Ph.D. & Int. Ph.D PHYSICAL SCIENCES

Programme Code: PHYS04/ PHYS05

Programme Outcome:

- Manpower development with the ability to apply basic concepts and methods in physics to research problems.
- Training of manpower with the ability to work in interdisciplinary subjects, particularly those in the interface of different disciplines in physics.
- Developing an understanding of modern mathematical methods and using them in the research environment.
- Training of manpower which has the ability to work in diverse areas and adapt to change in professional and national requirements.

COURSE WORK

Two streams lead to the Doctoral degree in Physics at IMSc: a Ph.D stream for students who join after their master's degree and an Integrated Ph.D (IPhD) stream for students who join after their Bachelor's degree. The coursework for the PhD program is for two semesters (**Semesters III & IV in Table 1**), while that for the IPhD is for four semesters (**Semesters I–IV and Summer in Table 1**). Students in the IPhD and PhD programs earn **75 credits** and **37 credits** respectively at the end of the coursework completion.

Semester I (16 Credits)

Sr.no.	Course Code	Course Title	Hours (L)	Credits
1	10-PHYS05-011-C	Classical Mechanics	75	5
2	10-PHYS05-012-C	Quantum Mechanics	75	5
3	10-PHYS05-013-C	Electromagnetic Theory	45	3
4	10-PHYS05-014-C	Mathematical Methods	45	3

Semester II (18 Credits)

Sr.no.	Course Code	Course Title	Hours (L)	Credits
1	10-PHYS05-021-C	Quantum Mechanics II	75	5
2	10-PHYS05-022-C	Computational Physics	75	5
3	10-PHYS05-023-C	Condensed Matter Physics	45	3
4	10-PHYS05-024-C	Statistical Mechanics	75	5

Summer Semester (4 Credits)

Sr.no.	Course Code	Course Title	Hours (L)	Credits

1	10-PHYS05-001-PR	Summer Project	128	4

Semester III (16 Credits)

Sr.no.	Course Code	Course Title	Hours (L)	Credits
1	10-PHYS05-031-C	Quantum Field Theory	75	5
2	10-PHYS05-032-C	Mathematical Methods II	45	3
3	10-PHYS05-033-C	Statistical Mechanics II	75	5
4	10-PHYS05-034-C	Particle Physics	45	3

Semester IV (21 Credits)

Sr.no.	Course Codes	Course Title	Hours (L)	Credits
1	10-PHYS05-001-PR	Project	256	8
2	10-PHYS05-035-C	Research Methodology & Research Publication Ethics	45	3
3	10-PHYS05-041-E to 10-PHYS05-046-E	Electives	75 + 75	5 + 5

Electives (5 + 5)

Sr.no.	Course Code	Elective Title (5 Credits)	Hours (L)	Credits
1	10-PHYS05-041-E	Quantum Field Theory II	75	5
2	10-PHYS05-042A-E	Cosmology and Gravity	75	5
3	10-PHYS05-042B-C	Particle Physics II	75	5

4	10-PHYS05-043-E	Advanced Condensed Matter Physics	75	5
5	10-PHYS05-044A-E	Nonlinear Dynamics	75	5
6	10-PHYS05-044B-E	Quantum Information and Computation	75	5
7	10-PHYS05-044C-E	Statistical Field Theory	75	5
8	10-PHYS05-045-E	Computational Physics (same as 22)	75	5
9	10-PHYS05-046-E	Stochastic Process: Theory and Applications	75	5

Credit and Hours:

- 5 credits: 5 hours class work / week (Total 15 weeks: 75 hours)
- 3 credits: 3 hours class work / week (Total 15 weeks: 45 hours)
- Summer project (4 credit): 16 hours /week (Total 8 weeks: 128 hours)
- Project (8 credit): 16 hours/week (Total 16 weeks/256 hours)

CORE COURSE COORDINATORS

Course	Coordinators	Email
Classical Mechanics	Prof. S. Vemparala	vani@imsc.res.in
Quantum Mechanics		
Electromagnetic Theory		
Mathematical Methods		
Quantum Mechanics II		
Computational Physics		
Condensed Matter Physics		
Statistical Mechanics		
Quantum Field Theory		
Mathematical Methods II		
Statistical Mechanics II		
Particle Physics		

ELECTIVE COURSE COORDINATORS

Course	Coordinators	Email
Quantum Field Theory II	Prof. S. Vemparala	vani@imsc.res.in
Cosmology and Gravity		
Particle Physics II		
Advanced Condensed Matter Physics		
Nonlinear Dynamics		
Quantum Information and Computation		
Statistical Field Theory		
Computational Physics (same as 22)		
Stochastic Process: Theory and Applications		

CORE COURSES

SEMESTER I

10-PHYS05-011-C: Classical Mechanics (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Lagrangian formulation and the action principle:**
  Configuration space, generalized coordinates Constrained systems, holonomic constraints as coordinate transformations, motion in a central field, including Kepler problem, Rutherford scattering, Small oscillations, normal modes, total time derivatives, non-uniqueness of Lagrangian, Noether's theorem, Conservation laws;

- **Rigid body kinematics and dynamics:**
  Kinematics, rotational kinetic energy, moments of inertia, inertia tensor, Euler angles, angular momentum, Free rigid body motion, axisymmetric tops;

- **Hamiltonian formulation:**
  The Legendre transformation, canonical momentum Poisson brackets, Phase space reduction, cyclic coordinates, Phase space description and evolution, surfaces of section, periodically driven systems, Liouville's theorem, Poincare recurrence;

- **Canonical transformations, Hamilton−Jacobi theory, perturbation theory:**
  Definition; point transformations; time-independent transformations; symplectic transformations and time-dependent transformations, Invariants of canonical transformations, Generating functions Hamilton-Jacobi equation, action-angle variables, Perturbation theory as a sequence of canonical transformations of a perturbed integrable system;

- **Relativistic mechanics (including Lagrangian formulation):**
  Space-time, 4-vectors, Lorentz transformations, basic relativistic kinematics and dynamics.

Course Outcomes:

- After successfully completing the course, the students should have mastery over Lagrangian and Hamiltonian formulations, Hamilton-Jacobi formalism, methods of dealing with constrained classical systems, canonical transformations, symmetries in the classical world, relativistic mechanics, rudiments of non-linear dynamics.
- The students should acquire the knowledge of dealing with generic dynamical systems (be it classical or quantum) using the language of Lagrangian and Hamiltonian.
- Students should develop analytical as well as numerical powers to solve problems in Mechanics – both for theoretical purpose as well as for problems of practical interests.

References:

1. L. Landau and E. Lifshitz, Mechanics : Course of Theoretical Physics, Vol.1, Pergamon, 1974.
2. W. D. McComb, Dynamics and Relativity, Oxford University Press, 1999.

3. V. I. Arnold, Mathematical Theory of Classical Mechanics, Springer, l977.
4. M. Tabor, Chaos and Integrability in Nonlinear Dynamics, Wiley, l989.
5. H. Goldstein, Classical Mechanics, Narosa, l990.
6. Percival and D. Richards, Introduction to Dynamics, Cambridge, l99l
7. J.V. Jose and E.J. Saletan, Classical dynamics: A contemporary approach, Cambridge, l998.

10-PHYS05-012-C: Quantum Mechanics I (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Fundamentals of Quantum Theory:**
  The breakdown of classical physics, the polarization of photons, Wave-particle duality: Particle properties of photons and wave properties of electrons, Schrodinger evolution, Hamiltonian, examples: free particle, one-dimensional potential well, potential barrier, harmonic oscillator, etc., Hilbert space formulation of Quantum Mechanics: states, observables, measurement, evolution, collapse of wave function, uncertainty relation and its interpretation, Discrete and continuous spectra, canonically conjugate observables, Schrodinger, Heisenberg and interaction pictures, Virial theorem, Ehrenfest's theorem, semi-classical quantization;
- **Theory of spin−1/2 systems:**
  Stern-Gerlach experiment for the existence of spin Quantum Mechanics of two-level systems
- **Spherically symmetric potentials:**
  Schrodinger equation for spherically symmetric potentials, Orbital angular momentum and spherical harmonics, Hydrogen atom problem and three dimensional harmonic oscillator;
- **Symmetries and conservation laws:**
  What is a symmetry, Wigner's theorem, Continuous transformations, Rotation, Euclidean and Galilean groups, Transformations and invariances;
- **Angular momentum theory in Quantum Mechanics:**
  Orbital and spin angular momenta, Raising and lowering operators, Addition of angular momenta, Clebsch-Gordon coefficients, Schwinger oscillator model, Spherical tensors and WignerEckart Theorem, Spin-orbit coupling,
- **Exactly solvable models:**
  Charged particle in a magnetic field, Landau levels, Quantum Hall effect;
- **Time−independent perturbation theory:**
  Non-degenerate and degenerate cases, An-harmonic oscillator, Van der Waal's force, Dipole interactions for spin-l/2 systems, Stark effect, Zeemann effect;
- **Time−dependent perturbation theory:**
  Approximate solution of Schrodinger equation, Sinusoidal perturbation of two-level system: resonance phenomenon, Coupling with states of continuous spectrum, Fermi's golden rule, Interaction of atom with electromagnetic wave,

Course Outcomes:

- Students should learn and internalize the formalism required to describe principles of Quantum Mechanics: Hilbert space formalism involving states, observables, dynamics, and measurement.
- After internalizing and maneuvering principles of Quantum Mechanics, the students should master the techniques of solving exactly (and thereafter, approximately) one, two, and three-dimensional potential problems.
- They should also learn how to deal with different symmetries.

References:

1. 1. C. Cohen-Tannoudji, B. Diu and F. Laloe, Quantum Mechanics, Vols. I and II, Wiley, 1970.
2. J. J. Sakurai, Modern Quantum Mechanics, Addisson Wesley, 1995.
3. Leslie E. Ballentine, Quantum Mechanics: A Modern Development, World Scientific, 1998.

10-PHYS05-013-C: Classical Electromagnetism: (45 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Electrostatics and Magneto−statics:**
  Mathematical preliminaries, boundary value problems using Green function techniques, special techniques for calculating potentials, electrostatics of dielectric media, magnetic vector potential and the gauge problem, Biot-Savart law, magnetic dipole moment and the Larmor precession, magnetic susceptibility and permeability, ferromagnetism;
- **Maxwell Electrodynamics :**
  Motion of charges in external fields, electromagnetic waves in vacua and propagation through continuous media, gauge transformations, Lorentz covariant formulation of electrodynamics, energy-momentum of electromagnetic field and Poynting's theorem, Lagrangian and Hamiltonian formulation of electrodynamics;
- **Radiation Theory :**
  Advanced and retarded Green functions, Lienard-Wiechert potentials, dipole radiation and Larmor's formula, spectral resolution and angular distribution of radiation from a relativistic point charge, synchrotron radiation, Rayleigh and Thomson scattering;
- **Classical Electron Theory :**
  Radiation reaction, acausality and preacceleration, incompleteness of Maxwell electrodynamics;

Course Outcomes:

- Techniques of Electrostatics and Magnetostatics should be learnt properly.
- Students should learn, understand, and internalize Mawell's equations, their interpretations, and applications, particularly in Radiation Theory, Antenna Theory, etc.
- Students should also learn the four-vector formalism to treat Maxwell's equations in terms of Electromagnetic field.

References:

1. D. J. Griffiths, Introduction to Electrodynamics, Prentice Hall, 1981.
2. L. Landau and E. Lifshitz, The Classical Theory of Fields, Pergamon, 1979.
3. J. D. Jackson, Classical Electrodynamics, Wiley Eastern, 1986.

10-PHYS05-014-C: Mathematical Methods I (45 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Linear Algebra:**
  Linear Vector spaces, Determinants & Matrices, Special matrices: orthogonal, hermitian, unitary, Eigenvalue problem: matrix diagonalization, Canonical Forms, Infinite-dimensional vector spaces: Hilbert space & Hermitian operators, Numerical solution of linear equations;

- **Complex Analysis:**
  Complex algebra, analytic functions, infinite sequences and series, tests of convergence, Weierstrass theorem, Taylor and Laurent series, classification of isolated singularities, poles & calculus of residues, contour integration, residue theorem and applications;

- **Differential and Integral Equations:**
  Ordinary differential equations, linear differential equations up to second order, orthogonal polynomials and functions, Integral transforms: Laplace and Fourier transforms, partial differential equations, classification of PDEs, Laplace and wave equations, boundary value problems, Special functions, Integral equations and Green functions, Ideas about nonlinear equations, Approximation methods: WKB approximation (at the level of Mathews-Walker);

Course Outcomes:

- Students should learn the theory of Complex Analysis as well as its applications in different problems in Physics.
- Students should develop mastery over different aspects of Linear Algebra and its applications in different branches of Physics.
- Students should develop adequate working knowledge (together with thorough knowledge in the corresponding theory) in solutions of ordinary differential and integral equations, different integral transforms, etc.

References:

1. J Mathews and R L Walker, Mathematical Methods for Physicists, Benjamin, l964.
2. G Arfken, Mathematical Methods for Physicists, Academic Press, l995.

SEMESTER II

10-PHYS05-021-C: Quantum Mechanics II (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Quantum theory of identical particles:**
  Symmetrization of wave functions, Pauli's exclusion principle, Bosons and fermions, Spinstatistics theorem, Second quantization formalism, Quantum theory of many-electron atoms, Electron gas: application to solids;
- **Approximation methods:**
  WKB approximation, Variational methods, Absorption and stimulated emission of radiation;
- **Scattering theory:**
  Lipmann-Schwinger equation, Born approximation, Partial waves, The optical theorem, Determination of phase-shifts, Hard sphere scattering, Low energy scattering, Resonances;
- **Path integral approach to Quantum Mechanics:**
  Kernel of wave-packet evolution, Feynmann's approach, Examples of free particle and harmonic oscillator, Path-integral approach to spin systems, Aharonov-Bohm effect, The adiabatic theorem, Berry's phase;
- **Relativistic Quantum Mechanics:**
  Dirac and Klein-Gordon equations and their solutions, Relativistic invariance, Space reflection and time reversal, Idea of spin, Helicity, Hydrogen atom, fine structure of spectral lines;
- **Phase–space description of Quantum Mechanics:**
  Coherent states, squeezed states and thermal states, Wigner's phase-space quasi-probability distribution, Glauber-Sudarshan's P-representation, Husimi distribution, Symplectic transformation and covariance matrix, Non-classical states of light;
- **Foundations of Quantum Mechanics:**
  Density operators formalism, Contradiction of Quantum Theory with local realism, The causality issue.

Course Outcomes:

- Students should learn and thereby apply the method of second quantization – required to treat system of indistinguishable particles – while dealing with many-body quantum systems.
- WKB approximation, various variational methods, etc. Should be learnt and internalized by the students. Moreover, the students should develop clear idea about rudiments of scattering in the quantum world.
- Students should develop mastery over Path Integral Approach to Quantum Mechanics and its applications.
- Students should also develop skills to deal with the phase-space description of Quantum Mechanical systems – particularly useful to deal with the continuous-variable case.

References:

1. C. Cohen-Tannoudji, B. Diu and F. Laloe, Quantum Mechanics, Vols. I and II, Wiley, 1970.
2. J. J. Sakurai, Modern Quantum Mechanics, Addisson Wesley, 1995.

3. Marlan O. Scully and M. Suhail Zubairy, Quantum Optics, Cambridge University Press, 1997.
4. W. Greiner, Relativistic Quantum Mechanics: Wave Equations, Springer, 1997.
5. Leslie E. Ballentine, Quantum Mechanics: A Modern Development, World Scientific, 1998.
6. S. D. Bjorken and J. D. Drell, Relativistic Quantum Mechanics, McGraw-Hill Science/Engineering/Math, 1998.

10-PHYS05-022-C: Computational methods in Physics - I (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Solving of ordinary differential Equations:**
  Using Runge-Kutta methods, and using to solve Laplace's equation (1D) in electrodynamics and Schrödinger's equations in quantum mechanics.
- **Solving Partial Differential Equations:**
  Diffusion equation in the context of heat propagation, time evolution in Schrödinger's equation, Laplace's equation in 2 and 3 dimensions in electromagnetism, wave equation, Navier–Stokes equation (hydrodynamics) in 1+1 and 2+1 D. Discussion of different techniques including symplectic integrators and also basis of finite element method.
- **Various techniques of Numerical Integration.**
- **Linear Algebra and Eigensystem:**
  LU decomposition, eigenvalue solvers like the Ritz method, Lanczos and comparison. Iterative methods like Jacobi or Gauss-Seidel methods for solving systems of linear equations. Eigenvalue solvers can be discussed with examples in quantum mechanics, classical mechanics and electrodynamics (TEM modes).
- **Monte Carlo methods for numerical integration:**
  Statistical mechanics, Metropolis and over-relaxation algorithm with a special example of solving Ising model. Generating random numbers.
- **Data Processing and Plotting:**
  Fast-Fourier transform, spline interpolation of data, chi-square distribution and numerical error analysis. Theory of distribution functions and generating trial data using normal, log-normal and exponential functions.
- **Basics of Parallel programming using MPI, OPEN-MP**
- **Language: C/C++, Fortran, Python**

Course Outcomes:

- Students should learn and thereby apply the method of second quantization – required to treat system of indistinguishable particles – while dealing with many-body quantum systems.
- WKB approximation, various variational methods, etc. Should be learnt and internalized by the students. Moreover, the students should develop clear idea about rudiments of scattering in the quantum world.
- Students should develop mastery over Path Integral Approach to Quantum Mechanics and its applications.
- Students should also develop skills to deal with the phase-space description of Quantum Mechanical systems – particularly useful to deal with the continuous-variable case.

References:

1. Numerical Recipes 3rd Edition: The art of scientific computing by W. H. Press, S. A. Teukolsky, W. T. Vetterling
2. Computational Physics by Mark E. J. Newman
3. Numerical Methods for Scientists and Engineers by H. M. Antia

4. Numerical Methods for Partial Differential Equations by Sandip Mazumder
5. Data Reduction and Error Analysis for the Physical Sciences by Philip R.

Additional References:

1. Practical Statistics for Astronomers by Christine R. Jenkins, J. V. Wall, C. R. Jenkins
2. Statistical Mechanics: Algorithms & Computations by Werner Krauth
3. Finite Element Methods: Theory, Implementation and Application by M. J. Larson & E. Bengzon
4. The Lanczos and Conjugate Gradient Algorithms: From Theory to Finite Precision Computations by Gerard Meurant
5. Parallel Scientific Computing in C++ and MPI – Volume 1 by G. Karniadakis, R. M. Kirby.

10-PHYS05-023-C: Condensed Matter Physics I (45 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Introduction:**
  Length, time and energy scales in condensed matter, soft and hard condensed matter, examples of materials properties, bonding and interactions, van der Waals interaction, hydrogen bonding;

- **Condensed matter systems:**
  Crystals: Lattice, basis, 2-d and 3-d crystals, point and space groups, symmetries, experimental determination of structure, scattering, lattice with basis, Miller indices, structure factor, form factors, defects in crystals; Liquids and glasses, Liquid crystals, Polymers, Quasicrystals;

- **Electronic Properties:**
  Jhelium model: Single electron model, density of states, Fermi surface and quasiparticles;
  Thermodynamic properties: Review of thermodynamics, statistical mechanics of non-interacting electrons, Sommerfeld expansion, specific heat, magnetic susceptibility;
  Transport properties: Drude Model, electrical conductivity, thermal conductivity thermoelectric phenomena.
  Band theory: Electrons in periodic potentials, Bloch's theorem, Kronig-Penney model, Brillouin zones, nearly free and tightly bound electrons, Fermi surfaces, band theory, effective mass, Wannier functions and tight binding, survey of the periodic table;

- **Lattice vibrations:**
  Cohesion of solids, mechanical properties, elasticity, constitutive relations;
  Modes of lattice vibrations. Quantization and phonons. Statistical mechanics of phonon gas, Einstein and Debye models, umklapp processes, thermal expansion, Kohn anomalies, chargedensity waves;
  Electron phonon interactions;

- **Semiconductor Physics:**
  Introduction: Valence and conduction bands. Doping and the Fermi level;
  Band diagrams, metal interfaces, work functions, Schottky barrier, diodes and transistors; Nano-electronics: heterostructures, quantum wells, quantum wires and quantum dots;

- **Optical Properties:**
  Optical properties of metals, optical properties of semiconductors, direct and indirect band gaps, polarization, Clausius-Mosotti relation, polarons, point defects and color centres, metals at low frequencies, anomalous skin effect, plasmons, Brillouin and Raman scattering;

- **Superfluidity and Superconductivity:**
  Superfluidity of Helium, BEC, Landau argument, two-fluid model, BEC in atomic gases, superconductivity, phenomenology including Meissner effect, type-I and type-II superconductors;

- **Magnetism:**
  Atomic magnetism, Hunds rules, Curie's law, Pauli paramagnetism, Landau diamagnetism, quantum mechanics of interacting moments, Heisenberg model, spin waves;

Course Outcomes:

- Students should develop concrete ideas about length, time, and energy scales while dealing with manybody

systems – both soft and hard condensed matter.
- Particularly, the students should develop mastery over different properties of crystals, electronic properties of many body systems, lattice vibrations, rudiments of semi-conductor physics, optical properties of different materials, the notion of super-fluidity and different magnetism properties.

References:

1. N. Ashcroft and N. Mermin, Solid State Physics, Holt, Rinehart and Winston, l976.

10-PHYS05-024-C: Statistical Mechanics I (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Fundamental principles:**
  Elements of probability theory, algebra and calculus of random variables, binomial, Poisson and Gaussian distributions, moments and cumulants of probability densities, the central limit theorem, the basic postulate of statistical mechanics, first discussion of ergodicity and mixing;

- **Thermodynamics:**
  Macroscopic definition of thermodynamic variables, temperature, pressure, work and heat, the Carnot cycle and empirical definition of entropy, free energy and other thermodynamic potentials, convexity of entropy and thermodynamic potentials, thermodynamic potentials as Legendre transforms of the entropy, thermodynamic relations of Maxwell, Gibbs and Duhem, Clausius and Clapeyron, and Clausius and Mosotti, the third law of thermodynamics;

- **The Gibbs distribution:**
  Gibbs definition of entropy, the Gibbs distribution as maximisation of entropy subject to constraints, connection with Legendre transforms, connection to thermodynamics, the three canonical distributions, the Maxwell-Boltzmann distribution, the probability distribution of a classical and quantum harmonic oscillator;

- **Non−interacting systems I:**
  Classical ideal gas, the Boltzmann distribution and classical statistics, the counting approach to the Boltzmann distribution, free energy and equation of state of the ideal gas, the law of equipartition, ideal gases with internal degrees of freedom, diatomic and polyatomic gases, the magnetism of an ideal gas;

- **Non−interacting systems II:**
  Fermi distribution, Bose distribution, counting approach to Fermi and Bose distributions, Fermi and Bose gases of elementary particles, the degenerate electron gas, the specific heat of the degenerate electron gas, magnetism of an electron gas, the degenerate Bose gas, black body radiation;

- **Non−interacting systems III:**
  Solids at high temperature and the Dulong-Petit law, solids at low temperatures and Einstein's theory of specific heat, the Debye interpolation formula, thermal expansion of solids;

- **Interacting systems I :**
  Deviations of gases from ideality, van der Waals equation, the conditions of phase equilibrium, the Clausius-Clapeyron equation, the critical point, law of corresponding states, virial and cluster expansions, the method of correlation functions, the Ornstein-Zernike relation;

Course Outcomes:

- Students should develop thorough knowledge in fundamental principles of Statistical Mechanics: Probability Theory, Ergodicity, Mixing, etc.
- Students should have prior familiarity with the laws of Thermodynamics, so that they can apply their knowledge of Statistical Mechanics of the present course to derive different laws of Thermodynamics.
- The notion of Gibbs distribution should be thoroughly understood and internalized.
- Students should also develop clear understanding regarding how to deal with system of noninteracting/interacting particles.

References:

1. L. D. Landau and E. M. Lifshitz, Statistical Physics, 3rd Edition, Butterworth-Heinmann, l980.
2. H. B. Callen, Thermodynamics and an Introduction to Thermo−statistics, 2nd Edition, Wiley,1985.
3. D. Chandler, Introduction to Modern Statistical Mechanics, Oxford Univ. Press, l987.
4. M. Plischke and B. Bergersen, Equilibrium Statistical Mechanics, World Scientific, l994.
5. R. K. Pathria, Statistical Mechanics, Butterworth-Heinmann, l996.
6. M. Kardar, Statistical Mechanics of Particles, Cambridge Univ. Press, 2007.
7. F. Reif, Fundamentals of Statistical and Thermal Physics, Waveland Pr. Inc., 2008.

SUMMER SEMESTER

10-PHYS05-001-PR: Summer Project (128/16 hours of work per week for 8 weeks)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- The project will consist of reading classic papers and presenting what the student has learnt. The project will be done under the guidance of the monitoring committee.

Course Outcomes:

- Acquiring knowledge of the method of second quantization for the study of many particle nonrelativistic systems.

SEMESTER III

10-PHYS05-031-C: Quantum Field Theory I (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

First two-third portion of the course is meant for all students, while a bifurcation is made at the end of this for separately orienting students towards HEP and LEP, during the remaining one-third portion of the course. Thus the common section has 32 lectures, the other two parts have l6 to l8 lectures.

- **QFT I part I:**

  (Common to all students. Knowledge of Relativistic Quantum Mechanics, i.e., Dirac equation and KG equation is expected. Some basic notions of the Lorentz group and Poincare group are also expected)

  - **Elements of Classical Field theory:**
    Lagrangian and Hamiltonian densities, quantization of KG and Dirac and electromagnetic fields, propagators for KG, Dirac and vector (photons)
  - **Perturbation theory:**
    Wick’s theorem and Wick expansion, Feynman diagrams, cross sections and S matrix. Feynman rules for scalars, spinors and gauge fields (Abelian)
  - **Elementary processes in PED:**
    electron positron annihilation, Compton scattering, Bhabha scattering, crossing symmetry etc.
  - **Radiative corrections for scalar theory:**
    loop corrections, regularization and renormalization, dimensional regularization. elementary ideas of the systematics of renormalization
  - **Functional method techniques:**
    Scalar field theory quantization (with, if time permits, some discussion of critical phenomena in this approach)
  - **Non−interacting electrons:**
    Tight binding models, the many body ground state, quasi-particle and quasi-hole excitations. Partially filled bands and Fermi surface kinematics

- **QFT 1 part II: (For HEP students)**

  - **LSZ formalism:**
    one loop diagrams in QED, Ward Takahashi identities, regularization in QED
  - **Path integral/Functional method**
    Quantization in spinor and vector (gauge) theories
  - **Systematics of renormalixation:**
    Power counting, idea of counter terms, structure of one loop and beyond in scalar and QED. (no explicit 2 loop calculations etc.)

- **QFT I part III: (Many Body Theory for Condensed Matter/LEP students)**
  - **Second quantixation in operator formalism (non−relativistic):**
    Diagrammatic perturbation theory, Retarded Greens functions, Spectral function, quasiparticle lifetimes, Angle resolved photoemission spectroscopy (ARPES)
    Linear response theory and Kubo formulae
  - **Interacting bosons:**
    Symmetry breaking, semi-classical spectrum. Applications to cold atoms and superfluids
  - **Mean ffeld theory:**
    BCS hamiltonian and superconductivity
  - **Magnetism:**
    Heisenberg models. Spin waves. Coherent states and path integrals for spin systems. Non-linear sigma models

Course Outcomes:

- Acquiring knowledge of the method of second quantization for the study of many particle nonrelativistic systems.
- Acquiring knowledge of the Lorentz group and its role in relativistic quantum field theory.
- Acquiring knowledge of the quantization of the Klein Gordon, Dirac and Maxwell fields.
- Acquiring knowledge of the basics of quantum electrodynamics and the study of various processes at tree level.
- Understanding of the role of gauge invariance in quantum electrodynamics.

References:

1. M. E. Peskin and D. V. Schroyder, Quantum Field Theory, Sarat Book House, 2005.
2. G. D. Mahan, Many−Particle Physics, Springer, 2010.

10-PHYS05-032-C: Mathematical Methods ll (45 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Numerical interpolation techniques (including Lagrange method)**
- **Advanced Complex Analysis:**
  Analytic continuation, branch cuts, Multivalued functions, Riemann surfaces, Conformal Mapping, Method of steepest descent;
- **Group theory:**
  Discrete and continuous groups;
- **Numerical methods:**
  Numerical solution of integrals, Numerical solution of ODEs, Numerical solution of PDEs: finite difference Monte Carlo method (especially solving integrals), Spectral techniques (including FFT) Numerical minimization techniques;
- **Probability and statistics:**
  Brief survey of probability theory and statistical distributions, Bayesian probability Data analysis;

Course Outcomes:

- Students are supposed to learn and thereby apply different numerical techniques: interpolation methods, numerical solutions of ordinary and partial differential equations, Monte-Carlo method, numerical optimization, numerical techniques of dealing with fast Fourier transforms, etc.
- Students should develop a thorough working knowledge (together with the corresponding theoretical development) in the representation theories of discrete as well as continuous groups used in Classical and Quantum Mechanics.
- Students should develop working knowledge (as well as theoretical understanding) in topics of advanced Complex Analysis: analytic continuation, branch cuts, Riemann surfaces, conformal mapping, etc.
- Students should develop working knowledge in rudiments of Probability Theory.

References:

1. C. M. Bender and S. A. Orszag, Advanced Mathematical Methods for Scientists and Engineers: Asymptotic Methods and Perturbation Theory (vol. l), Springer, l999.
2. T. W. Gamelin, Complex Analysis, Springer, 200l.
3. E. T. Jaynes and G. L. Bretthorst, Probability Theory: The Logic of Science (vol. l), Cambridge Univ. Press, 2003.
4. M. Tinkham, broup Theory and Quantum Mechanics, Dover, 2003.
5. R. Gilmore, Lie broups, Lie Algebras, and Some of Their Applications, Dover, 2006.
6. J. H. Mathews and R. W. Howell, Complex Analysis for Mathematics and Engineers, Jones and Bartlett, 2006.
7. N. G. Van Kampen, Stochastic Process in Physics and Chemistry, 3rd Edition, North Holland, 2007.

10-PHYS05-033-C: Statistical Mechanics II (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
vani@imsc.res.in

Course Details:

- **Introduction to critical phenomena:**
  Survey of experimental results, scaling hypothesis and empirical scaling relations, self-similarity and fractals;
- **Interacting systems:**
  Critical phenomena and continuous phase transitions, symmetry and the order parameter, Landau theory, introduction to the Ising model, Curie-Weiss mean field theory, the absence of phase transitions in one dimension;
- **Criticality in spin systems:**
  The Ising model in one dimensions, solution using transfer matrices, the lack of phase transitions in one dimensions, the Landau-Peirls argument. The Ising model in two dimensions, Wannier's calculation of the critical temperature, mean field solutions of the Ising model, survey of principle results of Onsager's exact solution;
- **Criticality in classical ffeld theories:**
  Landau-Ginzburg theory, the Landau-Ginzburg functional as an effective Hamiltonian, calculation of correlation functions, exponents and thermodynamic quantities, mean field and RPA closures, the problem of divergences;
- **Introduction to the renormalisation group:**
  Historical survey, integration of short-wavelength degrees of freedom, classification of fixed points, flow equations, illustration with Kadano block spins in the ld Ising model;
- **Perturbative renormalisation in momentum space:**
  Philosophy of the perturbative RG scheme, significance of the upper critical dimension, diagrammatic expansion in momentum space, the expansion, exponents and thermodynamic quantities in powers of , comparison with mean field approximations;
- **Non−perturbative renormalisation in real space:**
  Kadano block spins, techniques of approximate non-perturbative renormalisation, numerical renormalisation in the Ising model;
- **Broken Symmetry:**
  Continuous symmetry groups and effective Hamiltonians, the consequences of broken symmetry, Goldstone modes and fluctuations, elastic variables, topological defects, fluctuation destruction of long-range order, the Mermin-Wagner and Landau-Peirles arguments, the disclination and dislocation unbinding transitions;
- **Disorder:**
  Disorder in physical systems, quenched and annealed disorder, the Parisi solution for quenched disorder, illustrative examples;
- **Dynamics of fluctuations:**
  Linear response in physical systems, the regression of fluctuations and Onsager's hypothesis, symmetry of kinetic coefficients, the Fokker-Planck and Langevin descriptions of fluctuations, the fluctuation-dissipation theorem;

Course Outcomes:

- Students should develop a working knowledge about critical phenomena: scaling hypothesis, selfsimilarity, and fractals. Moreover, they should develop a thorough knowledge regarding criticality in spin systems, classical field theory, etc.
- Students should understand, internalize, and thereby, apply techniques of renormalization group – including both perturbative as well as non-perturbative cases.
- Students should develop a very good understanding about broken symmetry, how deal with disorders in systems, and dynamics of fluctuations (including the fluctuation-dissipitation theorem).

References:

1. L. D. Landau and E. M. Lifshitz, Statistical Physics, 3rd Edition, Butterworth-Heinmann, l980.
2. H. E. Stanley, Introduction to Phase Transitions and Critical Phenomena, Oxford Univ. Press, l987.
3. D. Chandler, Introduction to Modern Statistical Mechanics, Oxford Univ. Press, l987.
4. M. Plischke and B. Bergersen, Equilibrium Statistical Mechanics, World Scientific, l994.
5. R. K. Pathria, Statistical Mechanics, Butterworth-Heinmann, l996.
6. S.-k. Ma, Modern Theory of Critical Phenomena, Westview Press, 2000.
7. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics, Cambridge Univ. Press, 2000.

10-PHYS05-034-C: Particle Physics I (45 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Symmetries and Quarks:**
  Discrete symmetries, isospin-SU(2), G-parity, SU(3)-classification of mesons and baryons, mass formula, magnetic moments, motivation for colour as an internal symmetry;
- **Scattering Processes:**
  Relativistic kinematics, phase space, lifetimes and cross-sections, Golden rule; scattering of a spinless charged particle by electromagnetic field, scattering of electrons by electromagnetic field, e – μ scattering, Moller scattering, electron-proton scattering and form factors, higher order corrections, vacuum polarization, charge renormalization, Lamb shift, g - 2;
- **Parton Model and PCD:**
  Deep inelastic scattering (DIS) of electrons on nucleons, structure functions and scale invariance, parton model; quantum chromodynamics : Lagrangian, symmetries;
- **Early Developments :**
  Beta-decay, μ-decay, parity violation, V - A theory of weak interactions, conserved vector current (CVC) hypothesis;
- **Strange particle decay, mixing of neutral K-mesons, Cabibbo theory, current-current interaction, PCAC and current algebra;**
- **CP Problem :**
  C,P,T transformations, CP violation;
- **Electro−Veak Tniffed Theory:**
  Spontaneous symmetry breaking, Higgs mechanism, KS (2) − S (l) theory, electroweak unification, neutral current phenomena, W,Z bosons;
- **Current Phenomenology:**
  New flavours, KM-matrix and associated phenomenology, neutrinos, masses and mixing, neutrino oscillations.

Course Outcomes:

- Students should develop a thorough knowledge on standard model in Particle Physics, including symmetries & quarks, Parton model & QCD, etc.
- Moreover, students should develop concrete ideas about different decay processes, V-A theory of weak interactions, CP violation, etc.
- They should have a very good working knowledge in the unification of electromagnetic and weak interactions.
- Working knowledge about neutrinos.

References:

1. T. D. Lee, Particle Physics and Field Theory, Harwood, l98l.
2. F. Halzen, A.D. Martin, Puarks and Leptons, Wiley, l984.

ELECTIVE COURSE

10-PHYS05-041-E: Quantum Field Theory II (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Functional Methods in Quantum Field Theory:**
  Quantization of the Klein-Gordon and Dirac fields and their interactions, derivation of the Feynman rules of covariant perturbation theory, quantization of the Maxwell field, issues of gauge fixing, BRST invariance and QED Ward identities;

- **Functional Integral Quantization of Non−abelian Gauge Fields:**
  Faddeev-Popov method of gauge fixing, BRST invariance and Slavnov-Taylor identities, Gribov ambiguities, loop computations in non-abelian gauge theories and renormalizability;

- **Renormalization Group and its Applications:**
  The Gell-Mann, Low and Wilson approaches to the renormalization group, Callan-Symanzik equations and fixed points of the beta function, asymptotic freedom of non-abelian gauge theories, applications to perturbative QCD;

- **Anomalies in Abelian and Non−abelian Gauge Theories:**
  The axial vector anomaly in QED and its implications, non-abelian anomalies, anomaly freedom vs renormalizability and unitarity, Fujikawa's approach to anomalies;

- **Topological Solutions:**
  Soliton solutions and their implications, Polyakov-'t Hooft magnetic monopole and the BPS limit, instantons and tunneling in quantum field theory;

Course Outcomes:

- This advanced-level course in Quantum Field Theory (QFT) aims at training the students to the extent where they can initiate some research project in High Energy Physics.
- In this course, students are supposed to develop working expertise in topics like: functional methods in QFT, functional integral quantization of non-Abelian gauge fields, applications of renormalization group, anomalies in abelian as well as nonabelian gauge theories, etc.

References:

1. S. Coleman, Aspects of Symmetry, Cambridge University Press, 1985.
2. R. Rajaraman, Solitons and Instantons, Elsevier, 1986.
3. M. Peskin and D. Schroeder, An Introduction to Quantum Field Theory, Addison-Wesley, New York, 1995.
4. S. Weinberg, Quantum Theory of Fields, Vols. I and II, Cambridge University Press, 1996.

10-PHYS05-042A-E: Cosmology and Gravitation (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- Principle of relativity, principle of equivalence, tensors, tensor calculus on Riemannian manifolds, symmetries of Riemannian manifolds, hypersurfaces, extrinsic curvatures, Gauss-Codazzi equations;
- **Einstein's field equations:**
  Newtonian limit, tests of general relativity, gravitational radiation;
- **Solutions of Einstein's equations:**
  Schwarzschild solution, Kerr solution, black holes;
- **Tetrad formulation of gravity, generalizations to arbitrary dimensions;**
- **Hamiltonian formulation:**
  For metric gravity, for tetrad formulation, canonical quantization and path integral quantization;
- **Cosmology: Robertson-Walker model, early universe;**
- **Singularity theorems;**

Course Outcomes:

- This advanced-level course in Cosmology & Gravitation aims at training the students to the extent where they can initiate some research project in Astrophysics, Cosmology, etc.
- In this course, students are supposed to develop working expertise in topics like: Einstein's field equations and their different solutions, Hamiltonian formulation of Gravity, Cosmology, singularity theorems, etc.

References:

1. S. Weinberg, Gravitation and Cosmology, Wiley, 1972.
2. R. Wald, General Relativity, Chicago, 1987.

10-PHYS05-042B-C: Particle Physics-II (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Basic Ingredients of the Standard Model:**
  Yang-Mills fields, Higgs mechanism, asymptotic freedom;
- **Electroweak Sector:**
  Weinberg-Salam Model, phenomenological consequences, families and flavours, anomaly cancellations, radiative corrections and precession tests;
- **Quantum Chromodynamics (PCD):**
  Lagrangian, perturbative QCD, Altarelli-Parisi equations, nonperturbative QCD and colour confinement models, strong CP problem, chiral perturbation theory, heavy quark effective theory, Skyrme model;
- **Neutrino Physics:**
  Solar neutrinos, double beta decay, neutrino masses and mixing models;
- **CP Violation:**
  CP violation in K0 – $\overline{K}0$ system B0 – $\overline{B}0$ system, models of CP Violation;
- **Supersymmetry:**
  Hierarchy problem, construction of the supersymmetric standard model, search for SUSY signals;
- **Other Approaches beyond the Standard Model : Grand unified theories;**

Course Outcomes:

- This advanced-level course in Particle Physics aims at training the students to the extent where they can initiate some research project in Particle Physics.
- In this course, students are supposed to develop working expertise in topics like: basics of the Standard Model, Electroweak interaction, Quantum Chromodynamics, Neutrino Physics, CP violation, Supersymmetry, Grand unified theory, etc.

References:

1. T Cheng and L. Li, bauge Theory of Elementary Particles, Oxford University Press, l984.

10-PHYS05-043-E: Advanced Condensed Matter Physics (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Correlated Electron Physics:**
  Second quantization review, Hubbard model, Heisenberg model; Materials phenomenology, magnetic phases, CDW states;
  Quantum magnetism, Stoner criterion, double exchange;
  Superconductivity, Cooper argument, BCS, gap equation, Bogoliubov-de Gennes equations, strong coupling theory, RVB and modern approaches to superconductivity in correlated systems;
  Quantum Hall effect, integer and fractional, edge states, Laughlin and Jain wave functions, topological defects; Luttinger liquids, Bethe ansatz;
  Mesoscopic physics;
  Disordered electronic systems and metal insulator transitions;

- **Soft Condensed Matter:**
  Physics Interactions in soft matter, entropic interactions, fluctuationinduced interactions, hard sphere statistical mechanics and crystallization;
  Self-assembly of amphiphiles, phases, theoretical approaches;
  Colloids, self-assembly, the freezing transition;
  Polymers, polymer structure, self-avoidance, Edwards model, osmotic pressure, Flory-Huggins theory, screening, semi-flexibility, persistence length;
  Membranes, biological membranes, lipid bilayers, physical properties, de Gennes-Taupin length, tethered membranes;
  Liquid crystals, nematic, cholesteric and smectic, order parameters, Frank free energy, Landau-de Gennes model defects, defect phases;
  Survey of hydrodynamics, hydrodynamic approaches to soft matter physics, dynamical properties of polymers, membranes, colloids;
  Soft matter away from equilibrium, shear-induced phases;
  Optional: Granular media and Glasses;

Course Outcomes:

- This advanced-level course in Condensed Matter Physics aims at training the students to the extent where they can initiate some research project in Hard/Soft Condensed Matter Physics.
- In this course, students are supposed to develop working expertise in: Correlated Electron Physics and Soft Condensed Matter Physics.

References:

For Strongly Correlated Systems:

1. M. P. Marder, Condensed Matter Physics, Wiley-Interscience, 2000.
2. Altland and B. Simons, Condensed Matter Field Theory, Cambridge University Press, 2006.
3. G. D. Mahan, Many−Particle Physics, Springer, 2010.

For Soft Condensed Matter:

1. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics, lst Edition, Cambridge University Press, 2000.

10-PHYS05-044A-E: Quantum Information and Computation (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Resume of Quantum Mechanics:**
  Composite quantum systems and tensor product Hilbert spaces, Subsystems and density operators, From Schr¨odinger to Liouville evolution; completely positive maps as quantum channels; From projective measurements to POVMs; State estimation;

- **Entanglement and its applications:**
  EPR argument and Bell inequalities; Separability vs. entanglement; Positive unphysical maps witnessing entanglement; Partial transpose criterion for checking separability; Other entanglement detection criteria; Multi-partite entanglement; Quantum teleportation, dense coding, entanglement swapping;

- **Connection with Shannon information theory:**
  Shannon's noiseless coding theorem and Schumacher's quantum counterpart; Accessible information and Holevo's bound; Shannon's noisy channel coding theorem and HSW theorem; Quantum channel capacities; Decoherence and quantum error correction;

- **Measures of entanglement:**
  Thermodynamic considerations of entanglement under LOCC; Entanglement concentration and dilution; Several measures of entanglement; Majorization;

- **Quantum Cryptography:**
  Basics of classical cryptography; RSA cryptosystem; Quantum key distribution; Security of quantum key distribution

- **Entanglement in continuous variable systems:**
  Gaussian states; Role of Wingner description and symplectic transformations; Quantum information processing with continuous variable systems;

- **Quantum computation:**
  Classical and quantum computers; Circuit complexity; Oneand two-qubit gates; Universality of gates; Deutsch-Jozsa algorithm; Grover's search algorithm; Quantum Fourier transform and Shor's factorization algorithm;

- **Implementations:**
  Quantum key distribution experiments; Unconditional quantum teleportation using continuous variable systems; Implementations of quantum computers using NMR, trapped ions, Josephson junctions, linear optical devices, etc.;

Course Outcomes:

- This advanced-level course aims at training the students to the extent where they can initiate some research project in different branches of Physics where Information Theory plays a vital role – apart from Quantum Information & Computation itself.
- In this course, students are supposed to develop working expertise in: Entanglement Theory and itsapplications, Shannon's Theory of Classical Information & its Quantum generalizations, Quantum Cryptography, Quantum Computation, physical implementations, etc.

References:

1. Quantum Computation and Information, Michael A. Nielsen and Issac L. Chuang (Cambridge University Press, 2000);
2. John Preskill's Lectures on Quantum Information and Computation, available at: http://theory.caltech.edu/people/preskill/ph229/Zlecture;
3. David Mermin's Lectures on Quantum Computation, available at: http://people.ccmr.cornell.edu/ mermin/qcomp/CS483.html;
4. The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation, Dik Bouwmeester, Artur Ekert, Anton Zeilinger (eds.) (Springer, 2000);
5. Elements of Information Theory, Thomas M. Cover and Joy A. Thomas (John Wiley & Sons, l999);
6. Contemporary review articles available at:http://xxx.imsc.res.in/archive/quant-ph

10-PHYS05-044B-E: Nonlinear Dynamics (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Hamiltonian formulation:**
  Iterative maps, fixed points, Lyapunov exponents, Integrable systems, Perturbed integrable systems, Poincareffi-Birkho construction (illustration with driven pendulum);
- **Deterministic Nonlinear Dynamics:**
  Discrete dynamics and maps, differentiable dynamics : dissipative systems, non-dissipative systems, Hamiltonian systems;
- **Integrability Aspects of Hamiltonian Dynamics : Liouville-Arnold theorem, KAM theory;**
- **Chaos:**
  In discrete dynamical systems, in Hamiltonian systems, in dissipative systems;
- **Semiclassical Analysis:**
  Berry-Tabor theory, Gutzwiller Theory;
- **Quantum Aspects.**

Course Outcomes:

- This advanced-level course in Nonlinear Dynamics (NLD) aims at training the students to the extent where they can initiate some research project in different branches of Physics where Nonlinear Dynamics plays a vital role – apart from Nonlinear Dynamics itself
- In this course, students are supposed to develop working expertise in: Hamiltonian formulation of NLD, Deterministic NLD, Integrability of Hamiltonian Dynamics, Chaos, Semiclassical Analysis of NLD, Quantum Aspects of NLD, etc.

References:

1. M. Tabor, Chaos and Integrability in Nonlinear Dynamics, Wiley, 1989.
2. M. C. Gutzwiller, Chaos in Classical and Quantum Mechanics, Springer, 1990.
3. Percival and D. Richards, Introduction to Dynamics, Cambridge, 1991.
4. L. Reichl, A Modern Course in Statistical Physics, Wiley, 1998.
5. S.H. Strogatz, Nonlinear dynamics and Chaos: Applications to Physics, Biology, Chemistry and Engineering, Cambridge, 2001.
6. M. Lakshmanan and S. Rajasekar, Nonlinear Dynamics, Springer, 2003.
7. L. Reichl, The transition to Chaos, Springer, 2004.

10-PHYS05-044C-E: Statistical Field Theory (75 Lecture Hrs)

Coordinators: Prof. S. Vemparala
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Course Details:

- Review of quantum statistical mechanics, functional integration representation of partition function, scalar field, charged scalars and Bose-Einstein condensation, Fermions, interactions and diagrammatic techniques, self-coupled scalar field theory, Yukawa theory, QED, renormalization and loop corrections to ln Z.
- Spontaneous symmetry breaking and Higgs model QCD, deconfinement phase transitions.
- Salem-Weinberg model and symmetry restoration, early universe, nuclear matter and pion condensates, neutron stars.

Course Outcomes:

- This advanced-level course aims at training the students to the extent where they can initiate some research project in Statistical Mechanics or its applications in fields like Condensed Matter Physics, Particle Physics, etc.
- In this course, students are supposed to develop working expertise in: BoseEinstein condensation, Fermions, diagrammatic techniques, self-coupled scaler field theory, Yukawa theory, spontaneous symmetry breaking & Higgs model of Quantum Chromodynamics, deconfinement phase transition, SalamWeinberg model and symmetry restoration, early universe, nuclear matter & pion condensation, neutron stars, etc.

References:

1. P. Kapusta, Finite Temperature Field Theory, Cambridge University Press, 1989.

10-PHYS05-045-E: Computational Physics - I (5 hours of class work per week, 5 credits)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Solving of ordinary differential Equations:**
  Using Runge-Kutta methods, and using to solve Laplace's equation (1D) in electrodynamics and Schrödinger's equations in quantum mechanics.
- **Solving Partial Differential Equations:**
  Diffusion equation in the context of heat propagation, time evolution in Schrödinger's equation, Laplace's equation in 2 and 3 dimensions in electromagnetism, wave equation, Navier–Stokes equation (hydrodynamics) in 1+1 and 2+1 D. Discussion of different techniques including symplectic integrators and also basis of finite element method.
- **Various techniques of Numerical Integration.**
- **Linear Algebra and Eigensystem:**
  LU decomposition, eigenvalue solvers like the Ritz method, Lanczos and comparison. Iterative methods like Jacobi or Gauss-Seidel methods for solving systems of linear equations. Eigenvalue solvers can be discussed with examples in quantum mechanics, classical mechanics and electrodynamics (TEM modes).
- **Monte Carlo methods for numerical integration:**
  Statistical mechanics, Metropolis and over-relaxation algorithm with a special example of solving Ising model. Generating random numbers.
- **Data Processing and Plotting:**
  Fast-Fourier transform, spline interpolation of data, chi-square distribution and numerical error analysis. Theory of distribution functions and generating trial data using normal, log-normal and exponential functions.
- **Basics of Parallel programming using MPI, OPEN-MP**
- **Language: C/C++, Fortran, Python**

Course Outcomes:

- Students should learn and thereby apply the method of second quantization – required to treat system of indistinguishable particles – while dealing with many-body quantum systems.
- WKB approximation, various variational methods, etc. Should be learnt and internalized by the students. Moreover, the students should develop clear idea about rudiments of scattering in the quantum world.
- Students should develop mastery over Path Integral Approach to Quantum Mechanics and its applications.
- Students should also develop skills to deal with the phase-space description of Quantum Mechanical systems – particularly useful to deal with the continuous-variable case.

References:

1. Numerical Recipes 3rd Edition: The art of scientific computing by W. H. Press, S. A. Teukolsky, W. T. Vetterling
2. Computational Physics by Mark E. J. Newman
3. Numerical Methods for Scientists and Engineers by H. M. Antia

4. Numerical Methods for Partial Differential Equations by Sandip Mazumder
5. Data Reduction and Error Analysis for the Physical Sciences by Philip R.

Additional References:

1. Practical Statistics for Astronomers by Christine R. Jenkins, J. V. Wall, C. R. Jenkins
2. Statistical Mechanics: Algorithms & Computations by Werner Krauth
3. Finite Element Methods: Theory, Implementation and Application by M. J. Larson & E. Bengzon
4. The Lanczos and Conjugate Gradient Algorithms: From Theory to Finite Precision Computations by Gerard Meurant
5. Parallel Scientific Computing in C++ and MPI – Volume 1 by G. Karniadakis, R. M.

10-PHYS05-046-E: Stochastic Processes: Theory and Applications (5 hours of class work per week, 5 credits)

Coordinators: Prof. S. Vemparala
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Course Details:

- **Probability and statistics:**
  Rudiments and common examples of probability distributions, Basic notion of noise and fluctuations; Limit theorems.
- **Stochastic Calculus:**
  Applications to Brownian motion – Langevin and Fokker-Planck equations, Ornstein-Uhlenbeck process (colloidal particle in a trap), Polymers in a fluid.
- **Markov processes in discrete and continuous time:**
  Master equation, equilibrium & steady state, ergodicity, illustration via two-state system, random walks.
- **Non-Markov processes:**
  Continuous time random walk, anomalous processes and diffusion in viscoelastic fluids.
- **First passage process:**
  Kramer's escape problem, general theory for the first passage time quantities (mean first passage time, coefficient of variation).
- **Stochastic Thermodynamics:**
  Thermodynamic laws at the microscopic scale, refined second law of thermodynamics, applications to colloids, biopolymers etc.
- **Extreme value statistics and preliminaries:**
  Gnedenko's classical law of extremes, examples.
- **Interdisciplinary applications:**
  chemical reactions (microscopic view of the rate of a chemical reaction), stochastic gene expression, queues, intermittent target search by protein on DNA, molecular motors, and transport through ion channels.

Course Outcomes:

- Develop a strong understanding of probability, stochastic processes, and statistical methods to model noise, fluctuations, and random phenomena in physical and interdisciplinary systems.
- Apply stochastic calculus, Markov and non-Markov process frameworks, and first-passage concepts to analyze Brownian motion, diffusion, reaction kinetics, and transport processes.
- Gain the ability to connect stochastic thermodynamics and extreme value statistics with real-world applications in physics, chemistry, biology, and interdisciplinary systems such as molecular motors, gene expression, and ion channels.

References:

1. Handbook of stochastic methods for physics, chemistry, and the natural sciences by Cris Gardiner
2. Stochastic processes in physics and chemistry by Van Kampen
3. First steps in random walks: From Tools to Applications, Igor M. Sokolov and Joseph Klafter
4. A guide to first-passage processes by Sidney Redner

5. Single Molecule Science Physical Principles and Models by Dmitrii E. Makarov
6. Molecular driving forces by Ken A Dill and Sarina Bromberg
7. Non-equilibrium statistical physics of small systems Edited by Klages, Just and Jarzynski

ANNEXURE

Course Title:

- Research and Publication Ethics (RPE) **Course for awareness about the publication ethics and publication misconducts.**

Course Level:

- 2 Credit course (30 hrs.)

Eligibility:

- M.Phil, Ph.D. students and interested faculty members (it will be made available to post graduate students at later date)

Fees:

- As per University Rules

Faculty:

- Interdisciplinary Studies

Qualifications of faculty members of the course:

- Ph.D. in relevant subject areas having more than 10 years of teaching experience

ABOUT THE COURSE

Course Code:

- CPE – RPE

Overview:

- This course has total 6 units focusing on basics of philosophy of science and ethics, research integrity, publication ethics. Hands-on-sessions are designed to identify research misconduct and predatory publications. Indexing and citation databases, open access publications, research metrics (citations, h-index, Impact Factor, etc.) and plagiarism tools will be introduced in this course.

Pedagogy:

- Class room teaching, guest lectures, group discussions, and practical sessions.

Evaluation

- Continuous assessment will be done through tutorials, assignments, quizzes, and group discussions. Weightage will be given for active participation. Final written examination will be conducted at the end of the course.

COURSE STRUCTURE

The course comprises of six modules listed in table below. Each module has 4–5 units.

Module	**Unit title**	**Teaching hours**
Theory		
RPE 01	Philosophy and Ethics	4
RPE 02	Scientific Conduct	4
RPE 03	Publication Ethics	7
Practice		
RPE 04	Open Access Publishing	4
RPE 05	Publication Misconduct	4
RPE 06	Databases and Research Metrics	7
Total		**30**

SYLLABUS IN DETAIL

THEORY	
RPE 01: Philosophy and Ethics (3 hrs.)	
S. No.	**Topics**
1	Introduction to philosophy: definition, nature and scope, concept, branches
2	Ethics: definition, moral philosophy, nature of moral judgements and reactions
RPE 02: Scientific Conduct (5 hrs.)	
S. No.	**Topics**
1	Ethics with respect to science and research
2	Intellectual honesty and research integrity
3	Scientific misconducts: Falsification, Fabrication, and Plagiarism (FFP)
4	Redundant publications: duplicate and overlapping publications, salami slicing
5	Selective reporting and misrepresentation of data
RPE 03: Publication Ethics (7 hrs.)	
S. No.	**Topics**
1	Publication ethics: definition, introduction and importance
2	Best practices / standards setting initiatives and guidelines: COPE, WAME, etc.
3	Conflicts of interest

4	Publication misconduct: definition, concept, problems that lead to unethical behavior and vice versa, types
5	Violation of publication ethics, authorship and contributorship
6	Identification of publication misconduct, complaints and appeals
7	Predatory publishers and journals

PRACTICE

RPE 04: Open Access Publishing (4 hrs.)

S. No.	Topics
1	Open access publications and initiatives
2	SHERPA/RoMEO online resource to check publisher copyright & self-archiving policies
3	Software tool to identify predatory publications developed by SPPU
4	Journal finder / journal suggestion tools viz. JANE, Elsevier Journal Finder, Springer Journal Suggester, etc.

Publication Misconduct (4 hrs.)

A. Group Discussions (2 hrs.)

S. No.	Topics
1	Subject specific ethical issues, FFP, authorship
2	Conflicts of interest

3	Complaints and appeals: examples and fraud from India and abroad
B. Software Tools (2 hrs.)	
S. No.	**Topics**
1	Use of plagiarism software like Turnitin, Urkund and other open source software tools

RPE 06: Databases and Research Metrics (7 hrs.)

A. Databases (4 hrs.)

S. No.	**Topics**
1	Indexing databases
2	Citation databases: Web of Science, Scopus, etc.

B. Research Metrics (3 hrs.)

S. No.	**Topics**
1	Impact Factor of journal as per Journal Citation Report, SNIP, SJR, IPP, Cite Score
2	Metrics: h-index, g index, i10 index, altmetrics