School of Physical Sciences
Courses List

Course code	Course Title	Credit Structure			
		L	T	P	C
PH 801	Quantum Mechanics	2	1	0	3
PH 802	Equilibrium Statistical Mechanics	2	1	0	3
PH 803	Advanced Quantum Mechanics	2	1	0	3
PH 804	Non-equilibrium Statistical Mechanics	2	1	0	3
PH 805	Topical literature survey	2	1	0	3
PH 806	Field Theory	2	1	0	3
PH 807	Physics of Materials	2	1	0	3
PH 808	Advanced Computational Condensed Matter Physics	2	1	0	3
PH 808	Quantum Magnetism and Magnetic Materials	2	1	0	3
PH 810	Strongly Correlated Electrons systems	2	1	0	3
PH 811	Nanophotonics	2	1	0	3
PH 812	Topics in Biological Physics	2	1	0	3
PH 813	Advanced High Energy and Nuclear Physics	2	1	0	3
PH 815	Research Methodology	2	1	0	3
PH 816	Project work and Presentation	2	1	0	3

PH 801 **Quantum Mechanics** **2-1-0-3**

Foundation of quantum mechanics, Hilbert vector space, Dirac Bra-Ket notation, matrix representation, change of basis vectors, operators algebra in matrix representation, quantum dynamics and time evaluation operator, matrix mechanics and the theory of angular momentum, Clebsch–Gordan coefficients, the coupling of the orbital and spin angular momentum, total angular momentum, the addition of angular moment, symmetries in quantum mechanics, continuous groups in quantum mechanics.

Suggested Books:

1. Lectures on Physics: *R. P. Feynman Lecture Series*, vol. III, Pearson Education, 2006.
2. B. H. Bransden and C. J. Joachain, *Quantum Mechanics*, Prentice Hall India, 2000.
3. D. J Griffith, *Introduction to Quantum Mechanics*, Prentice Hall India, 2011.
4. A. K. Ghatak and S. Loanathan, *Quantum Mechanics Theory and Application*, Macmillan India, 2005.
5. Quantum Mechanics concept and application: N. Zettili, Wiley, 2009.
6. S. Gasiorowicz, *Quantum Physics*, John Wiley 2003.
7. J. J Sakurai, *Modern Quantum Mechanics*, Addison Wesley, 1993.

PH 802 **Equilibrium Statistical Mechanics** **2-1-0-3**

Objective and foundation of statistical mechanics, basic hypothesis and postulates, macro-micro states, ensembles. Boltzmann's postulate of entropy, Liouville's theorem, different ensembles, connection between thermodynamics and statistical physics, Quantum statistical systems, density matrix, simple case studies of density matrices, Identical particles -B-E and F-D distributions. Ideal Bose and Fermi systems, high and low temperature limits, electrons in magnetic field, para and diamagnetism. Black body radiation, phonons, B.E. condensation, Gibbs paradox.

Suggested Books

1. R. K. Pathria and Paul D. Beale, *Statistical Mechanics*, Academic Press, 2011.
2. K. Huang, *Statistical Mechanics*, Wiley, 1987.
3. F. Reif, *Fundamentals of Statistical and Thermal Physics*, Waveland Press, 2009
4. L. D. Landau and E. M. Lifshitz, *Statistical Physics (Part-I),*Butterworth-Heinemann, 1996.

PH 803 **Advanced Quantum Mechanics** **2-1-0-3**

Various approximation methods in Quantum mechanics, time-independent and time-dependent perturbation theory, WKB, and variational approximation method, identical particles: integral and half-integral spin particles, Kinematics of Spin, many electronic systems, Slater determinant, and Hartree-Fock method, quantum systems with external electric and magnetic fields, the theory of quantum scattering, relativistic quantum mechanics for spin-0 and 1/2 particles, the theory of quantum measurements, EPR paradox, Bell's inequality, the concept of entanglement.

Suggested Books:

1. J. J Sakurai, *Modern Quantum Mechanics*, Addison Wesley, 1993.
2. Lectures on Physics: *R. P. Feynman Lecture Series*, vol. III, Pearson Education, 2006.
3. B. H. Bransden and C. J. Joachain, *Quantum Mechanics*, Prentice Hall India, 2000, 2nd Edition.
4. E. Merzbacher, *Quantum Mechanics*, Wiley, 3rd Edition.
5. J. D Bjorken and S. D. Drell, *Relativistic Quantum Mechanics*, McGraw-Hill, 1964.
6. W. Griener, *Relativistic Quantum Mechanics*, Springer 2000.

7. C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics (vol 2.),* Wiley VCH, 2006.
8. S. Raimes, *Many Electron Theory*, North Holland, 1972.
9. 10. A. Szabo and N. S. Ostlund, *Modern Quantum Chemistry*, Dover Publication, 1996.
10. V. B Berestetskii, E. M. Lifshitz and L. T Pitaevskii, *Relativistic Quantum Theory*, Pergamon Press (1971)

PH 804 Non-Equilibrium Statistical Mechanics 2-1-0-3

Boltzmann transport equation, Langevin equation and its derivation, fluctuation dissipation relation, white noise, derivation of the Fokker-Planck equation from Langevin equation, Markov processes, master equations, one step process, Poisson processes, increase in entropy, generalized entropy, proof of detailed balance, expansion of master equation and linear noise approximation, first passage time using absorbing boundary approach, average exit time, central limit theorem, introduction to critical phenomena, first and second order phase transitions.

Suggested Books:

1. V. Kampen and N. Godfried. *Stochastic processes in physics and chemistry*. Vol. 1. Elsevier, (1992).
2. P. L. Krapivsky, S. Redner, and E. B. Naim. *A kinetic view of statistical physics*. Cambridge University Press, (2010).
3. N. Goldenfeld, *Lectures on phase transitions and the renormalization group*. CRC Press, (2018).

PH 805 Topical Literature Review 2-1-0-3

Students have been asked to do an extensive literature review on a subject asked by the supervisor and are evaluated based on a report they present.

PH 806 Field Theory 2-1-0-3

Landau Ginzburg model, Saddle point approximation and Mean Field Theory, Lower critical dimension, Fluctuation correction to saddle point, Scaling hypothesis, Renormalization Group, Perturbative Renormalization Group.

Klein-Gordon equation, Dirac equation, Lagrangian formulation to Klein-Gordon, Dirac and Maxwell equations, Symmetries (Noether's theorem), Gauge Field Theory, Canonical quantization of scalar and Dirac fields, Wick's theorem, Feynman diagrams, Cross-section and S-matrix, Renormalization.

Introduction to QCD, Asymptotic freedom, Structure of hadrons (form factors, structure functions), Parton model, Deep inelastic scattering, Introduction to lepton and hadron colliders.

PH 807 Physics of Materials 2-1-0-3

Crystallography, Defects, Phonon and lattice vibration, Electrical properties: Free electron theory and Band theory, Tight binding model, Dielectric and optical properties of materials, Spin-Spin interactions, Magnon and magnetic properties of materials, Metals, Semiconductors and Insulators, Superconductivity and Super fluidity.

Exotic materials and phases: Liquid Crystal, Quasicrystal, Penrose tilling, topological phase of matter, topological insulator, Dirac Fermions, Weyl semi-metal. Low dimensional materials and quantum confinement, thin films, nanostructures, metamaterials. Special carbon solids (Fullerene, Carbon Nanotube and Graphene), and 2D materials.

Experimental characterization techniques: Optical & Electron Microscopy (SEM & TEM), Structural (X-ray Diffraction, Neutron), Spectroscopic techniques (EDX, UV-VIS, Raman, PL, XPS, UPS, ARPES, NMR, Mössbauer), Magnetic (VSM and SQUID).

PH 808 Advanced Computational Condensed Matter Physics 2-1-0-3

Occupation number representation and basic concept of first and second quantization of single-particle and many-particle systems, Bosonic and Fermionic operators; Generalized Fermionic Hamiltonian of a solids, Adiabatic approximation; Hartee and Hatree-Fock theory, Single particle product wave function and Slater detrimental wave functions, matrix elements of one and two-particle operators, Exchange interaction and exchange hole, Koopmans theorem; H-F approximation of the free electron gas; ground state energy and Cohesive energy in metals.

Basics of Density Functional Theory (DFT), Hohenberg-Kohn Theorem; Kohn-Sham Equation; Energy minimization, exchange and correlation functional and different approximation schemes, LDA, GGA, hybrid functional and beyond; Practical usefulness and limitations of DFT. Introduction to basis set and its utility in many body calculations, energy dependent and independent basis set, detail analysis of LMTO and plane wave basis set and their applicability. Concept of pseudopotential and its necessity in plane wave basis set, different scheme for developing pseudo-potential. Introduction to the molecular dynamics and quantum Monte Carlo.

Hubbard model; Onsite Hubbard U, solutions of Hubbard models in specific cases, different limiting situations of Hubbard model, t-J model, spin model: Ising & Heisenberg spin model, Band insulators vs. Mott insulators, charge transfer insulator and Mott transition, role of electron correlation.

PH 809 Quantum Magnetism and Magnetic Materials 2-1-0-3

Absence of magnetism in classical statistics; review of diamagnetism, paramagentism, ferromagnetism, antiferromagnetism, ferri magnetism. Circular and helical order, Origin of the exchange interaction; Goodenough-Kanamori rule of exchange interactions, direct exchange, superexchange, indirect exchange, RKKY and itinerant exchange; Spin-spin interaction: Magnons. Spin-waves in ferromagnets, magnons, spontaneous magnetization, thermodynamics of magnons; (semi classical and quantum treatment using Holstein Primakoff transformation), spontaneous symmetry breaking in magnetic systems with continuous symmetry, thermodynamics of magnons, mean field theory and critical behavior for large S models Spin-waves in lattices with a basis ferri and antiferromagnetism; Ordered magnetism of valence and conduction electrons, Stoner criterion, Heisenberg antiferromagnet. Correlated lattice model: Hubbard model; different limiting situations of Hubbard model, lattice model to spin model, t-J model, spin model: Ising, Heisenberg, X-Y model, J_1-J_2 spin model, magnetic disordered states: Valance Bond theory and Anderson prescription.

Quantum magnetic materials, CMR-GMR, Spintronics, low dimensional magnetism, Multiferroic, spin glass, spin liquid, frustrated magnetism, Skyrmion, effect of Spin orbit on magnetism, Rashba effect, Dzyaloshinskii-Moriya interaction, J_{eff} state in real materials. Correlated oxides; perovskite, double perovskite, spinel etc.

PH 810 Strongly Correlated Electron Systems 2-1-0-3

Mott insulator and Hubbard model, role of electron correlation, limiting situations of Hubbard model - spin models, t-J model, Ising and Heisenberg spin model, classification of correlated insulators; Band vs Mott vs. charge transfer insulator. Quantum Phase Transitions: Quantum Rotor Model, Scaling, Mean-Field Solution and Landau-Ginsburg theory. High Tc cuprates and pnictide, breakdown of BCS theory. Fermi liquid theory: Basic concept, calculation of specific heat, magnetic susceptibility, sound velocity. Electron gases and Luttinger liquids, Quantum Hall effect at low dimension, magneto-resistance, Quantum anomalous Hall effect, Spin Hall, fractional and Integer Hall state. Laughlin wave function for Hall state and Composite Fermion theory for fractional Hall states. Magnetic disorder states: Spin Glass, Spin Liquid, Frustrated Magnetism, Valance Bond theory and Anderson prescription. Correlated electronic phases: Colossal magneto-resistance, Spintronics, Low dimensional magnetism, Multiferroic, Kondo effect, Heavy Fermion systems.

PH 811 Nanophotonics 2-1-0-3

Light-matter interaction (electromagnetic wave-equations and boundary conditions, Fresnel equations and optical fibre; Scattering, Polarization, and Coherence of light).

Quantization of light (Photon statistics, Photon antibunching, and Photon number states); Quantization of matter (Single/bound/quasi Particles; Excitation and recombination of elementary-charged and bound particles); Concept of quantum information, qubits, and Bloch sphere; Quantum information processing (Q. Cryptography, Q. Computing, Q. Teleportation, and Q. Metrology); Physical systems for qubits.

Quantum Photonic Platforms; Single-photon Sources; Single spin, decoherence mechanisms and its coherent control; Single-spin sources; Quantum entanglement and EPR paradox; Spin-photon entanglement.

Nanostructures for quantum photonics: materials, growth, fabrication, and characterization; Experimental realization of quantum entanglements.

PH 812 Topics in Biological Physics 2-1-0-3

Physics of molecular motors, Collective phenomenon in biological systems with focus on active hydrodynamics, Information processing in biological systems, Physics of pattern formation, Membrane and fluid vesicles.

PH 813 Advanced High Energy Nuclear Theory 2-1-0-3

Relativistic kinematics: Kinematic variables and their transformations, Decay kinematics, Rapidity, Pseudo-rapidity, Space-like and time-like. Deep inelastic scattering of electron off proton, Parton distribution functions, Form factor. Quark gluon plasma, Hadrons in thermal bath, Thermodynamics of strongly interacting matter, QCD phase transition in the laboratory, Signals of quark gluon plasma.

Space time evolution of Quark Gluon Plasma and relativistic hydrodynamics. Heavy quark and Langevin dynamics.

PH 814 Collective Phenomena of Quantum Matters 2-1-0-3

Second quantization and the electron gas, One-electron Bloch theory, Phonons in crystals and electron–phonon interactions, semiclassical theory of metals, Fermi liquid theory, General theory of phase transitions and instabilities in electronic systems, General Bose systems and Superconductivity, Interacting localized spins and magnons, Chemical approach of many electrons problem, Electrons with Coulomb interaction, Strong correlation, Magnetic impurities in metals, Relativistic approximations in electrons in solids, Dirac electrons.

Suggested References:

1. P. L. Taylor and O. Heinonen, *A Quantum Approach to Condensed Matter Physics*, Cambridge Univ. Press, 2002.
2. D. I. Khomskii, *Basic Aspects of the Quantum Theory of Solids*, Cambridge Univ. Press, 2012.
3. P. Fazekas, *Lecture Notes on Electron Correlation and Magnetism*, World Scientific, 1999.
4. P. M. Chaiken and T. C. Lubensky, *Principles of Condensed Matter Physics*, Cambridge Univ. Press., 1995.
5. R. M White, *Quantum Theory of Magnetism*, Springer, 2007.
6. P. Phillips, *Advanced Solid State Physics*, Cambridge Univ. Press., 2012.
7. C. Kittel, *Quantum Theory of Solids*, Wiley, 1987.
8. M. Tinkham, *Introduction to Superconductivity*, Dover Publication, 2004.
9. E. Kaxiras and J. D. Joannopoulos, *Quantum Theory of Materials*, Cambridge Univ. Press. 2019.

10. J. Kohanoff, *Electronic Structure Calculations for Solids and Molecules*, Cambridge Univ. Press. 2006.

11.

10. A. A. Abrikosov and I. M. Khalatnikov, *The theory of a Fermi liquid*, Rep. Prog. Phys. 22, 329 (1959)

10. X. L. Qi and S. C. Zhang, *Topological Insulator and Superconductor*, Rev. Mod. Phys. 83, 1057 (2011).

11. N. P. Armitage, E. J. Mele, and A. Vishwanath, *Weyl and Dirac semimetals in three-dimensional solids*, Rev. Mod. Phys. 90, 015001 (2018).

12. M. Z. Hasan and C. L. Kane, *Topological Insulator*, Rev. Mod. Phys. 82, 3045 (2010).

PH 815 Research Methodology 2-1-0-3

Motivation for Research, Time and Effort Management, Finding and solving research problems, scientific writing and presentation, publishing and reviewing a paper, science norms and conventions, ethics, plagiarism, error analysis, basic programming, data analysis.

PH 816 Project Work and Presentation 2-1-0-3

PhD students are assigned to do some preliminary research work in the direction of the thesis by the respective supervisor and are evaluated through seminar presentation.
