

## Ph.D. PHYSICAL SCIENCES

*Programme Code:* PHYS04

*Programme Outcome:*

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower to take up research in frontier areas of physics
- Building human resource in carrying out R&D in physical and nuclear sciences
- Training of manpower in working in interdisciplinary subjects with physics as one of the subjects

The syllabus of the prevailing courses for the IGCAR-HBNI Physical discipline has already been approved by the Board of Studies (BOS) in Physical Sciences, Homi Bhabha National Institute.

**Now without altering the above approved syllabus, the credit of the individual course has been duly revised in compliance with the new UGC guidelines as per the circular HBNI/RO/6/2024/297 dated 6/3/2024.**

The prevailing courses with the revised credits are given in Table-1.

## **1. Course work for PhD students**

The objective of the course work for PhD students is twofold: firstly to provide them a broad perspective of Physics as a discipline and prepare them to appreciate developments in various key branches of physics, and secondly, to impart advanced training in the area of their research.

The Standing committee of Physical Sciences, IGCAR, will allot suitable course works with total **18 credits (including research methodology)** to PhD students, based on their research topic and background.

## **2. Course work for Employees registering for PhD**

### ***Employees through Training School***

For employees who register for PhD within 2 years of completion of their training school programme, the Standing committee of Physical Sciences, IGCAR, will allot suitable course works with total **12 credits (including research methodology)** based on their research topic and background.

### ***Other Employees***

The course structure for the other employees (not joined through OCES programme and have qualified in PhD entrance test of HBNI) will be same as that specified for PhD students amounting to **18 credits**.

## DETAILED COURSE STRUCTURE

| <b>CORE COURSE</b> |             |                                   |                    |         |
|--------------------|-------------|-----------------------------------|--------------------|---------|
| Sr. No             | Course Code | Course name                       | No. of Lecture Hrs | Credits |
| 1                  | CC-1        | Mathematical Physics              | 30                 | 2       |
| 2                  | CC-2        | Electromagnetic Theory            | 30                 | 2       |
| 3                  | CC-3        | Computational Physics             | 30                 | 2       |
| 4                  | CC-4        | Statistical Physics               | 30                 | 2       |
| 5                  | CC-5        | Physics of Materials and Surfaces | 30                 | 2       |
| 6                  | RM-6        | Research Methodology (By HBNI)    | 45                 | 3       |

| <b>ELECTIVE COURSE</b> |             |  |                    |         |
|------------------------|-------------|--|--------------------|---------|
| Sr. No                 | Course Code | Course & Code  | No. of Lecture Hrs | Credits |
| 1                      | EC-1        | Modeling & Simulations in Physics  | 30                 | 2       |
| 2                      | EC-2        | Advanced Reactor Physics   | 30                 | 2       |
| 3                      | EC-3        | Laser-Matter Interactions and Applications to Advanced Material Processing | 30                 | 2       |
| 4                      | EC-4        | Radiation Detectors and Health Physics                                     | 30                 | 2       |

|    |       |  |    |   |
|----|-------|--|----|---|
| 5  | EC-5  | Quantum Mechanics                                    | 30 | 2 |
| 6  | EC-6  | Defects and Radiation Damage                         | 45 | 3 |
| 7  | EC-7  | Soft Condensed Matter                                | 45 | 3 |
| 8  | EC-8  | Superconductivity and Magnetism                      | 45 | 3 |
| 9  | EC-9  | Science and Applications of Nanostructured Materials | 45 | 3 |
| 10 | EC-10 | Sensors, Detectors & Laboratory Automation           | 45 | 3 |
| 11 | EC-11 | Atmospheric Physics and Dynamics                     | 45 | 3 |
| 12 | EC-12 | Atmospheric Transport and Dispersion Modeling        | 45 | 3 |
| 13 | EC-13 | Advanced Condensed Matter Physics                    | 45 | 3 |

### LAB WORK AND SELF STUDY

| Sr. No | Course Code | Course & Code                                | No. of Lecture Hrs | Credits |
|--------|-------------|--|--------------------|---------|
| 1      | LW-1        | Lab work + Seminar–LW-1                      | 30                 | 1       |
| 2      | SS-1        | Self Study–I + Written test–I + Seminar–I    | 30                 | 2       |
| 3      | LW-2        | Lab work + Seminar–LW-2                      | 30                 | 1       |
| 4      | SS-2        | Self Study–II + Written test–II + Seminar–II | 30                 | 2       |

**Research Methodology course is already approved and will be conducted by HBNI.**

**\*\* 1 Credit is equivalent to 15 contact hours of classroom teaching as per the new UGC guideline.**

**\*\*\* 1 Credit is equivalent to 30 contact hours of Lab work/project as per the new UGC guideline.**

## CORE COURSES CO-ORDINATORS

| Course  | Coordinators             | Email  |
|---|--------------------------|--|
| CC-1: Mathematical Physics                      | Dr. NR Sanjay Kumar      | <a href="mailto:sanju@igcar.gov.in">sanju@igcar.gov.in</a>     |
| CC-2: Electromagnetic Theory                    | Dr. Awadhesh Mani        | <a href="mailto:mani@igcar.gov.in">mani@igcar.gov.in</a>       |
| CC-3: Computational Physics                     | Dr. Sharat Chandra       | <a href="mailto:sharat@igcar.gov.in">sharat@igcar.gov.in</a>   |
| CC-4: Statistical Physics                       | Dr. AT Satyanarayana     | <a href="mailto:atsatya@igcar.gov.in">atsatya@igcar.gov.in</a> |
| CC-5: Physics of Materials and Surfaces         | Dr. C David              | <a href="mailto:edward@igcar.gov.in">edward@igcar.gov.in</a>   |
| RM: Research Methodology (By HBNI)              | HBNI Mumbai              | <a href="mailto:ddutta08@hbni.ac.in">ddutta08@hbni.ac.in</a>   |
| LW-1: Lab work + Seminar–LW-1                   | Respective Guides and DC | =  |
| SS-1: Self Study–I + Written test–I + Seminar–I | Respective Guides and DC | =  |

## ELECTIVE COURSES CO-ORDINATORS

| Course   | Coordinators                              | Email  |
|--|---|--|
| EC-1: Modeling & Simulations in Physics  | Dr. Gurpreet Kaur                         | <a href="mailto:gurpreet@igcar.gov.in">gurpreet@igcar.gov.in</a>   |
| EC-2: Advanced Reactor Physics   | Dr. A Jasmin Sudha                        | <a href="mailto:jasmin@igcar.gov.in">jasmin@igcar.gov.in</a>   |
| EC-3: Laser-Matter Interactions and Applications to Advanced Material Processing | Dr. Rajendra Joshi                        | <a href="mailto:rgjoshi@igcar.gov.in">rgjoshi@igcar.gov.in</a>   |
| EC-4: Radiation Detectors and Health Physics                                     | Dr. S Amirthapandian<br>Dr. O Annalakshmi | <a href="mailto:pandian@igcar.gov.in">pandian@igcar.gov.in</a><br><a href="mailto:anna@igcar.gov.in">anna@igcar.gov.in</a> |
| EC-5: Quantum Mechanics  | Dr. K Gururaj                             | <a href="mailto:gururaj@igcar.gov.in">gururaj@igcar.gov.in</a>   |
| EC-6: Defects and Radiation Damage   | Dr. C David                               | <a href="mailto:david@igcar.gov.in">david@igcar.gov.in</a>   |
| EC-7: Soft Condensed Matter  | Dr. Rajendra Joshi                        | <a href="mailto:rgjoshi@igcar.gov.in">rgjoshi@igcar.gov.in</a>   |
| EC-8: Superconductivity and Magnetism  | Dr. AT Satyanarayana                      | <a href="mailto:atsatya@igcar.gov.in">atsatya@igcar.gov.in</a>   |
| EC-9: Science and Applications of Nanostructured Materials                       | Dr. S Tripurasundari                      | <a href="mailto:sundari@igcar.gov.in">sundari@igcar.gov.in</a>   |
| EC-10: Sensors, Detectors & Laboratory Automation                                | Dr. S Abhaya                              | <a href="mailto:sab@igcar.gov.in">sab@igcar.gov.in</a>   |
| EC-11: Atmospheric Physics and Dynamics  | Dr. CV Srinivas                           | <a href="mailto:cvstri@igcar.gov.in">cvstri@igcar.gov.in</a>   |
| EC-12: Atmospheric Transport and Dispersion Modeling                             | Dr. CV Srinivas                           | <a href="mailto:cvstri@igcar.gov.in">cvstri@igcar.gov.in</a>   |
| EC-13: Advanced Condensed Matter Physics   | Dr. A Edward Prabu                        | <a href="mailto:edward@igcar.gov.in">edward@igcar.gov.in</a>   |
| LW-2: Lab work + Seminar–LW-2  | Respective Guides and DC                  | -  |
| SS-2: Self Study–II + Written test–II + Seminar–II                               | Respective Guides and DC                  | -  |

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## CORE COURSES

### CC-1. Mathematical Physics (30 lecture Hrs)

Coordinators: Dr. NR Sanjay Kumar  
sanju@igcar.gov.in

#### Course Details:

- **Symmetries and groups:**  
Point groups, abelian and non-abelian groups, characters, representations of simple groups, Lie groups, symmetric groups, braid group.
- **Functions of a complex variable:**  
Analytic and multi-valued functions, Cauchy residue theorem and complex integration, Riemann surfaces, applications to fluid mechanics and quantum mechanics.
- **Ordinary differential equations (ODE):**  
Linear and nonlinear first-order equations, classification of ODEs, linear independence and Wronskian, singular points, Frobenius series solutions for second-order differential equations, Green function, system of ODEs, phase portraits, hypergeometric and confluent hypergeometric equations, relation with special functions.
- **Partial differential equations:**  
Classifications, characteristics, method of integral transforms, Green functions for Poisson equation, diffusion equation, wave equation, Helmholtz equation.
- **Integral equations:**  
Fredholm, Volterra, Abel integral equations, solutions by Liouville–Neumann, Fredholm method, Hilbert–Schmidt theory, Sturm–Liouville problems.

#### Course Outcomes:

- Understand symmetry, group theory, and complex analysis and apply them to physical problems.
- Solve ordinary and partial differential equations using analytical methods.
- Apply integral equation techniques and Sturm–Liouville theory to mathematical physics problems.

#### References:

1. Groups and Symmetry: A Guide to Discovering Mathematics, D. W. Farmer (Universities Press, 1998).
2. Mathematical Methods in Physics, J. Mathews, R. L. Walker (Addison-Wesley, 1971).
3. Advanced Mathematical Methods for Scientists and Engineers, C. M. Bender, S. A. Orszag (Springer, 2010).
4. Elements of Green's Functions and Propagation, G. Barton (Clarendon Press, 1989).
5. Mathematical Methods for Physicists, Seventh Ed., G. B. Arfken, H. J. Weber, F. E. Harris (Elsevier, 2013).
6. Fundamentals of Mathematical Physics, E. A. Kraut (McGraw-Hill, 1967).

## CC-2. Electromagnetic Theory (30 lecture Hrs)

Coordinators: Dr. Awadhesh Mani  
mani@igcar.gov.in

### Course Details:

- **Background:**  
Overview of EM theory and revision of basic concepts. Role and scope of EM theory and its applications. Laws of Induction. Induced fields. Displacement current. Maxwell's equations in vacuum and media.
- **Electrostatics and Magneto-statics:**  
Boundary value problems. Separation of variables. Numerical methods. Finite difference representation of Poisson's Equation. Relaxation methods and Successive Over Relaxation Method (SOR).
- **Maxwell's Equations:**  
General solutions of Maxwell's Equation and Electromagnetic radiation. Electromagnetic waves in free space. General time dependent solutions of Maxwell's Equation: Wave-guides and cavities. Microwaves. Dipole Radiation. Bremsstrahlung. Cyclotron. Radiation as a diagnostic tool.
- **Propagation of electromagnetic waves through matter:**  
Reflection of waves in bounded media. Phase velocity, group velocity, wave equation; continuity theorem, Brillouin diagram for empty cavity; generation of modes in a cavity/waveguide; TEM, TE, TM modes; mode creation and identification. Boundary conditions; generation of an electric field in an empty cavity; dispersion relation; frequency mode evaluation, etc.
- **Potentials and Fields:**  
Gauge transformations. Retarded Potentials. Lienard–Wiechert potentials.
- **Relativistic electrodynamics:**  
Lorentz transformation. Four Vectors. Covariant and contravariant tensors. Electrodynamics in Tensor Notation. Relativistic Potentials. Invariance.
- **Dynamics of charged particles in Electromagnetic fields:**  
Orbit theory. Drifts ( $\mathbf{ExB}$ , grad B perpendicular and parallel to B). Adiabatic invariance. Magnet mirror.

### Course Outcomes:

- Develop a comprehensive understanding of Maxwell's equations, electromagnetic fields, and wave propagation in free space and media.
- Analyze boundary value problems, waveguides, cavities, radiation mechanisms, and electromagnetic wave behavior in matter.
- Apply relativistic electrodynamics and charged particle dynamics concepts to understand motion in electromagnetic fields and related physical phenomena.

### References:

1. The Feynman Lectures on Physics, Vol. 2, R.P. Feynman, R.B. Leighton and M. Sands, 1st edition, (Addison-Wesley Publication company, 1963).
2. Introduction to Electrodynamics, D.J. Griffiths, 3rd Edition (Prentice Hall India, 2000).
3. Classical Electrodynamics, J.D. Jackson, 2nd Edition (John Wiley & Sons, 1975).
4. Electrodynamics of Continuous Media, Vol. 6 of Course of Theoretical Physics, L.D. Landau and E.M. Lifshitz, 2nd Edition (Butterworth Heinemann, 1988).

## CC-3. Computational Physics (30 lecture Hrs)

Coordinators: Dr. Sharat Chandra  
sharat@igcar.gov.in

### Course Details:

- **Computer programming:**  
Introduction to Linux, Programming in Fortran, Introduction to C and Parallel Processing. Hands on experience at the computer, Data plotting using programs such as gnuplot.
- **Numerical Methods:**  
Errors in Numerical Methods, Data Statistics & Curve Fitting, Interpolation and Extrapolation, Integration of Functions, Solution of System of Linear Equations, Solution of Nonlinear Equation or Root Finding, Solution of Ordinary Differential Equations, Solution of Partial Differential Equations, Solution of Integral Equations.
- **Project Assignments:**  
Various realistic physics problem to be solved using numerical algorithms coded into programs to be run on the computer.

### Course Outcomes:

- Develop programming skills in Linux, Fortran, and C, including basics of parallel processing and scientific data visualization.
- Apply numerical methods to solve algebraic equations, differential equations, integral equations, and data analysis problems.
- Implement computational algorithms to solve realistic physics problems through project-based learning.

### References:

1. Computer Programming in FORTRAN 90 and 95, V. Rajaraman (Prentice-Hall of India Private Limited, 2006).
2. Upgrading to FORTRAN 90, C. Redwing (Springer-Verlag New York, 1995).
3. C: The Complete Reference, H. Schildt (McGraw-Hill, 1987).
4. Computer Programming in C, V. Rajaraman (Prentice-Hall of India Private Limited, 1994).
5. C++: The Complete Reference, H. Schildt (Tata McGraw-Hill, 2003).
6. Numerical Recipes: The Art of Scientific Computing, W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery (Cambridge University Press, 1996).
7. Numerical Algorithms:
8. Computations in Science and Engineering, E. V. Krishnamurthy and S. K. Sen (East-West Press, 1986).
9. Numerical Methods for Engineers – A Programming Approach, D. V. Griffiths & I. M. Smith (Chapman and Hall, 2006).
10. Numerical Methods for Scientists and Engineers, H. M. Antia (Birkhauser, 2002).

**CC-4. Statistical Physics (30 lecture Hrs)**

**Coordinators: Dr. AT Satyanarayana**  
**atsatya@igcar.gov.in**

**Course Details:**

- **Background:**  
Revision of main results of thermodynamics.
- **Formalism:**  
Introduction to micro-canonical, canonical and grand canonical ensembles with example for each, derivations of Fermi-Dirac and Bose-Einstein distribution for a quantum ideal gas, specific heat of a degenerate Fermi gas. Blackbody radiation, Bose-Einstein Condensation.
- **Phase transitions:**  
Introduction to phase transitions, notion of continuous and discontinuous transitions, Landau Theory–Mean field and Gaussian fluctuations.
- **Monte Carlo Techniques and applications:**  
Introduction to Monte Carlo methods, metropolis algorithm, Application to numerical integration, application to Ising Model.
- **Applications:**  
BBKGY equations, Vlasov equation, Saha ionization formula, Statistical nuclear physics.
- **Irreversible processes:**  
Master equation, Brownian motion and Langevin equation, Fluctuation–Dissipation theorem and calculation of friction constant.

**Course Outcomes:**

- Develop a strong foundation in statistical mechanics, including thermodynamic ensembles, quantum statistics, blackbody radiation, and phase transitions.
- Apply theoretical and computational methods such as Landau theory and Monte Carlo techniques to analyze many-body systems and models like the Ising model.
- Understand irreversible processes and advanced applications including kinetic equations, fluctuation–dissipation theorem, and statistical descriptions of physical systems.

**References:**

1. Statistical Mechanics, K. Huang, 2nd Edition (Wiley, 1987).
2. Statistical Mechanics, R. K. Pathria, 2nd Edition (Butterworth-Heinemann, 1996).
3. Fundamentals of statistical and thermal physics, F. Reif, 1st Indian Edition (Levant Books, 2004).
4. Principles of condensed matter Physics, P. M. Chaikin and T. C. Lubensky, 1st paperback Edition (Cambridge University Press, 2000).
5. Reports on Progress in Physics 60, 487 (1997), K Binder.
6. Saha Equation, Hale Bradt, (soft copy available).
7. Saha and his Formula, I. G. Venkataraman, 1st Edition (Universities Press India Ltd., 1995).
8. Statistical Models for Nuclear Decay, A. J. Cole (IO Publishing Ltd, 2000).
9. Treatise on Heavy Ion Science, R. Stokstad, Ed. D. A. Bromley (Plenum, New York, 1985), Vol. 3, p. 83.

## CC-5. Physics of Materials and Surfaces (30 lecture Hrs)

Coordinators: Dr. C David  
edward@igcar.gov.in

### Course Details:

- **Background:**  
Symmetry, nature of bonding, crystalline structure and classification, 2D and 3D lattice types, symmetry tables, constraints on physical properties by symmetry, diffraction for structure studies, nuclear and magnetic scattering, small angle scattering.
- **Lattice vibrations and phonons:**  
Debye models, dynamical matrix, acoustic and optical branches, outline of experimental techniques, like neutron inelastic scattering, Raman and Brillouin scattering, special features in phonon spectra like softening, Kohn anomaly, etc.
- **Electronic states:**  
Independent particle picture and periodic boundary conditions, metal–insulator semiconductor bands, Fermi surface, relation to many electron system total energy, exchange–correlation terms, relation to experiments like photoemission, optical absorption,
- **Magnetism:**  
Magnetic materials, types of magnetic ordering and interactions, principles of adiabatic demagnetization and cooling, magnetic domains, linearized spin waves in ferromagnets.
- **Superconductivity:**  
Meissner effect, energy gap, London equation, type-I and type-II superconductors, vortices, tunneling junctions, outline of modern superconductivity theories, new superconducting materials.
- **Semiconductors:**  
Intrinsic and extrinsic semiconductors, p-n junction and its applications, heterostructures and semiconductor superlattices.
- **Dielectrics and Ferroelectrics:**  
Dielectric relaxation and loss, ferroelectric and related materials, comparison with ferromagnets.
- **Introduction to surface structures:**  
Stability and reactivity. Surface reconstructions and relaxation. Surface processes: Physisorption and chemisorptions.
- **Surface modification techniques:**  
Physical vapor deposition (thermal evaporation, electron beam, laser ablation, sputtering, molecular beam epitaxy), chemical vapor deposition. Self assembled monolayers. Langmuir-Blodgett techniques.
- **Surface characterization techniques:**  
Morphology (optical, scanning electron, atomic force, scanning tunneling and tunneling electron microscopies); Structure (low energy electron diffraction, high energy reflected electron beam diffraction, grazing X-ray diffraction); composition (X-ray photoelectron spectroscopy, energy dispersive X-ray analysis, Rutherford back scattering, secondary ion mass spectrometry).

### Course Outcomes:

- Develop a comprehensive understanding of solid-state physics, including crystal structures, lattice

vibrations, electronic states, magnetism, superconductivity, semiconductors, and dielectric properties.

- Analyze physical phenomena using symmetry principles, band theory, phonon dynamics, and experimental characterization techniques.
- Gain knowledge of surface physics, surface modification methods, and advanced surface characterization techniques relevant to modern materials science.

***References:***

1. Solid State Physics, N. W. Ashcroft and N. D. Mermin, (Saunders College, 1967).
2. Introduction to Solid State Physics, 8th Edition, C. Kittel (Wiley 2004).
3. Solid State Physics, A. J. Dekker (Macmillan Limited, 2000).
4. Physics of Surfaces and Interfaces, H. Ibach (Springer, 2006).

## **RM: Research Methodology**

**Coordinators: HBNI Mumbai**

### ***Course Details:***

The course on Research Methodology includes design, analysis and presentation of scientific projects, objectives and planning of research, literature survey, statistical methods, mathematical modeling, documentation and presentation, laboratory safety and research ethics. The course syllabus is already approved and will be conducted by HBNI.

### ***Course Outcomes:***

- Develop skills in research design, planning, literature survey, and scientific problem formulation.
- Apply statistical methods and mathematical modeling for data analysis and interpretation.
- Demonstrate competence in scientific documentation, presentation, laboratory safety, and research ethics.

## Elective Courses

### EC-1: Modeling and Simulations in Physics (30 lecture Hrs)

**Coordinators: Dr. Gurpreet Kaur**  
gurpreet@igcar.gov.in

#### *Course Details:*

- **Basics:**  
Modelling in different domains: Continuum, Mesoscopic, Atomistic and Quantum descriptions, setting up a computer experiment: Starting structure and dynamics length and time scales.  
Electronic Structure Theory:  
Many-body Schrödinger Equation, Born–Oppenheimer approximation, Hartree–Fock theory and Slater Determinants, Density Functional theory (DFT) Thomas–Fermi and Exchange and correlation (and different xc types).
- **Methods of Solution:**  
Basis sets: Gaussian and Plane Wave, Analytic gradients and Hessians, the potential surface, Geometry optimization, Transition state calculations.  
Simulation Methods:
- **Monte Carlo (MC):**  
Monte Carlo integration, Averaging procedure in various ensembles, Importance sampling, metropolis schemes.
- **Classical Molecular Dynamics (MD):**  
Newtonian, lagrangean and Hamiltonian dynamics, basic algorithms, time averages and ensemble averages, Molecular Dynamics in various ensembles, Interatomic potentials (pair potential and beyond), Force-fields and their parameterization, handling long-range forces, Analysis of Simulation results.
- **First Principles MD:**  
Born–oppenheimer Molecular Dynamics, Car–Parrinello Molecular Dynamics (CPMD), Mermin functional and Free Energy MD (FEMD).
- **Hybrid schemes:**  
Combined classical MD and DFT-hybrid QM/MM schemes.
- **Reactive schemes:**  
General problems in chemical reactions, Path sampling methods, Blue Moon ensemble approach, Metadynamics.
- **Beyond DFT:**  
Time dependent DFT, Dynamical Mean Field Theory, GW-Approximation.
- **Quantum Chemistry Methods:**  
Configuration interaction, many-body perturbation theory, Moller–Plesset perturbation theory, Multi-Configuration self consistent field theory, Coupled cluster theory.

#### *Course Outcomes:*

- Develop a strong foundation in computational modelling approaches, electronic structure theory, and quantum chemistry methods for describing atomic and molecular systems.
- Apply simulation techniques such as Monte Carlo, classical and first-principles molecular dynamics, and hybrid QM/MM methods to study physical and chemical processes.
- Analyze reaction mechanisms and advanced many-body methods beyond DFT to investigate complex materials and chemical systems.

**References:**

1. Electronic Structure – Basic Theory and Practical Methods, Richard Martin (Cambridge University Press, 2004).
2. Electronic Structure Calculation for Solids and Molecules, Jorge Kohanoff (Cambridge University Press, 2006).
3. Computer Simulation of Liquids, M. P. Allen and D. J. Tildesley (Oxford Science Publications, 1989).
4. The Art of Molecular Dynamics Simulation, D. C. Rapaport (Cambridge University Press, 2004).
5. Ab Initio Molecular Dynamics – Basic Theory and Advanced Methods, Dominik Marx and Jueg Hutter (Cambridge University Press, 2009).

**EC-2:Advanced Reactor Physics (30 lecture Hrs)**

**Coordinators: Dr. A Jasmin Sudha**  
**jasmin@igcar.gov.in**

**Course Details:**

- **Neutron Transport Theory:**

Various formulations of neutron transport theory: Integro-differential equation, integral equation, surface integral equation, invariant imbedding theory. Transport equations for special geometries; Numerical methods for solution of transport equation: Energy groups and group cross sections, PN<sub>2</sub> method and diffusion theory, Discrete ordinates and discrete SN<sub>2</sub> methods, Collision probability and related methods and

their applications, Methods of characteristics; Adjoint equation, perturbation theory, variational method.

Numerical methods for solution of the Multi-group neutron diffusion equation:

Finite difference method and nodal methods.

- **The Monte Carlo method:**

Random numbers; methods of generation and properties tests for randomness; Methods for sampling distributions; Mechanics of particle transport; Source and criticality problems; Errors and variance reduction methods. Methods for burnup and control rod worth calculation.

- **Reactor Dynamics:**

Point kinetics: point kinetics equations. Stability Analysis. Linear stability theory, Routh's stability criterion, Root-Locus method, Nyquist plot, Non-linear stability analysis, Space dependent reactor Dynamics and related topics; Accident analysis for thermal and fast reactors.

- **Reactor Noise and its applications:**

Stochastic kinetics and zero power Reactor Noise, power reactor noise, reactor Noise in Accelerator Driven Systems.

**Course Outcomes:**

- Develop a comprehensive understanding of neutron transport theory, diffusion methods, and numerical techniques used in reactor analysis.
- Apply Monte Carlo methods and computational approaches to solve particle transport, criticality, burnup, and control problems.
- Analyze reactor dynamics, stability, noise behavior, and safety aspects in thermal and fast reactor systems.

**References:**

1. Nuclear Reactor Theory, G. I. Bell & S. Glasstone (Van Nostrand, 1970).
2. Computing Methods in Reactor Physics, H. Greenspan (Ed.) (Gordon and Breach, 1968).
3. Dynamics of Nuclear Reactors, L. Hetrick (University of Chicago Press, 1971).
4. Random Processes in Nuclear Reactors, M. M. R. Williams (Pergamon, 1974).
5. Neutron Fluctuations – A Treatise on Theory of Branching Processes, L. Pal and Imre Pázsit (Elsevier Publishing Company, 2007).
6. Computational Methods of Neutron Transport, E. E. Lewis and W. F. Miller, Jr., (Wiley, 1984).
7. Nuclear Reactor Physics, W. M. Stacey (Wiley, 2001).
8. Particle Transport Simulations with the Monte Carlo Method, L. L. Carter and E. D. Cashwell, Report TID-26607 (1975).

## EC-3: Laser-Matter Interactions and Applications to Advanced Material Processing (30 lecture Hrs)

Coordinators: Dr. Rajendra Joshi  
rgjoshi@igcar.gov.in

### Course Details:

- **Introduction to Laser Matter Interaction:**  
Basics of pulsed, Ultrashort and CW lasers typically employed for laser processing; Mode Locking, Kerr Lens Modelocking, Pulse Compression, Chirped Pulse Amplification.
- **Surface Characterization, Measurement & Diagnostic Techniques:**  
(i) SEM, Optical microscope, X-ray Diffraction technique (XRD), Atomic Force Microscopy (AFM), X-ray photoelectron spectroscopy (XPS), Electron probe X-ray micro-analysis (EPMA), Auger electron Microscopy (AES), Energy Dispersive X-ray spectroscopy (EDX), Differential Thermal Analysis (DTA), Surface Profilometer Surface hardness, Micro-indentation.
- **Plasma and Vapour diagnostics:**  
Time of flight (TOF), Langmuir Probe, LIBS, TRLIF etc.
- **Laser diagnostics:**  
Short pulse – autocorrelator, FROG (frequency resolved optical gating), SPIDER (spectral phase interferometry for direct electric field reconstruction), Spatial profilometer-array detector.
- **Laser Matter Interaction:**  
Excitation Mechanisms, and Relaxation Times, Multiphoton Excitation, Photochemical Process – Catalytic Effects, Photophysical & Thermal Processes; Heating & Surface melting, Evaporation.

### Course Outcomes:

- Develop a fundamental understanding of laser systems and laser–matter interaction mechanisms, including ultrafast laser techniques and excitation processes.
- Gain knowledge of advanced surface, plasma, and laser diagnostic techniques for material characterization and analysis.
- Apply laser processing concepts to study thermal, photophysical, and photochemical effects in materials.

### References:

1. Laser Processing and Chemistry, D. Bäuerle, 4th Edition (Springer, 2011).
2. Laser Material Processing, W. M. Steen, 4th Edition (Springer, 2010).
3. Pulsed Laser Deposition of Thin Films, D. B. Chrisey and G. K. Hubler (Wiley Interscience, 2007).

**EC-4: Radiation Detectors and Health Physics (30 lecture Hrs)**

(About 70% of the syllabus of this course will be covered)

**Coordinators: Dr. S Amirthapandian & Dr. O Annalakshmi  
pandian@igcar.gov.in & anna@igcar.gov.in****Course Details:**

- **Part-I: Nuclear and Radiation Detectors**

- **Interaction of radiation with matter:**

Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe–Bloch formulae), Cherenkov radiation. Energy loss of electrons and positrons: Electronic stopping and energy loss by bremsstrahlung radiation, Interaction of photons: Photoelectric absorption, Compton scattering, Pair production, Electromagnetic shower in high energy photon and electron interaction with matter, Interaction of Neutron: elastic scattering, radiative capture, positive Q-value reactions such as (n, p), (n,  $\alpha$ ), (n, fission) and hadron shower production at high energies.

- **Radiation Detectors:**

General characteristics of detectors: efficiency, response in energy, time resolution and corresponding resolution, recovery time or count rate handling capability. Gas detectors: Basic processes, Q–V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Müller counter. Large area MWPC, PPAC. Semiconductor detectors: Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors). Germanium detectors (planar and cylindrical). Photovoltaic cells, charge coupled devices. Scintillation detectors: Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes, Compton suppressed high purity germanium detectors for high resolution gamma spectroscopy. Miscellaneous detectors: Cryogenic detectors, thermal detectors, channeltrons and microchannel plates, plastic track detectors, hybrid detectors.

- **Experimental Techniques:**

Electronic modules for pulse processing: Preamplifiers (charge, voltage sensitive), amplifiers (spectroscopy or high resolution, fast and timing filters), timing discriminators (leading edge and constant fraction types), gate and delay generators, SCA, ATC, ADC, QDC, TDC, MCA, computer based data acquisition system (DAQ). Particle identification methods (dE–E telescope, pulse shape discrimination, Cherenkov radiation), time of flight technique, magnetic spectrometers including recoil separator. Monte Carlo simulation of detectors.

- **Part-II: Health Physics**

- **Introduction:**

Radiation sources, quantities and units: natural and induced radioactive sources, units of radioactivity, half-life, decay constant, specific activity. Definition of various dosimetric terms (exposure, absorbed/equivalent/effective dose, concept of radiation weighting factors and importance of organs/tissues weighting factors and their importance (stress should be given to use only SI units however for continuity sake old and new units relation can be given)). Exposure measurement: Free air and air wall chambers (concept of wall thickness should be given), Exposure dose relationship, Bragg–Gray principle.

- **Biological Effects, Radiation Protection and Regulation:**

Human Body: cells, tissues and organs, structure of cell, cellular effects. Factors which influence the

damage of cell.

- **Interaction of radiation with biological matter:**  
Radiation effects: stochastic and deterministic. Acute and delayed effects. Importance of radiation protection programme in DAE. Types of exposure (natural, occupational, medical and public). National and International regulatory bodies, their role and responsibilities. Dose limits stipulated by these bodies. Dose limits observed in India. Radiation protection philosophy. Principles of radiation protection, concept of ALI & DAC (with suitable problems). Latest recommendations of ICRP-103. Fundamentals of ICRP respiratory model (only basics), entry through ingestion, GI track mode (only basics). Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.
- **Radiation Protection and Measurement (External and Internal):**  
Control of external exposures (with problems in each case). Buildup concept, shielding of alpha, beta, gamma and neutron sources. Shielding from mixed sources. Routes of intake of radioactive material, radiotoxicity and classification of laboratories, design of laboratory for radioactive work, radioactive waste classification and management. Personal monitoring, area monitoring, air monitoring. Bioassay, whole body counting, Liquid Scintillation Spectrometry (LSS) techniques. Use of personal dosimeters (TLDs, pocket dosimeters).
- **Radiation Protection Procedures:**  
Procedures followed in radiation work places, work permits, zoning concept, contamination control methods, and rubber areas. Spill pack (contain gloves + absorbing paper). Decontamination techniques. Precautions during radioactive source storage and handling. Safety during transportation. Nuclear Accidents, Emergency Preparedness and Management:  
Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergency, emergency preparedness.
- **Industrial Safety (Non radioactive):**  
Principles of industrial safety and industrial hygiene; legislation related to health and safety and major hazard control.

#### **Course Outcomes:**

- Understand the interaction of radiation with matter and the working principles of various radiation detectors used in nuclear and particle physics experiments.
- Explain detector characteristics and experimental techniques, including signal processing electronics, particle identification methods, and data acquisition systems.
- Understand fundamental concepts of health physics, including radiation quantities, biological effects of radiation, and radiation protection principles.
- Apply radiation safety, monitoring, shielding, and regulatory guidelines for safe handling, measurement, and management of radioactive materials and radiation sources.

#### **Reference:**

1. Radiation Detection and Measurement, G. F. Knoll, 4th edition (John Wiley & Sons, New York, 2010).
  2. Techniques for Nuclear and Particle Experiments, W. R. Leo, 2nd Edition, Springer International Students Edition (Narosa Publishing House, New Delhi, 1995).
  3. Introduction to Health Physics, Herman Cember, 4th Edition (McGRAW-HILL, 2009).
  4. Physics for Radiation Protection, James E. Martin, 2nd Edition (Wiley-VCH Verlag GmbH, 2006).
  5. IAEA Regional Basic Professional Training Course on Radiation Protection (Course jointly organized by
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BARC and IAEA), October 26-December 18, 1998.

6. Nuclear Radiation Detection, W. J. Price, 2nd Edition, (McGRAW-HILL, 1964).
7. Radiobiology for Radiologists, Eric J. Hall, 7th Edition, (Lippincott Williams & Wilkins, 2012).
8. Accident Prevention Manual for Industrial Operation, Vol. 2, National Safety Council, 11th Edition, (National Safety Council, USA, 1997).

## EC-5: Quantum Mechanics (30 lecture Hrs)

Coordinators: Dr. K Gururaj  
gururaj@igcar.gov.in

### Course Details:

- UV Catastrophe, Findings of Max Planck & Einstein, Bohr's proposition of quantum nature of atomic spectrum, Frank-Hertz experiment, Quantization of Linear momentum, Space and Angular momentum. Success of QM, Stern-Gerlach experiment, Foundation of quantum mechanics, Postulates of QM, Schrödinger equation.
- **Matrix mechanics:**  
Linear vector space, Hilbert space, State vectors, Bra & Ket notations, Observables and operators, Uncertainty relations, Coordinate and momentum space representations, Unitary transformations.
- **Time evolution, Pictures in QM:**  
Perturbation theory: Stationary perturbation and time dependent perturbation theory, Scattering problems: Green's function and S matrix methods.
- **Symmetries in QM, Discrete symmetries:**  
Space inversion and time reversal, Continuous symmetries: Proper rotation groups, Unitary (U) and Special Unitary (SU) groups.
- **Elements of relativistic QM:**  
Klein-Gordon and Dirac equations.

### Course Outcomes:

- Develop a strong foundation in the principles and formalism of quantum mechanics, including Schrödinger equation, matrix mechanics, and operator methods.
- Apply perturbation theory, scattering theory, and symmetry principles to analyze quantum systems.
- Understand the basics of relativistic quantum mechanics through Klein–Gordon and Dirac equations.

### References:

1. Quantum Mechanics by Leonard I. Schiff
2. Quantum Mechanics by Cohen-Tannoudji, B. Diu and F. Laloë
3. A Textbook of Quantum Mechanics by P. M. Mathews and K. Venkatesan

## EC-6: Defects and Radiation Damage (45 lecture Hrs)

Coordinators: Dr. C David  
david@igcar.gov.in

### Course Details:

- **Introduction to defects and their influence on physical and mechanical properties:**  
Types of lattice imperfections, Defects in semiconductors and insulators and their influence on electrical and optical properties including band gap engineering.
- **Point defects in solids:**  
Point defects in elemental crystals – equilibrium vacancy concentration – equilibrium concentration of divacancies – equilibrium concentration of interstitials – point defects in two-component ionic crystals.
- **Diffusion in solids:**  
Fick's laws – atomic picture of diffusion – random-walk theory – diffusion mechanisms in cubic crystals – jump frequency – thermal diffusion – surface diffusion, Radiation enhanced diffusion.
- **Dislocations and grain boundaries:**  
Slip in single crystals – dislocations – strain energy for dislocations – force on a dislocation – miscellaneous features of dislocations – interaction forces between nearby edge dislocations – grain boundaries and grains – creep.
- **Radiation damage:**  
Introduction – binary elastic collision dynamics – basic concepts – potential functions and energy transfer cross-sections – energy loss to electrons – displacement threshold – displacements produced by primary knock-ons – displacement per atom (dpa), Kinchen–Pease and modified methods – focusing and channeling – displacements and damage in a fast-neutron flux – computer simulation of collision cascades – fission-fragment collision cascades in nuclear fuels.
- **Production of defects:**  
Defect production by Quenching, Charged particle beams, nuclear reactors, Introduction to particle accelerators and Nuclear reactors. Thermal and fast fission reactors, Fusion and ADS system, Comparison of defect structures introduced by different methods, Simulation of radiation damage using charged particles.
- **Evolution of defects and microstructures:**  
Evolution of defects, defect clusters, interstitial and vacancy loops, Phase stability under irradiation, Evolution of defects, Kinetic rate theory, type of sink and sink strengths.
- **Characterization of defects at atomic scale and defect microstructure:**  
High resolution TEM, X-ray methods: Diffuse scattering, Positron annihilation, DLTS, Photoluminescence, Atom probe tomography, TDPAC, RBS/Channeling, in-situ TEM.
- **Radiation effects in metal-void swelling and irradiation creep, radiation hardening:**  
Introduction – observed characteristics of voids – nucleation of voids – nucleation of interstitial dislocation loops – point-defect balances and the void-growth law – void continuity equation and void swelling – irradiation creep.
- **Multiscale materials modeling of radiation damage:**  
Ab-initio calculations, MD simulation of defects and defect cascades, Kinetic montecarlo methods, Reaction rate theory and continuum models.

**Course Outcomes:**

- Develop a comprehensive understanding of lattice defects, diffusion, dislocations, and their influence on the physical and mechanical properties of materials.
- Analyze radiation damage mechanisms, defect production, evolution of microstructures, and radiation-induced effects in materials.
- Apply advanced characterization techniques and multiscale modeling methods to study defects and radiation damage in solids.

**References:**

1. Donald R. Olander, Fundamental aspects of nuclear reactor fuel elements, NTIS, Springfield, 1977.
2. Damask A. C., Dienes G. J., Point defects in metals, Gordon and Breach, New York, 1963.
3. Borg R. J., Dienes J. H., Introduction to solid state diffusion, Academic Boston, 1988.
4. Weertman J., Weertman J. R., Elementary dislocation theory, Oxford University Press, New York, 1992.
5. Hull D., Introduction to dislocations, Pergamon Press, Oxford, 1975.
6. Thompson M. W., Defects and radiation damage in metals, Cambridge University Press, Cambridge, 1969.
7. Ziegler J. F., Ed., Handbook of ion implantation technology, North Holland Publishing, Amsterdam, 1992.

## EC-7: Soft Condensed Matter (45 lecture Hrs)

Coordinators: Dr. Rajendra Joshi  
rgjoshi@igcar.gov.in

### Course Details:

- **Introduction to Soft matter:**

Forces, energies, length and time scales and in soft matter. Soft matter systems (colloids, surfactant/micellar systems, gels, polymer solutions, polymers, polyelectrolytes, microemulsions, membranes, biological macromolecules). Interactions (electrostatic, van der Waals, hydrophilic and hydrophobic interactions, depletion interaction). Soft matter in nature: DNA and RNA, Proteins, Polysaccharides, membranes. Some aspects of Industrial and Technological applications.

- **Experimental techniques to investigate structure and dynamics in soft matter:**

Scattering techniques (Small-angle X-ray scattering (SAXS), Ultra-small-angle X-ray scattering (USAXS), Small-angle (SANS) and inelastic neutron scattering), Static and Dynamic light scattering (SLS & DLS), NMR, Optical microscopy, digital video microscopy, confocal laser scanning microscopy, Atomic Force Microscopy (AFM), Electron microscopy (TEM & SEM). Optical Tweezers.

- **Colloids:**

Sterically stabilized and charge stabilized colloids, Colloidal interactions, Synthesis of monodisperse colloidal particles, Characterization, Structure and Ordering. Dynamics, Phase Transitions (Gas-liquid, Melting/Freezing, Glass Transition, Crystal, Amorphous), Magnetic colloids, Core-shell particles, Colloids under confinement, Colloidal alloys, Colloidal epitaxy, Rheology, Applications of colloidal crystals: Photonic band gap materials, Diffraction devices, Optical switches and chemical sensors. Modeling colloidal systems and comparison with experiments.

- **Biological systems:**

Structure and dynamics of isotropic (spherical) and anisotropic (non-spherical) bacterial suspensions. Determination of translational and rotational diffusion coefficients and motility. Some aspects of bio-corrosion, bio-fouling and bio-remediation.

- **Surfactants:**

Types of surfactants, self-assembled phases in solutions, Micellization and critical micelle concentrations (CMC), Langmuir-Blodgett films, Monolayer, Bilayers and Vesicles, Lyotropic liquid crystalline phases, Complex phases in surfactant solutions and micro emulsions, lipids.

Polymer Solutions and Polyelectrolytes:

A single ideal chain; mean-square end-to-end distance, radius of gyration. Gaussian chain. Freely jointed chain. Worm-like chain. Stretching and confinement, structure factor, excluded volume, solvent quality, theta-...

- **Temperature. Polymer solutions:**

Flory–Huggins Theory, osmotic pressure, scaling laws for good solvents, Size of a polymer in semi-dilute solutions, poor solvents and phase separation, Measurements of polymer sizes in solution: osmotic pressure, light scattering, intrinsic viscosity, Polyelectrolytes: Debye–Huckel theory, Donnan equilibrium, Manning condensation. Rheology.

- **Gels:**

Classes of gels: physical gels, chemical gels and photo-polymerized gels, Sol–Gel transition, Swelling and shrinking of gels, Theory of gelation, hydrogels, formation of hydrogels, Characterization of hydrogels, Application of hydrogels, Colloids immobilized in hydrogels.

**Course Outcomes:**

- Develop a fundamental understanding of soft matter systems, their interactions, structures, and physical properties in both natural and industrial contexts.
- Apply experimental and theoretical techniques to investigate the structure, dynamics, and phase behavior of colloids, polymers, surfactants, gels, and biological systems.
- Analyze soft matter phenomena such as self-assembly, phase transitions, rheology, and transport processes using modeling and comparison with experiments.

**References:**

1. Soft Matter: Complex Materials on Mesoscopic scales, J. K. G. Dhont, G. Gompper and D. Richter (Eds.) (Forschungszentrum Jülich GmbH, Jülich, 2002).
2. Ordering and Phase Transitions in Charged Colloids, A. K. Arora and B. V. R. Tata (Eds.).
3. Colloidal Dispersions, W. B. Russel, D. A. Saville and W. R. Schowalter (Cambridge University Press, Cambridge, 1989).
4. Intermolecular and Surface Forces, J. N. Israelachvili (Academic Press, London, 1992).
5. Micelles, Membranes, Microemulsions and Monolayers, edited by W. M. Gilbert, A. Ben-Shaul and D. Roux (Springer-Verlag, Berlin, 1994).
6. Principles of Condensed Matter Physics, P. M. Chaikin and T. C. Lubensky (Cambridge University Press, Cambridge, 1995).
7. Polymer Solutions: An Introduction to the Physical Properties, Iwao Teraoka (John Wiley & Sons, 2002).
8. Polymer Physics, M. Rubinstein and R. C. Colby (Oxford University Press, 2003).
9. Physical Properties of Polymeric Gels, J. P. C. Addadi (John Wiley & Sons, 1996).
10. Neutrons, X-rays and Light: Scattering Methods Applied to Soft Condensed Matter, P. Lindner and T. Zabels (North Holland-Elsevier, 2002).
11. Dynamic Light Scattering: Applications of Photon Correlation Spectroscopy, R. Pecora (Plenum, 1985).
12. Sulfate Reducing Bacteria by Larry L. Batton (Springer, 1995).

**EC-8: Superconductivity and Magnetism (45 lecture Hrs)**

(About 70% of the syllabus of this course will be covered)

**Coordinators: Dr. AT Satyanarayana**  
atsatya@igcar.gov.in**Course Details:**

- **Introduction to superconductivity:**

Basic properties of the superconducting state; Zero resistance and Meissner effect; critical temperature, critical field and critical current density of a superconductor; signature of superconducting transition in resistivity, AC susceptibility, specific heat, IR reflectivity, tunneling etc.; concepts of penetration depth, coherence length and surface energy; distinction between type I and type II superconductors; Energy gap in a superconductor; Isotope effect; Superconducting wires— notion of stability in multifilamentary wires; superconducting magnets; high temperature superconductors.

- **Thermodynamics of superconductors:**

Free energy difference between normal and superconducting states, interrelations between thermal and magnetic properties, thermodynamic order of the superconducting phase transition.

Electron–electron interaction by exchange of virtual phonons:

Pairing hypothesis; Wavefunction, energy and spatial extension of a single Cooper pair; BCS Ground State and Excitation Spectrum, Ground State Energy; Density of States in a superconductor; BCS Theory at finite temperatures; calculation of transition temperature and specific heat.

Coherence factors and their effect on the temperature dependence of ultrasonic attenuation and nuclear relaxation rate; Comparison of BCS model with experiment; weak and strong coupling superconductors; effect of Coulomb repulsion; McMillan equation; Spatial variation of order parameter, Ginzburg–Landau equations, calculation of surface energy; Vortices in superconductors and their interactions; Mixed state of Type II superconductors; Linearised Ginzburg–Landau equations; elementary theory of the upper critical field.

- **Weakly coupled superconductors:**

Number–phase uncertainty relation; Josephson Effect; Josephson penetration depth; behavior of small and large Josephson junctions; SQUID devices—design and fabrication.

- **Symmetry of the energy gap:**

Unconventional superconductors and their properties; Experimental scenario in heavy fermion superconductors and high temperature superconductors; Behavior of order parameter near a superconductor–normal metal interface; proximity effects; Andreev reflection.

- **Critical states:**

Introduction; Critical field relations; Critical state models; Fixed pinning model; Bean Model; Reversed critical states and hysteresis; Kim model; Comparison of critical state models with experiment.

- **SQUIDs and Josephson Junction:**

Transition edge sensors to detect x-rays and  $\gamma$ -rays; Josephson electronics; SQUID applications.

- **Applications of superconductivity:**

SC Magnet application; Energy storage; Power transmission; MRI magnets.

Magnetism – Phenomenology of magnetism at the macroscopic scale:

Presentation of some types of magnetic behaviors—Diamagnetism, Paramagnetism, Antiferromagnetism, Ferromagnetism, Ferrimagnetism.

- **Magnetic properties of materials:**  
Phenomenology of strongly magnetic materials; Isothermal magnetization curves; Weiss domains and Bloch walls; Magnetic anisotropy; Cubic symmetry; Tetragonal symmetry; Quadratic symmetry; Uniaxial symmetry.
- **Phenomenology of magnetism at the microscopic scale:**  
The classical model of diamagnetism; Case of localized electrons; Systems with non-interacting localized magnetic moments; Effect of a uniform field on a magnetic moment—precession; Assembly of localized magnetic moments without interaction; Curie paramagnetism; Ferromagnetism in the molecular field model; Antiferromagnetism in the molecular field models.
- **Exchange interaction:**  
Direct, Indirect, Magnetic dipolar, Super exchange: General; Goodenough–Kanamori rules etc; RKKY; Double exchange; Itinerant magnetism; Crystal field effect.
- **Theoretical Approach to Magnetism:**  
Magnetism in the localized electron model—Magnetism of free atom or ion; Single electron orbital magnetic moment; Spin magnetic moment; States of individual electrons or hydrogen-like atoms; Many electron atoms; Hartree’s method; Multiplets.
- **Magnetism of bound atoms:**  
Localized and itinerant magnetism; The influence of neighbouring atoms: crystal field effects, and some examples of localized magnetic moments; quenching of the orbital moment; Low & high spin states; influence of symmetry; the Kondo effect; spin glasses; cluster glass and frustration; Also, meta-magnetism, superparamagnetism.
- **Thermodynamic aspects of magnetism:**  
Basic thermodynamics, Thermodynamic potentials, Maxwell relations and inequalities, Landau-type free energy, Critical exponents and scaling laws, Magnetic anomalies near  $T_c$ .
- **Coupling effects and other effects:**  
Magnetocrystalline effects, Magnetocaloric effects, Magneto-optic effects, Magnetotransports, Metal to insulator transition (in oxides), Bulk oxides, Nanophase, Quantum dots.
- **Techniques (for identification of magnetic states with examples):**  
Magnetisation: VSM, SQUID (magnetization, susceptibility, ZFC, FC, hysteresis), AC Susceptibility, frequency dependence, in presence of bias field, Hall effect, anomalous Hall effect, Magneto-optic techniques, Electron Spin resonance, Nuclear magnetic resonance, Neutron diffraction and scattering, AFM, MFM.

**Course Outcomes:**

- Develop a comprehensive understanding of superconductivity and magnetism, including fundamental properties, theoretical models (BCS and Ginzburg–Landau), Josephson effects, critical states, and various magnetic phenomena at microscopic and macroscopic scales.
- Analyze superconducting and magnetic materials using thermodynamic principles, exchange interactions, symmetry considerations, and phase transition concepts.
- Apply experimental techniques and device concepts such as SQUIDs, superconducting magnets, and magnetic characterization methods to study and utilize advanced materials.

**References:**

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1. Magnetism – Principles and Applications, Derek Craik (Wiley, New York, 1995).
2. Magnetism in the Solid State: An Introduction, Peter Mohn, 2nd Edition (Springer, 2005).
3. Introduction to Superconductivity, M. Tinkham (Dover Publications, 1996).

**EC-9: Science and Applications of Nanostructured Materials (45 lecture Hrs)**

**Coordinators: Dr. S Tripurasundari**  
**sundari@igcar.gov.in**

**Course Details:**

- **Introduction to nano-structured materials:**  
 Different classes of nano-structured materials, nano-powders, nano-composites, nano-phase materials, nano-structured thin films.
- **Synthesis of nano-structured materials:**  
 Chemical precipitation, sol–gel method, ball milling, physical vapour deposition, thermal decomposition, solid-state precipitation, co-sputtering, silver ion-exchange, ion-implantation, methods for obtaining monodispersed particles.
- **Characterization methods:**  
 X-ray diffraction, grazing-incidence x-ray diffraction, small-angle x-ray scattering, dynamic light scattering, high-resolution transmission-electron microscopy, atomic-force microscopy, photoluminescence spectroscopy, optical absorption spectroscopy, Raman spectroscopy.
- **Properties and applications:**  
 Optical properties – electron and hole confinement in semiconductor quantum dots, band-gap engineering, blue-shift of optical absorption and photoluminescence, efficiency of optical processes, metal nanoparticles – applications in nonlinear optical devices.  
 Vibrational properties – phonon confinement models, confined acoustic phonons, low-frequency phonon modes.  
 Catalytic properties and applications in sensors.  
 Mechanical behavior of nano-crystalline thin films and nano-phase compacts – applications in hard tribological coatings and machinable ceramics.  
 Dielectric properties – tailored ferroelectric materials.  
 Magnetic properties – high-density magnetic data storage devices.
- **Carbon nano-tubes and related structures:**  
 Single and multi-wall carbon nano-tubes, porous silicon, semiconductor and metal nano-rods.

**Course Outcomes:**

- Develop a fundamental understanding of nano-structured materials, their synthesis techniques, and structural characterization methods.
- Analyze size-dependent optical, vibrational, mechanical, dielectric, magnetic, and catalytic properties of nanomaterials.
- Explore applications of nanomaterials including quantum dots, thin films, carbon nanotubes, and devices for sensing, data storage, and advanced coatings.

**Reference:**

1. Nanoparticles and Nanostructured Films: Preparation, Characterization, and Applications, Ed. J. H. Fendler (Wiley-VCH, New York, 1998).
2. Fundamental properties of Nanostructured Materials, Eds. D. Fiorani (World Scientific, Singapore, 1994).
3. Advanced Catalysts and Nanostructured Materials:
4. Modern Synthetic Methods, Ed. W. R. Moser (Academic, San Diego, 1996).

5. Semiconductor Quantum Dots, L. Banyai and S. W. Koch (World Scientific, Singapore, 1993).
6. Encyclopedia of Nanoscience and Nanotechnology, Vol. 8, Ed. H. S. Nalwa (American Scientific Publishers, 2004) p. 499.
7. Nanostructured Magnetic Materials and their Applications, Eds. D. Shi et al. (Springer, Berlin, 2002).
8. Mechanical Properties and Deformation Behavior of Materials having Ultrafine Microstructures, Eds. M. Nastasi et al. (Kluwer, Amsterdam, 2002).

**EC-10: Sensors, Detectors & Laboratory Automation (45 lecture Hrs)**

**Coordinators: Dr. S Abhaya  
sab@igcar.gov.in**

**Course Details:**

- **Interaction of radiation with matter:**  
Energy loss of heavy charged particles in matter – Electronic stopping power (Bohr and Bethe–Bloch formulae), Cherenkov radiation; Energy loss of electrons and positrons – Electronic stopping and energy loss by bremsstrahlung radiation; Interaction of photons – Photoelectric absorption, Compton scattering, pair production; Electromagnetic shower in high energy photon and electron interaction with matter.
- **Nuclear Radiation detectors:**  
General characteristics of detectors – efficiency, response in energy, time resolution and corresponding resolution, recovery time or count rate handling capability. Gas detectors – Basic processes, Q–V characteristics as a function of primary ionization, charge multiplication. Ionization chamber, proportional counter, avalanche counter and Geiger Müller counter. Large area MWPC, PPAC. Semiconductor detectors – Silicon detectors (surface barrier, PIN diodes, Li drifted silicon detectors), Germanium detectors (planar and cylindrical geometry). Photovoltaic cells, charge coupled devices. Scintillation detectors – Inorganic and organic scintillators, photomultipliers, photodiodes, avalanche photodiodes.
- **Electronic Devices and Circuits:**  
Review of Analog Electronics – Diodes (junction diodes, special diodes), power supplies, transistors, FETs, MOSFETs, Operational amplifier.  
Review of Digital Electronics – logic gates, Binary adders, subtractors, decoders, encoders, flip-flops, counters, DAC, ADC, pulse width modulator (PWM), voltage-to-frequency converter (VFC).  
Pulse processing instrumentation – preamplifiers (charge, voltage, current sensitive), amplifiers (spectroscopy or high resolution, fast and timing filter), single channel analyzers, timing discriminators (leading edge and constant fraction types), gate and delay generators, coincidence (fast and slow units), linear gate and stretchers, time to amplitude converter (TAC), charge to digital converter (QDC), analog to digital converter (ADC), time to digital converter (TDC), multichannel analyzers (MCA), scalers and rate dividers;
- **Intelligent electronics:**  
microprocessors, micro controllers, programmable peripheral programmable interface (PPI) ICs, FPGA, ASIC, system on chip and its architectures.  
Interfacing: Analog, digital interfacing and process controls; Electromagnetic interference & grounding of electronic equipments.
- **Experimental Automation:**  
Front-end Electronic designs. Standalone systems. Intelligent systems. Embedded designs; Recent trends in Laboratory Automation.
- **Computers in Experimental Automation:**  
Personal Computers introduction. Personal Computer Interfacing Standards: PC Parallel (LPT) Port – Pins, signals, I/O and cables. PC Serial (COM) Port – Pins, signals, I/O and cables, USB ports and GPIB Interface. Interfacing.
- **Experimental setup with computers:**  
Wireless communication for experimental automation. Indigenous system design with examples.
- **Software Design:**

Graphical Language (G-language), Virtual Instrument Concept, LabVIEW Fundamentals, programming & applications. User friendly experimental automation with the implementation of G-language. Dynamic Data Exchange (DDE) commands. Networking experiments in LabVIEW. Data analysis, math functions, filtering, plotting, 1D, 2D, 3D curve fitting using G-language.

▪ **Sensors & Read out electronics:**

Front electronics for temperature, pressure, flow, displacement sensors, photomultiplier tube (PMT), charge coupled devices (CCD), piezo electric sensors, accelerometers, strain gauge & load cells, SQUIDS and Flux locked loop electronics and lock-in amplifiers.

▪ **Micro Sensors:**

Introduction to Micro Electro Mechanical Systems (MEMS). MEMS Design, Fabrication and its applications. Various MEMS based sensors.

**Course Outcomes:**

- Develop a comprehensive understanding of radiation–matter interaction and the working principles of nuclear radiation detectors and associated electronics.
- Gain knowledge of analog and digital electronics, pulse processing instrumentation, intelligent systems, and experimental automation using modern hardware and software tools.
- Apply computer interfacing, LabVIEW programming, sensor technologies, and MEMS concepts for the design and implementation of automated experimental systems.

**References:**

1. Techniques for Nuclear and Particle Physics Experiments – W. R. Leo, 2nd Ed. (Springer International Edition, Narosa Publishing House, New Delhi, 1995).
2. Radiation Detection and Measurement – G. F. Knoll, 3rd edition (John Wiley, New York, 2000).
3. Nuclear Radiation Detectors – S. S. Kapoor and V. S. Ramamurthy (Wiley Eastern Ltd., New Delhi, 1986).
4. Radiation Detectors – C. F. G. Delaney and E. C. Finch (Clarendon Press, 1992).
5. Optical and Infrared Detectors – Topics in Applied Physics, Vol. 19, Eds. R. J. Keyes (Springer Verlag, Berlin).
6. Electronic Principles – Malvino (Tata-McGraw Hill).
7. Integrated Electronics – Millman & Halkias (Tata-McGraw Hill).
8. Microprocessor System Design – Hardware, Programming, and Interfacing – Douglas V. Hall (McGraw-Hill Book Company, 2006).
9. Digital Electronics – Malvino & Leach (Tata-McGraw Hill).
10. 8051 Microcontroller and Embedded Systems – Muhammad Ali Mazidi, Janice Mazidi, Janice Gillispie Mazidi (Amazon.com, USA).
11. Fundamentals of Micro-fabrication – by Madou.
12. IBM PC and Clones Hardware, Troubleshooting and Maintenance – B. Govindarajulu (Tata McGraw Hill Publishers, 2002).
13. PC Technical Reference Manual – Jakkalen Art & Science. (<http://www.tec.sci.fi/tecref/>)
14. LabVIEW – Technical Reference Manual, National Instruments. ([www.ni.com](http://www.ni.com)).
15. Digital Signal Processing System-Level Design Using LabVIEW – K. Ketharnavaz (Elsevier Publishers).

**EC-11: Atmospheric Physics and Dynamics (45 lecture Hrs)**

**Coordinators: Dr. CV Srinivas**  
**cvsri@igcar.gov.in**

**Course Details:**

- **Atmospheric Structure & Composition:**  
 Constituents of dry air, carbon dioxide, ozone, water vapour and aerosols; Vertical thermal structure of the atmosphere: Troposphere, stratosphere, mesosphere, thermosphere and exosphere; Standard atmosphere.
- **Thermodynamics of air:**  
 Adiabatic processes in the atmosphere; Potential temperature; Equation of state of dry air; Poisson's equation for dry air; The Clausius and Clapeyron equation; Equation of state for water vapour; Moisture variables (Absolute humidity, specific humidity, relative humidity, mixing ratio); Relationship between  $R_m$  and  $R_d$ ; Virtual temperature, dew point temperature; Wet bulb temperature; Equivalent temperature; Adiabatic expansion of unsaturated and saturated air; Vertical stability of the atmosphere: Dry adiabatic lapse rate; Standard adiabatic lapse rate; Stability of layers.
- **Equations of Motion:**  
 Pressure Gradient, Gravitational, Friction, Coriolis, Centrifugal forces; Equations of motion in Cartesian, spherical polar co-ordinates; Scale Analysis; Hydrostatic approximation; Balanced flow: Geostrophic flow, Gradient flow, thermal wind; Continuity equation; Thermodynamic energy equation; Basic equations in Isobaric Coordinates.
- **Properties of flow fields:**  
 Differential Properties of wind Fields: Translation, Divergence, Rotation and Deformation; Differential equation for stream lines; Vertical Variation of Winds; Thermal Wind; veering and backing; hodograph.
- **Kinematics of Pressure Fields:**  
 Intensification and Weakening: Deepening and Filling.
- **Circulation, vorticity, Divergence:**  
 Stokes Theorem, Divergence Theorem, Circulation theorems – Kelvin's Theorem and Bjerknes Theorem and applications of Circulation theorems – Sea Breeze and Land Breeze; General Circulation. Solenoidal Vector, Barotropic and baroclinic fluids. Vorticity and divergence equations, scale analysis, balance, split of vorticity and divergence equations into rotational and irrotational terms.
- **Atmospheric waves:**  
 Phase velocity, Group Velocity, Dispersion, Sound waves, Gravity waves, Inertial Waves, Rossby waves, Haurwitz Rossby waves, Concept of Instability, Inertial Instability, Barotropic Instability, Baroclinic Instability, Kelvin Helmholtz Instability.
- **Atmospheric General Circulation:**  
 Time mean fields and other statistics of observed general circulation; zonally symmetric and asymmetric components; mean-meridional circulation and eddies; Walker circulation. Maintenance of zonally mean circulation and eddies. Energetics of the atmosphere – Available Potential Energy; Kinetic Energy.

**Course Outcomes:**

- Develop a strong understanding of atmospheric structure, thermodynamics, and equations governing air motion.
- Analyze atmospheric circulation, vorticity, divergence, stability, and wave dynamics using physical and

mathematical principles.

- Apply concepts of general circulation, instabilities, and atmospheric energetics to interpret large-scale weather and climate systems.

**Reference Books:**

1. The Atmosphere – Frederick K. Lutgens & Edward J. Tarbuck
2. Dynamical and Physical Meteorology – G. J. Haltiner and F. L. Martin
3. Introduction to Theoretical Meteorology – S. L. Hess, 1959
4. Compendium of Meteorology – WMO Pub., Physical Meteorology, 1973, Vol. 1, No. 2
5. The Physics of Atmospheres – J. T. Houghton, Cambridge Univ. Press (CUP), 2002
6. Seinfeld J. H. and S. Pandis, Atmospheric Chemistry and Physics, John Wiley, 1998
7. An Introduction to Dynamic Meteorology – J. R. Holton, Academic Press
8. Atmospheric and Oceanic Fluid Dynamics – G. K. Vallis, Cambridge Univ. Press, 2006

**EC-12: Atmospheric Transport and Dispersion Modelling (45 lecture Hrs)**

**Coordinators: Dr. CV Srinivas**  
**cvsri@igcar.gov.in**

**Course Details:**

- **Introduction to Air Pollution:**  
 Common Air Pollutants, Chemical and Hazardous substances; Radioactive pollutants; Atmospheric Systems and Pollutant Transport – Structure and Dynamics of Atmosphere – Atmospheric Stability – Conservation Laws and atmospheric dynamics – Atmospheric Circulations – Large scale flows – Synoptic scale flows – Mesoscale flows – Microscale flows – Energy exchange in the Earth–atmospheric system.
- **Atmospheric Turbulence:**  
 Vertical distribution of temperature, winds in PBL – turbulence general theories of PBL turbulence and its parameterization for dispersion, semi-empirical estimates of boundary layer parameters – surface layer, mixed layer, PBL height, mixing height, roughness length, friction velocity, surface stress, Km in the surface layer, scaling parameters, Monin–Obukhov length.
- **Dispersion Concepts:**  
 Reynolds averaging – Probability functions – Autocorrelation functions – Spectral functions – Taylor’s Hypothesis – Statistical Theory of Turbulence – Observed spectra and scales – Gradient Transport Theories – Eulerian approach for diffusion – Advection–diffusion equation – Fickian diffusion – Gradient Transport (K) theory – its Limitations – Application to atmospheric diffusion – Lagrangian Description of Turbulence – Plume diffusion from continuous sources – Puff diffusion from instantaneous releases – Similarity theory of dispersion – Lagrangian similarity theory for the stratified and mixed layers – Application to dispersion in PBL.
- **Atmospheric Dispersion Models:**  
 Eulerian models – Analytical solutions – Numerical solutions – Vertical and Horizontal diffusivity – Box models – Advanced Eulerian models – Second order closure modeling, Large eddy simulations – Gaussian diffusion models – Gaussian approach – Calculation of  $\sigma_y$ ,  $\sigma_z$  – Non dimensional functions  $S_y$  and  $S_z$  for Gaussian models – Semi-empirical  $\sigma$  equations, dry, wet deposition and chemical transformation.
- **Lagrangian dispersion models:**  
 Lagrangian Approach – particle treatment of diffusion – Langevin’s Stochastic transport equation – Deterministic and statistical calculation of fluctuations ( $u'$ ) – Hanna’s semi-empirical relations – Concentration calculation in Particle models – Monte-Carlo Particle models, computation of chemistry, dry & wet deposition.
- **Atmospheric Aerosols:**
  - **Uniform particle motion:**  
 Newtons Resistance Law, Stokes Law, Settling velocity, Slip correction factor, Equivalent diameter, Particle Acceleration, relaxation, stopping distance, curvature correction, Stokes number, inertial impaction, cascade impactor.
  - **Particle motion:**  
 Brownian motion, Diffusion, Thermophoresis, Electrophoresis, Aerosol behavior: Coagulation: thermal and kinematic coagulation. Aerosol properties: Extinction, Scattering, Aerosol charging. Aerosol statistics: Normal and binormal distribution, moment averages, weighted Distribution, Lognormal distribution, log probability graph, Hatch–Choate conversion equation.

- **Particle measurement instrumentation:**

Single particle counter, QCM, SMPS, ELPI.

- **Characteristics of Atmospheric Aerosols:**

Composition, Structure and Residence Time of the Species. Geochemical Cycles of Elements.

- **Atmospheric Aerosols:**

Formation, Physical and Chemical, Characteristics, Aerosol Optical Depth (AOD) etc. Gas Phase & Aqueous Phase Atmospheric Reactions. Atmospheric Photochemical Reactions and Smog Formation, Chemistry of Organic Pollutants in the Atmosphere.

- **Application of Dispersion Models:**

Valley effect, Coastal diffusion and Fumigation – dispersion inside and above IBL – Overwater dispersion rates – diffusion around buildings (building wake effects) – Gravitational settling – Heavy Gas dispersion – Cooling Tower Plumes – Source emission modeling of Accidental Spills – Indoor Air Pollution – Regulatory modeling – Urban air quality impact assessment.

**Course Outcomes:**

- Develop a comprehensive understanding of air pollution sources, atmospheric turbulence, aerosol behavior, and pollutant transport mechanisms in the atmosphere.
- Analyze atmospheric dispersion using Eulerian and Lagrangian models, turbulence theories, and statistical approaches for predicting pollutant spread.
- Apply dispersion modeling and aerosol science concepts to environmental impact assessment, air quality management, and regulatory applications.

**Reference Books:**

1. Air Pollution Modelling – Theories, Computational Methods and Available Software by Paolo Zannetti, Computational Mechanics Publications, Southampton Boston, 1990.
2. Principles of Air Pollution Meteorology by Tom Lyons and Bill Scott, Belhaven Press, London, 1990.
3. Handbook on Atmospheric Diffusion by S. R. Hanna, G. A. Briggs and R. P. Hosker, Technical Information Center, U.S. Dept of Energy, 1982.
4. Fundamental of Air Pollution by A. C. Stern, H. C. Wohlers, R. W. Boubel, W. P. Lowry, Academic Press, London.
5. An Introduction to Boundary Layer Meteorology by Roland B. Stull, Kluwer Academic Publishers, 1994.
6. Introduction to Micrometeorology by S. Pal Arya, Academic Press, International Geophysical Series Vol. 79, 2001.
7. Chemistry of Atmospheres by R. P. Wayne, Oxford University Press, 1985.
8. Campbell, I. M., Energy and the Atmosphere: A Physical-Chemical Approach, John Wiley & Sons Ltd., 1977.
9. Finlayson, B. J., Pitts Jr., Atmospheric Chemistry, John Wiley & Sons, 1986.
10. Hobbs, P. V., Basic Physical Chemistry for the Atmospheric Science, Cambridge University Press, 1995.
11. Seinfeld, J. H., and Pandis, S. N., Atmospheric Chemistry and Physics, John Wiley, 2006.
12. Aerosol Technology, William C. Hinds, John Wiley & Sons, 1998.
13. Aerosol Measurement, Principles and Technique, Paul A. Baron and Klaus Willeke, Wiley Interscience, 2001.

**EC-13: Advance Condensed Matter Physics (45 lecture Hrs)**

**Coordinators: Dr. A Edward Prabu**  
**edward@igcar.gov.in**

**Course Details:**

- **Noninteracting Electron Gas:**  
Born–Oppenheimer Approximation – Basic Hamiltonian, Adiabatic Approximation, Reduced-Electron Problem, beyond the relaxation time approximation, beyond the independent electron approximation; Hartree–Fock Approximation – Noninteracting Limit, Hartree–Fock Approximation, Fermi liquid theory.
- **Metal–insulator transitions:**  
Criterion for insulator, classes of insulator, important types of metal–insulator transitions, band, Peierls, Anderson and Mott insulators.
- **Localization:**  
Introduction to Localization, Strong Localization: The Anderson Transition, Scaling Theory, Weak Localization, Exceptions to Localization.
- **Second Quantization and electron gas:**  
Second quantization of fermions, Fermion operators, spin waves in electron gas, second quantization of bosons; Interacting Electron Gas – Uniform Electron Gas, Hartree–Fock Excitation Spectrum, Cohesive Energy of Metals, Excitation Spectrum.
- **Mean field theory:**  
Basics of Mean field theory.
- **Magnetic Moments in Metals – Local Moments:**  
Phenomenology, Mean-Field Solution, The Kondo Problem – Kondo Hamiltonian, Scattering and the Resistivity Minimum, Electron Impurity Scattering, Plasma Oscillations, Condensed phase screening and Plasmon–Thomas–Fermi Screening, Plasma Oscillations, Linear-Response Theory, Dielectric Response Function, Stopping Power of a plasma.
- **Electron–phonon interaction:**  
Harmonic Chain, The Fröhlich Hamiltonian, Acoustic Phonons, Phonon frequencies and the Kohn anomaly, The Peierls transition, Polarons and mass enhancement, The Nakajima Hamiltonian, Electron–Phonon Interaction, Ultrasonic Attenuation, Electrical Conduction, Hydrodynamic Limit: phonon drag, Sound propagation, ultrasonic attenuation.
- **Superconductivity:**  
Superconductivity – Phenomenology, Electron–Phonon Effective Interaction, Model Interaction, Cooper Pairs, Pair Amplitude, BCS Ground State, Pair Fluctuations, Ground State Energy, Critical Magnetic Field, Energy Gap, Quasi-Particle Excitations, Thermodynamics, Experimental Applications, Josephson Tunneling.
- **Low dimensional systems:**  
Condensed matter phenomena in low dimensional systems: semiconductor heterostructures, spin orbit coupled systems, two dimensional Dirac materials; Quantum Phase Transitions – Quantum Rotor Model, Scaling, Mean-Field Solution, Transport Properties, Experiments; Quantum Hall Effect – Landau Levels, The Role of Disorder, Currents at the Edge, Laughlin Liquid.

**Course Outcomes:**

- Develop a strong understanding of interacting and non-interacting electron systems, localization phenomena,

- metal–insulator transitions, and many-body formalisms such as second quantization and mean field theory.
- Analyze electron–phonon interactions, magnetic moments in metals, screening, collective excitations, and superconductivity using advanced theoretical models.
  - Explore low-dimensional systems, quantum phase transitions, and quantum Hall effects, linking theoretical concepts with experimental observations.

**References:**

1. Solid State Physics, N. W. Ashcroft and N. D. Mermin (Saunders College, 1967).
2. Advance Solid State Physics, Philip Phillips (Overseas Press, 2008).
3. Condensed Matter Physics, Akira Ishara (Dover Publications, 1991).
4. Many Particle Physics, G. D. Mahan (Kluwer, 2000).
5. Condensed Matter Physics in a Nutshell, G. D. Mahan (Princeton University Press, 2011).
6. Fundamentals of Condensed Matter Physics, M. L. Cohen and S. G. Louie (Cambridge Univ. Press, 2016).
7. The Mott Metal–Insulator Transition, F. Gebhard (Springer, 1997).
8. Basic Notions in Condensed Matter, P. W. Anderson (Taylor and Francis, 1984).
9. Solid State Physics, Michael P. Marder (John Wiley and Sons, 2010).
10. Elementary Excitations in Solids, David Pines (CRC Press, 1999).

## Lab Work Courses

### **LW-1 & LW-2. Lab Work Courses & Seminars (Credits: 1 per lab work course plus a seminar)** **Coordinators: Respective Guides and DC**

#### *Course Details:*

- A PhD student will take two lab work courses, one in each semester. Each of this will be with 30 hrs per semester. Each Lab work course will have 1 credit. These lab work courses will expose student to the experimental / computational tools relevant to the proposed area of research. The Doctoral committee of the students will formulate the lab work. Student will present his lab work (motivation + methodology + results + discussion) in the form of seminar at the end of the semester and doctoral committee will evaluate and assign marks.

#### *Course Outcomes:*

- Gain hands-on experience with experimental or computational tools relevant to the proposed research area.
- Develop practical skills in research methodology, data analysis, and interpretation under the guidance of the doctoral committee.
- Demonstrate the ability to present and critically discuss research work through seminar presentations and evaluations.

### **SS-1 & SS-2: Self Study Courses & Seminars (Credits: 2 per self study course plus a seminar)** **Coordinators: Respective Guides and DC**

#### *Course Details:*

- A PhD students will take up two self-study courses, one in each semester. The purpose of these courses is to initiate a student into the specific area of research and also to train the students in 'learning' a subject through self-study. The Doctoral Committee of the students will specify in writing the extent of course work, the course material and further will evaluate the performance of the student.
- Course material may include specialized books and/or review articles related to the topic of research in a manner that the course will prepare the student to understand and appreciate the current level of research in his/her area of work. A continuous interaction of the student with the doctoral committee is envisaged during the self-study courses.
- For evaluation of the performance of the candidate in the self-study courses, the doctoral committee will use both written and oral examinations.
- The self-study course will be deemed complete only after the delivery of an open seminar by the students. One open seminar per reading course is mandatory to improve the scientific communication skills of the students.

#### *Course Outcomes:*

- Develop in-depth knowledge in the chosen research area through guided self-study of advanced books and review literature.
  - Strengthen independent learning ability and critical understanding of current research through continuous interaction with the doctoral committee.
  - Demonstrate mastery of the subject and scientific communication skills through written/oral examinations and open seminar presentations.
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