of a gamma transition; Angular correlations; Relative strengths of different multipolar radiations in a transition between two low-lying states of an excited nucleus.

Books Recommended

1. Direct Nuclear Reactions-Hodgson and Gladioli, Bertuloni, and G.R. Satchler
2. Nuclear Physics- R. R. Roy and B. P. Nigam
3. Quantum Mechanics -L. I. Schiff

Phy 6203 Advanced Medical Physics **Credit: 3**

Interaction of ionizing radiation with matter: Basics concepts, energy absorption, detection, control, and production, and on their relation to medical applications.

Radiotherapy Physics: Isodose Distribution: Isodose chart; Measurement of isodose curves; Parameters of isodose curves; Wedge filters; Combination of radiation fields; Isocentric techniques and wedge field technique. Electron therapy, tissue air ratio (TAR), tissue maximum ratio (TMR), treatment planning, Biological predictions of therapy outcomes. Linear accelerator, Brachytherapy. Cobalt Therapy, IGRT, IMRT, CYBER Knife.

Medical Imaging: Image reconstruction from projections; Basic concepts: SPECT, X-ray Computer Tomography (CT), Positron emission tomography (PET).

(a) CT Physics: Conventional Radiography, Back Projection, Filtered Back Projection, CT Scanning Geometries, Helical Scanning, Interpolation & Extrapolation, Interpolation in Helical CT, Volume Imaging, CT Image Display, Scanned Projection Radiography.

(b) PET Physics: **The physical principles of PET:** Introduction, Positron emission and annihilation, Coincidence detection and electronic collimation, Photon interactions in human

tissue and correction for gamma-ray attenuation, Types of coincidence events. **2D mode and 3D mode:** Principles of operation, Sensitivity to true coincidence events, Sensitivity to scattered events, Sensitivity to random events, Effect of camera geometry. **Image reconstruction:** Introduction, Notation and mathematical theorems used Analytic image formation in 2D PET, Filtered Back-Projection in 3D and 3D-RP. **Detection systems in PET:** Introduction, Scintillators and scintillation detectors, Pulse processing, Coincidence processing, Dead-time, Block detectors, Camera configurations in PET.

Books Recommended:

1. Handbook of Radiotherapy Physics Theory and Practice, Edited by P. Mayles , A. Nahum , and J. C. Rosenwald. Publisher: Taylor & Francis 2007, Print ISBN: 978-0-7503-0860-1, eBook ISBN: 978-1-4200-1202-6
2. Principles and Applications of Radiological Physics- Churchill Livingstone, Donald Graham, and Paul Cloke, Publisher: CHURCHILL LIVINGSTONE, ISBN 13: 9780702043093 ISBN 10: 0702043095
3. Introduction to Health Physics - H. Cember, and Thomas A. Johnson, Publisher: McGraw-Hill Medical ISBN 13: 9780071423083 ISBN 10: 0071423087

Phy 6204 Reactor Physics **Credit: 3**

Fundamentals: Basis of Nuclear Structure and Fission, Concepts of Reactivity and Criticality, Neutron thermalisation and Reactor kinetics, Nuclear Fuel Cycle, Nuclear Interactions.
Reactor Kinetics: Fission product generation and origins of delayed neutrons. Delayed neutron properties. Point-kinetics. Temperature dependent reactivity feedback effects in power reactor systems. Reactor start-up and shut-down. Xenon build-up and its importance in reactor operation.
Design, Construction and Working Principles of Different types of Reactors: PWR, BWR, Breeder Reactor, Research Reactor etc.
Thermodynamics and Chemical Aspects of Nuclear Power Plant Operations: Introduction.
Nuclear Reactor Systems: Site Selection, Layout Safety, Control Room Design Reactor Assembly, Main Moderator System, Moderator Purification System
Heat Transport System: Control of HTS Pressure, Shutdown Cooling System, D_2O Handling, Fuel Handling Generation and Transmission of Electrical Power from a Power Reactor: Main Steam Supply and Feedwater System, Control of Boiler Level, Control of Boiler Pressure (BPC), Turbine- Generator and Associated Systems, Station Electrical Systems.
Plant Control: Liquid Injection Shutdown System, Emergency Core Cooling System, Shutdown Systems,
Radiation Protection : Radiation Hazards in the Nuclear Industry, Radiation Protection, External and Internal Dose Control at Nuclear Stations, Sources of Occupational Dose, Potential Consequences of an Accident and Description of Important Reactor Accidents, Radiation Emergency Response.
Waste Disposal: Solid and Liquid Radioactive Waste Disposal.

Books Recommended:

1. Nuclear Reactor Physics - W. M. Stacey, , John Wiley & Sons, 2001 (ISBN: 0-471-39127-
2. Introduction to Nuclear Engineering- J. R. Lamarsh, A. J. Baratta, Prentice-Hall, 2001 (ISBN: 0-201-82498-1)
3. Nuclear Reactor Analysis- J. J. Duderstadt, L. J. Hamilton, , John Wiley & Sons, 1976 (ISBN: 0-471-22363-8)
4. Dynamics of Nuclear Reactors- D. L. Hetrick, American Nuclear Society, 1993 (ISBN: 0-894-48453-2)