UNIVERSITY OF CALCUTTA

Notification No. CSR/ 14 /2013

It is notified for the information of all concerned that in terms of the provisions of Section 54 of the Calcutta University Act, 1979, (as amended), and, in exercise of his powers under 9(6) of the said Act, the Vice-Chancellor has, by an order dated 25.06.2013, **approved the Revised Syllabus** for the **M.Sc. Course of Study in Physics**, under this University, as laid down in the accompanying pamphlet.

The above will take effect from the academic session **2013-2014**.

02.07.2013

SENATE HOUSE
KOLKATA-700073
The 2nd July, 2013

(Prof. Basab Chaudhuri)

Registrar

SYLLABUS FOR M.Sc. COURSE IN PHYSICS

UNIVERSITY OF CALCUTTA

2013

Syllabus for the M.Sc. course in Physics
University of Calcutta

The structure of the revised syllabus for the M.Sc. course in Physics, applicable from the academic year 2009-10, is suggested to be as follows.

Part 1, 1st Semester

	Theoretical Courses	
PHY 411	Mathematical Methods	50 Marks
PHY 412	Classical and Relativistic Mechanics	50 Marks
PHY 413	Quantum Mechanics I	50 Marks
	Practical Courses	
PHY 414	General Practical 1	50 Marks
PHY 415	General Practical 2	50 Marks

Part 1, 2nd Semester

	Theoretical Courses	
PHY 421	Classical Electrodynamics	50 Marks
PHY 422	Quantum Mechanics II	50 Marks
PHY 423	Electronics and Instrumentation	50 Marks
	Practical Courses	
PHY 424	General Practical 3	50 Marks
PHY 425	Computer Practical	50 Marks

Part 2, 3rd Semester

	Theoretical Courses	
PHY 511	Atomic, Molecular, and Laser Physics	50 Marks
PHY 512	Statistical Mechanics	50 Marks
PHY 513	Nuclear and Particle Physics	50 Marks
PHY 514	Solid State Physics	50 Marks
	Practical Courses	
PHY 515	Advanced Experiments I	50 Marks

Part 2, 4th Semester

	Theoretical Courses	
PHY 521	Advanced Paper I	50 Marks
PHY 522	Advanced Paper II	50 Marks
PHY 523	Elective Paper	50 Marks
	Practical Courses	
PHY 524	Comprehensive Competence	50 Marks
PHY 525	Advanced Experiments II	50 Marks

The course has been divided into 13 theoretical and 7 experimental modules, each with full marks 50.

Total marks: 1000, Theory: 650, Experiment: 350

To have the M.Sc. degree, a student must pass in all the modules. To pass in a module, a student must get at least 40% marks. A student failing to secure 40% marks in more than two modules in a semester shall be deemed to have failed in that semester and shall not be allowed to proceed in the next semester; (s)he shall appear at the subsequent examination for that semester in all the modules

The general experiments PHY 414, PHY 415, and PHY 424 will have a common syllabus as a pool of experiments. A similar pattern will follow for PHY 515 and PHY 525, as a pool of advanced experiments. PHY 524 will have a written part based on the compulsory theoretical courses and a comprehensive viva.

Teaching period: Should be 14 weeks for each semester, followed by a study leave of about 3 weeks.

For Physics M.Sc. students, all modules except PHY 521 and PHY 523 must be taken in the department. For some choices of PHY 522, PHY 521 is fixed and must also be taken in the department. The open modules can be taken from courses (related to Physics and to be approved by the DC of the Physics department) offered by other departments of this university.

Students of other departments of this university can attend any theoretical course, provided the respective department permits.

Advanced and Elective Papers: Some of the following topics may be offered as Elective and Advanced papers. New topics may be added to the list from time to time.

Advanced I Papers (PHY 521)

1. Condensed Matter Physics I
2. Nuclear Structure
3. Quantum Electronics
4. Quantum Field Theory

Advanced II Papers (PHY 522)

1. Condensed Matter Physics II
2. Laser Physics
3. Materials Physics
4. Nuclear Reaction and Nuclear Astrophysics
5. Particle Physics
6. Solid State Electronics

Elective Papers (PHY 523)

1. Astrophysics and Cosmology
2. General Theory of Relativity
3. Many Body Theory
4. Microwave
5. Nonlinear Dynamics
6. Physics of Liquid Crystals
7. Selected Topics of Statistical Mechanics
8. Soft Matter Physics

Total number of lectures (plus tutorials) for theoretical papers is 60 for each unit of 50 marks (core courses: PHY 411, PHY 412, PHY 413, PHY 421, PHY 422, PHY 512) and 50 for each unit of 50 marks (applied courses: rest)

PHY 411: Mathematical Methods

1. Vector space and matrices (7)
   Vector space: Axiomatic definition, linear independence, bases, dimensionality, inner product; Gram-Schmidt orthogonalisation.
   Matrices: Representation of linear transformations and change of base; Eigenvalues and eigenvectors; Functions of a matrix; Cayley-Hamilton theorem; Commuting matrices with degenerate eigenvalues; Orthonormality of eigenvectors.
2. Group theory (10)
   Definitions; Multiplication table; Rearrangement theorem; Isomorphism and homomorphism; Illustrations with point symmetry groups; Group representations : faithful and unfaithful representations, reducible and irreducible representations; Lie groups and Lie algebra with SU(2) as an example.
3. Complex analysis (13)
   Recapitulation : Complex numbers, triangular inequalities, Schwarz inequality. Function of a complex variable — single and multiple-valued function, limit and continuity; Differentiation — Cauchy-Riemann equations and their applications; Analytic and harmonic function; Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchys Integral Formula and its corollaries; Series — Taylor and Laurent expansion; Classification of singularities; Branch point and branch cut; Residue theorem and evaluation of some typical real integrals using this theorem.
4. Theory of second order linear homogeneous differential equations (6)
   Singular points — regular and irregular singular points; Frobenius method; Fuch's theorem; Linear independence of solutions — Wronskian, second solution. Sturm-Liouville theory; Hermitian operators; Completeness.
5. Inhomogeneous differential equations : Green's functions (3)
6. Special functions (3)
   Basic properties (recurrence and orthogonality relations, series expansion) of Bessel, Legendre, Hermite and Laguerre functions.
7. Integral transforms (3)
   Fourier and Laplace transforms and their inverse transforms, Bromwich integral [use of partial fractions in calculating inverse Laplace transforms]; Transform of derivative and integral of a function; Solution of differential equations using integral transforms.
8. Tutorials (15)

PHY 412: Classical and Relativistic Mechanics

1. An overview of the Lagrangian formalism (3)
   Some specific applications of Lagarange's equation; small oscillations, normal modes and frequencies.
2. Hamilton's principle (6)
   Calculus of variations; Hamilton's principle; Lagrange's equation from Hamilton's principle; Legendre transformation and Hamilton's canonical equations; Canonical equations from a variational principle; Principle of least action.
3. Canonical transformations (6)
   Generating functions; examples of canonical transformations; group property; Integral variants of Poincare; Lagrange and Poisson brackets; Infinitesimal canonical transformations; Conservation theorem in Poisson bracket formalism; Jacobi's identity; Angular momentum Poisson bracket relations.
4. Hamilton-Jacobi theory (4)
   The Hamilton Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables.
5. Rigid bodies (8)
   Independent coordinates; orthogonal transformations and rotations (finite and infinitesimal); Euler's theorem, Euler angles; Inertia tensor and principal axis system; Euler's equations; Heavy symmetrical top with precession and nutation.

6. Lagrangian formulation for continuous systems (6)
   Lagrangian formulation of acoustic field in gases; the Hamiltonian formulation for continuous systems; Canonical equations from a variational principle, Poisson's brackets and canonical field variables.

7. Introduction to Chaos (4)
   Periodic motions and perturbations; Attractors; Chaotic trajectories and Liapunov exponents; The logistic equation.

8. Special theory of relativity (8)
   Lorentz transformations; 4-vectors, Tensors, Transformation properties, Metric tensor, Raising and lowering of indices, Contraction, Symmetric and antisymmetric tensors; 4-dimensional velocity and acceleration; 4-momentum and 4-force; Covariant equations of motion; Relativistic kinematics (decay and elastic scattering); Lagrangian and Hamiltonian of a relativistic particle.

9. Tutorials (15)

PHY 413: Quantum Mechanics I

1. Recapitulation of Basic Concepts (9)
   Wave packet: Gaussian wave packet; Fourier transform; Spreading of a wave packet; Fourier Transforms of δ and sine functions.
   Coordinate and Momentum space: Coordinate and Momentum representations; x and p in these representations; Parserval's theorem.
   Eigenvalues and eigenfunctions: Momentum and parity operators; Commutativity and simultaneous eigenfunctions; Complete set of eigenfunctions; expansion of wave function in terms of a complete set.
   One-dimensional problems: Square well problem ($E > 0$); Delta-function potential; Double-δ potential; Application to molecular inversion; Multiple well potential, Kronig-Penney model.

2. Operator method in Quantum Mechanics (8)
   Formulation of Quantum Mechanics in vector space language; Uncertainty principle for two arbitrary operators; One dimensional harmonic oscillator by operator method.

3. Quantum theory of measurement and time evolution (3)
   Double Stern-Gerlach experiment for spin-$\frac{1}{2}$ system; Schrodinger, Heisenberg and interaction pictures.

4. Three-dimensional problems (5)
   Three dimensional problems in Cartesian and spherical polar coordinates, 3-d well and Fermi energy; Radial equation of free particle and 3-d harmonic oscillator; Eigenvalue of a 3-d harmonic oscillator by series solution.

5. Angular momentum (6)
   Angular momentum algebra; Raising and lowering operators; Matrix representation for $j = \frac{1}{2}$ and $j = 1$; Spin; Addition of two angular momenta — Clebsch-Gordan coefficients, examples.

6. Approximation Methods (14)
   Time independent perturbation theory: First and second order corrections to the energy eigenvalues; First order correction to the eigenvector; Degenerate perturbation theory; Application to one-electron system – Relativistic mass correction, Spin-orbit coupling (L-S and j-j), Zeeman effect and Stark effect.
   Variational method: He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom.

7. Tutorials (15)

PHY 421: Classical Electrodynamics

1. Electrostatics and Magnetostatics (6)
   Scalar and vector potentials; Gauge transformations; Multipole expansion of (i) scalar potential and energy due to a static charge distribution (ii) vector potential due to a stationary current distribution. Electrostatic and magnetostatic energy. Poynting's theorem. Maxwell's stress tensor.

2. Radiation from time-dependent sources of charges and currents (7)
   Inhomogeneous wave equations and their solutions; Radiation from localised sources and multipole expansion in the radiation zone.

3. Relativistic electrodynamics (11)
   Equation of motion in an electromagnetic field; Electromagnetic field tensor, covariance of Maxwells equations; Maxwell's equations as equations of motion; Lorentz transformation law for the electromagnetic fields and the fields due to a point charge in uniform motion; Field invariants; Covariance of Lorentz force equation and the equation of motion of a charged particle in an electromagnetic field; The generalised momentum; Energy-momentum tensor and the conservation laws for the electromagnetic field; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field.

4. Radiation from moving point charges (12)
   Lienard-Wiechert potentials; Fields due to a charge moving with uniform velocity; Fields due to an accelerated charge; Radiation at low velocity; Larmor's formula and its relativistic generalisation; Radiation when velocity (relativistic) and acceleration are parallel, Bremsstrahlung; Radiation when velocity and acceleration are perpendicular, Synchrotron radiation; Cherenkov radiation (qualitative treatment only). Thomson and Compton scattering.

5. Radiation reaction (3)
   Radiation reaction from energy conservation; Problem with Abraham-Lorentz formula; Limitations of CED.

6. Plasma physics (6)
   Definition of plasma; Its occurrence in nature; Dilute and dense plasma; Uniform but time-dependent magnetic field: Magnetic pumping; Static non-uniform magnetic field: Magnetic bottle and loss cone; MHD equations, Magnetic Reynold's number; Pinched plasma; Bennett's relation; Qualitative discussion on sausage and kink instability.

7. Tutorials (15)

PHY 422: Quantum Mechanics II

1. WKB Approximation (3)
   Quantisation rule, tunnelling through a barrier, qualitative discussion of α-decay.

2. Time-dependent Perturbation Theory (6)
   Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations — Fermi's Golden rule; Sudden and adiabatic approximations.

3. Scattering theory (12)
   Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer-Townsend effect; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering — Green's function in scattering theory; Lippman-Schwinger equation; Born approximation.

4. Symmetries in quantum mechanics (12)
   Conservation laws and degeneracy associated with symmetries; Continuous symmetries — space and time translations, rotations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for $j = \frac{1}{2}$ and $j = 1$; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries — parity and time reversal.

5. Identical Particles (3)
   Meaning of identity and consequences; Symmetric and antisymmetric wavefunctions; Slater determinant; Symmetric and antisymmetric spin wavefunctions of two identical particles; Collisions of identical particles.

6. Relativistic Quantum Mechanics (9)
   Klein-Gordon equation, Feynman-Stückelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of γ matrices; Charge conjugation; Normalisation and completeness of spinors.

7. Tutorials (15)

PHY 423: Electronics and Instrumentation

1. Analog circuits (4)
   Comparators, Multivibrators, Waveform generators: Square wave, triangle wave and pulse generators.
2. Digital MOS circuits (6)
   NMOS and CMOS gates (AND, NAND and NOT), Dynamic MOS circuits, ratioinverter, two phase inverter; dynamic MOS shift register, static MOS shift registers, four phase shift registers. Memory Devices; Static and dynamic random access memories (SRAM and DRAM)
3. Transmission line (9)
   Transmission line equation and solution; Reflection and transmission coefficient; Standing wave and standing wave ratio; Line impedance and admittance; Smith chart.
4. Physics of Semiconductor devices I (8)
   Carrier concentrations in semiconductors; Band structure of p-n junction; Basic semiconductor equations; p-n diode current voltage characteristics; Dynamic diffusion capacitances; Ebers-Moll equation.
5. Physics of Semiconductor devices II (11)
   Metal semiconductor junctions: Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky barriers.
   Miscellaneous semiconductor devices: Tunnel diode; Photodiode; Solar cell; LED; LDR; p-n-p-n switch, SCR; Unijunction transistor (UJT); Programmable Unijunction transistor (PUT).
6. Experimental design (8)
   Scintillation detectors; Solid state detectors (Si and HPGe).
   Measurement of energy and time using electronic signals from the detectors and associated instrumentation, Signal processing; Multi channel analyzer; Time of flight technique; Coincidence measurements true-to-chance ratio.
7. Error analysis and hypothesis testing (4)
   Propagation of errors; Plotting of graphs, Distribution, Least square fit, Criteria for goodness of fit (χ^2-testing).

PHY 511: Atomic, Molecular, and Laser Physics

1. One Electron Atom (2)
   Introduction: Quantum States; Atomic orbital; Parity of the wave function; Angular and radial distribution functions.
2. Interaction of radiation with matter (6)
   Time dependent perturbation: Sinusoidal or constant perturbation; Application of the general equations; Sinusoidal perturbation which couples two discrete states — the resonance phenomenon.
   Interaction of an atom with electromagnetic wave: The interaction Hamiltonian — Selection rules; Nonresonant excitation — Comparison with the elastically bound electron model; Resonant excitation — Induced absorption and emission.
3. Fine and Hyperfine structure (10)
   Solution of Dirac equation in a central field; Relativistic correction to the energy of one electron atom. Fine structure of spectral lines; Selection rules; Lamb shift.
   Effect of external magnetic field - Strong, moderate and weak field.
   Hyperfine interaction and isotope shift; Hyperfine splitting of spectral lines; selection rules.
4. Many electron atom (6)
   Independent particle model; He atom as an example of central field approximation; Central field approximation for many electron atom; Slater determinant; L-S and j-j coupling; Equivalent and nonequivalent electrons; Energy levels and spectra; Spectroscopic terms; Hunds rule; Lande interval rule; Alkali spectra.

5. Molecular Electronic States (5)
   Concept of molecular potential, Separation of electronic and nuclear wavefunctions, Born-Oppenheimer approximation, Electronic states of diatomic molecules, Electronic angular momenta, Approximation methods for the calculation of electronic Wave function, The LCAO approach, States for hydrogen molecular ion, Coulomb, Exchange and Overlap integral, Symmetries of electronic wavefunctions; Shapes of molecular orbital; π and σ bond; Term symbol for simple molecules.

6. Rotation and Vibration of Molecules (3)
   Solution of nuclear equation; Molecular rotation: Non-rigid rotator, Centrifugal distortion, Symmetric top molecules, Molecular vibrations: Harmonic oscillator and the anharmonic oscillator approximation, Morse potential.

7. Spectra of Diatomic Molecules (4)
   Transition matrix elements, Vibration-rotation spectra: Pure vibrational transitions, Pure rotational transitions, Vibration-rotation transitions, Electronic transitions: Structure, Franck-Condon principle, Rotational structure of electronic transitions, Fortrat diagram, Dissociation energy of molecules, Continuous spectra, Raman transitions and Raman spectra.

8. Vibration of Polyatomic Molecules: Application of Group Theory (4)
   Molecular symmetry; Matrix representation of the symmetry elements of a point group; Reducible and irreducible representations; Character tables for C_{2v} and C_{3v} point groups; Normal coordinates and normal modes; Application of group theory to molecular vibration.

9. Laser Physics (10)
   Basic elements of a laser; Threshold condition; Four-level laser system, CW operation of laser; Critical pumping rate; Population inversion and photon number in the cavity around threshold; Output coupling of laser power.
   Optical resonators; Cavity modes; Mode selection; Pulsed operation of laser: Q-switching and Mode locking; Experimental technique of Q-switching and mode locking
   Different laser systems: Ruby, CO_2, Dye and Semiconductor diode laser;

PHY 512: Statistical Mechanics

1. Introduction (6)
   Objective of statistical mechanics. Central Limit Theorem. Macrostates, microstates, phase space and ensembles. Ergodic hypothesis, postulate of equal a-priori probability and equality of ensemble average and time average. Boltzmann's postulate of entropy. Counting the number of microstates in phase space. Entropy of ideal gas : Sackur-Tetrode equation and Gibbs' paradox. Liouville's Theorem.

2. Canonical Ensemble (4)
   System in contact with a heat reservoir, expression of entropy, canonical partition function, Helmholtz free energy, fluctuation of internal energy.

3. Grand Canonical Ensemble (3)
   System in contact with a particle reservoir, chemical potential, grand canonical partition function and grand potential, fluctuation of particle number. Chemical potential of ideal gas. Chemical equilibrium and Saha Ionisation Equation.

4. Classical non-ideal gas (4)
   Mean field theory and Van der Wall's equation of state; Cluster integrals and Mayer-Ursell expansion.

5. Quantum statistical mechanics (5)
   Density Matrix; Quantum Liouville theorem; Density matrices for microcanonical, canonical and grand canonical systems; Simple examples of density matrices – one electron in a magnetic field, particle in a box; Identical particles – B-E and F-D distributions.

6. Ideal Bose and Fermi gas (6)
   Equation of state; Bose condensation; Equation of state of ideal Fermi gas; Fermi gas at finite T.

7. Phase Transition and Critical Phenomeona (9)
   Ising model – partition function for one dimensional case; Chemical equilibrium and Saha ionisation formula. Phase transitions – first order and continuous, critical exponents and scaling relations. Calculation of exponents from Mean Field Theory and Landau's theory, upper critical dimension.

8. Non-equilibrium Statistical Mechanics (8)
   Irreversible processes, Classical Linear Response Theory, Brownian Motion, Master Equation, Fokker-Planck Equation

9. Tutorials (5)

PHY 513: Nuclear and Particle Physics

1. Nuclear properties (4)
   Basic nuclear properties: nuclear size, Rutherford scattering, nuclear radius and charge distribution, nuclear form factor, mass and binding energy, Angular momentum, parity and symmetry, Magnetic dipole moment and electric quadrupole moment, experimental determination, Rabi's method.

2. Two-body bound state (3)
   Properties of deuteron, Schrodinger equation and its solution for ground state of deuteron, rms radius, spin dependence of nuclear forces, electromagnetic moment and magnetic dipole moment of deuteron and the necessity of tensor forces.

3. Two-body scattering (6)
   Experimental n-p scattering data, Partial wave analysis and phase shifts, scattering length, magnitude of scattering length and strength of scattering, Signficance of the sign of scattering length; Scattering from molecular hydrogen and determination of singlet and triplet scattering lengths, effective range theory, low energy p-p scattering, Nature of nuclear forces: charge independence, charge symmetry and isospin invariance of nuclear forces.

4. Nuclear structure (7)
   Liquid drop model, Bethe-Weizsäcker binding energy/mass formula, Fermi model, Shell model and Collective model, γ-decay.

5. Nuclear reactions and fission (10)
   Different types of reactions, Quantum mechanical theory, Resonance scattering and reactions — Breit-Wigner dispersion relation; Compound nucleus formation and break-up, Statistical theory of nuclear reactions and evaporation probability, Optical model; Principle of detailed balance, Transfer reactions, Nuclear fission: Experimental features, spontaneous fission, liquid drop model, barrier penetration, statistical model. Elementary ideas about astrophysical reactions, Nucleosynthesis and abundance of elements.

6. β-decay and weak interaction (8)
   Energetics of various β decays, $V-A$ theory of allowed β decay, Selection rules for Fermi and Gamow-Teller transitions, Parity non-conservation and Wu's experiment, Goldhaber's experiment; Elementary ideas about the gauge theory of weak interaction. The problem of mass generation and the need for the Higgs mechanism. Pion decay.

7. Strong interaction (7)
   Symmetries and conservation laws, Hadron classification by isospin and hypercharge, SU(3) algebra; Young tableaux rules for SU(3); Quarks; Colour; Gell-Mann – Okubo mass relation. Magnetic moment of hadrons.

8. Electroweak theory (2)
   Elementary ideas of electroweak unification and Standard Model.

9. Big bang nucleosynthesis (3)
   Qualitative idea of BBN, relative abundances of hydrogen, helium, and deuterium.

PHY 514 Solid State Physics

1. Structure of solids (9)
   Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell; Symmetry operations and classification of 2- and 3-dimensional Bravais lattices; point group and space group (information only); Common crystal structures: NaCl and CsCl structure, close-packed structure, Zinc blende and Wurtzite structure, tetrahedral and octahedral interstitial sites, Spinel structure; Intensity of scattered X-ray, Friedel's law, Anomalous scattering; Atomic and geometric structure factors; systematic absences; Reciprocal lattice and Brillouin zone; Ewald construction; Explanation of

experimental methods on the basis of Ewald construction; Electron and neutron scattering by crystals (qualitative discussion); Surface crystallography; Graphene; Real space analysis — HRTEM, STM, FIM. Non crystalline solids — Monatomic amorphous materials; Radial distribution function; Structure of vitreous silica.

2. Band theory of solids (6)

   Bloch equation; Empty lattice band; Number of states in a band; Effective mass of an electron in a band: concept of holes; Classification of metal, semiconductor and insulator; Electronic band structures in solids - Nearly free electron bands; Tight binding method - application to a simple cubic lattice; Band structures in copper, GaAs and silicon; Topology of Fermi-surface; Quantization of orbits in a magnetic field, cyclotron resonance — de Haas-van Alphen effect; Boltzmann transport equation - relaxation time approximation, Sommerfeld theory of electrical conductivity.

3. Lattice dynamics and Specific heat (6)

   Classical theory of lattice vibration under harmonic approximation; Dispersion relations of one dimension lattices: monatomic and diatomic cases, Characteristics of different modes, long wavelength limit, Optical properties of ionic crystal in the infrared region; Inelastic scattering of neutron by phonon; Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity; Anharmonic effects in crystals - thermal expansion.

4. Dielectric properties of solids (6)

   Electronic, ionic, and orientational polarization; static dielectric constant of gases and solids; Complex dielectric constant and dielectric losses, relaxation time, Debye equations; Cases of distribution of relaxation time, Cole - Cole distribution parameter, Dielectric modulus; Ferroelectricity, displacive phase transition, Landau Theory of Phase Transition.

5. Magnetic properties of solids (9)

   Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: classical and quantum theory of paramagnetism; case of rare-earth and iron-group ions; quenching of orbital angular momentum; Van-Vleck paramagnetism and Pauli paramagnetism; Ferromagnetism: Curie-Weiss law, temperature dependence of saturated magnetisation, Heisenberg's exchange interaction, Ferromagnetic domains - calculation of wall thickness and energy; Ferrimagnetism and antiferromagnetism.

6. Magnetic resonances (4)

   Nuclear magnetic resonances, paramagnetic resonance, Bloch equation, longitudinal and transverse relaxation time; spin echo; motional narrowing in line width; absorption and dispersion; Hyperfine field; Electron-spin resonance.

7. Imperfections in solids (6)

   Frenkel and Schottky defects, defects by non stoichiometry; electrical conductivity of ionic crystals; classifications of dislocations; role of dislocations in plastic deformation and crystal growth; Colour centers and photoconductivity; Luminescence and phosphors; Alloys, Hume-Rothery rules; electron compounds; Bragg - Williams theory, order-disorder phenomena, superstructure lines; Extra specific heat in alloys.

8. Superconductivity (6)

   Phenomenological description of superconductivity - occurrence of superconductivity, destruction of superconductivity by magnetic field, Meissner effect; Type-I and type-II superconductors; Heat capacity, energy gap and isotope effect; Outlines of the BCS theory; Giaver tunnelling; Flux quantisation; a.c. and d.c. Josephson effect; Vortex state (qualitative discussions); High T_c superconductors (information only).

PHY 521: Advanced I
Condensed Matter Physics I

1. Fundamentals of many-electron system: Hartree-Fock theory (8)

   The basic Hamiltonian in a solid: electronic and ionic parts, the adiabatic approximation; Single-particle approximation of the many-electron system — single product and determinantal wave functions, matrix elements of one and two-particle operators; The Hartree-Fock (H-F) theory: the H-F equation, exchange interaction and exchange hole, Koopman's theorem; The occupation number representation: the many electron Hamiltonian in occupation number representation; the H-F ground state energy.

2. The interacting free-electron gas: Quasi electrons and Plasmon (8)
The H-F approximation of the free electron gas: exchange hole, single-particle energy levels, the ground state energy; Perturbation: theoretical calculation of the ground state energy; Correlation energy — difficulty with the second-order perturbation theoretic calculation, Wigner's result at high density, low-density limit and Wigner interpolation formula; Cohesive energy in metals; Screening and Plasmons; Experimental observation of plasmons.

3. Spin-spin interaction: Magnons (8)
Absence of magnetism in classical statistics; Origin of the exchange interaction; Direct exchange, super exchange, indirect exchange and itinerant exchange; Spin-waves in ferromagnets — magnons, spontaneous magnetisation, thermodynamics of magnons; Spin-waves in lattices with a basis — ferri- and antiferromagnetism; Measurement of magnon spectrum; Ordered magnetism of valence and conduction electrons, Stoner's criterion for metalic ferromagnet.

4. Superconductivity (8)
Electron-electron interaction via lattice: Cooper pairs; BCS theory; Bogoliubov transformation — notion of quasiparticles; Ginzburg-Landau theory and London equation; Meissner effect; Type II superconductors — characteristic length; Josephson effect; "Novel High Temperature" superconductors.

5. Superfluidity (5)
Basic Phenomenology; Transition and Bose-Einstein condensation; Two fluid model; Roton spectrum and specific heat calculation, Critical velocity.

6. Disordered systems (8)
Disorder in condensed matter — substitutional, positional and topographical disorder; Short- and long-range order; Atomic correlation function and structural descriptions of glasses and liquids; Anderson model; mobility edge; Minimum Metallic Conductivity, Qualitative application of the idea to amorphous semiconductors and hopping conduction

7. Selected topics (5)
Mott transition, Hubbard Model, Kondo effect.

Nuclear Structure

1. Nuclear Models (25)

   (a) Nuclear shell model: Individual particle model, Basic idea of an actual calculation (seniority scheme, qualitative discussion of cfp, diagonalization).
   (b) Collective model (especially for odd-A nuclei): Coupling of particle and collective motions, Ground state, β and γ bands (rotational).
   (c) Phenomenological description of collective degrees of excitations, VMI and anharmonic vibrator models, Behaviour of nuclei at high-spin.
   (d) Nilsson model.
   (e) Nuclei far away from the stability valley: Drip line, Extremely neutron rich nuclei, Superheavy nuclei.

2. Microscopic theory (11)
Occupation number representation, Creation and annihilation operators, One and two-body operators, Matrix elements, Wick's theorem.
Hartree-Fock approximation and HF equations. BCS model.

3. γ-decay (8)
Interaction of electromagnetic field with nuclei, Multipole expansion, Parity and angular momentum selection rules, Transition probability within single particle model, Angular distribution and directional correlation orientation ratio.

4. Quark degrees of freedom (6)
Introduction to quark degrees of freedom, Basic idea of confinement, Phenomenological Bag model, Bag model at finite temperature and equation of state.

Quantum Electronics

1. Semiconductor Laser (6)
Homojunction laser: Population inversion at a junction; Emission spectra; The basic semiconductor laser;
Heterojunction: Formation of ideal heterojunctions between (a) a p-type wide band-gap semiconductor and an n-type narrower band-gap semiconductor, (b) an n-type wide band-gap semiconductor and a p-type narrower band-gap semiconductor, (c) wide and lightly doped narrower band gap n-type semiconductors; Anderson's model of ideal heterojunction.
Heterojunction laser: Single and double heterojunction laser; Analysis of carrier confinement in a single heterojunction laser.
2. Electrons in quantum structures (6)
Energy level and wave functions for quantum well, quantum wire and quantum dot; Density of states for quantum well, quantum wire and quantum dot; Modulation — doped quantum well; Multiple quantum well; Coupling between quantum wells.
Super lattice: The concept of a super lattice; Kronig-Penney model of a super lattice — zone folding, Tight binding approximation for a super lattice.
3. Quantum Semiconductor Laser (3)
Light amplification in quantum well; Modulation bandwidth; Strained quantum well laser; Quantum wire laser; Blue quantum well laser.
4. Electro-optic effect in quantum structures (3)
Franz-Keldysh effect in Semiconductor; Electro-optic effect in quantum wells; Electro-optic effect in super lattice.
5. Parallel and Perpendicular Transport in Quantum Structures (6)
High field electron transport — Hot electrons in quantum structures; Double barrier resonant-tunneling structures; Super lattices and ballistic injection devices.
6. Quantum Transistor (6)
Resonant-tunneling unipolar and bipolar transistor; Velocity modulation and quantum interference transistor.
7. Guided wave optics (5)
(a) Waveguide modes, Modes characteristics for a planar waveguide, Step index planar waveguide, Maxwell equations in inhomogeneous media: TE modes and TM modes, Radiation modes, Guided modes, Leaky modes, Quasi modes.
(b) Propagation in optical fibre, Numerical aperture, Pulse dispersion in fibres, Scalar wave equation and modes of the fibre, Modal analysis for a step index fibre.
8. Masers (3)
Ammonia beam maser, Energy levels, Methods for population inversion, Maser operation.
9. Coherent interactions of a radiation field and an atomic system (5)
(a) Induced resonant transitions, Inclusions of decay phenomena, Rotating wave approximation, Exact Rabi Solution in the strong field, Rabi flopping, ?-pulse, Dressed state picture.
(b) Density matrix, Rate equation for density matrix, Optical Bloch equations, Vector model of density matrix, The Bloch sphere.
10. Semiclassical laser theory (7)
Electromagnetic field equations, Expansion in normal modes of a cavity, Lambs self-consistency equations, Density matrix equations, Polarization of the medium, Single mode operation, Non-linear effect in polarization, Hole burning, Steady state power, Frequency pulling and pushing.

Quantum Field Theory

1. Lorentz Group (5)
Continuous and discrete transformations, Group structure, Proper and improper Lorentz Transformations, SL(2,C) representations, Poincare group.

2. Canonical quantization of free fields (9)
   Real and complex scalar fields, Dirac field, electromagnetic field, Bilinear covariants, Projection operators, Charge conjugation and Parity on scalar, Dirac and electromagnetic fields.

3. Interacting fields (6)
   Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams.

4. QED (9)
   Feynman rules, Example of actual calculations: Rutherford, Bhabha, Moeller, Compton, $e^+e^- \to \mu^+\mu^-$. Decay and scattering kinematics. Mandelstam variables and use of crossing symmetry.

5. Higher order corrections (6)
   One-loop diagrams. Basic idea of regularization and renormalization. Degree of divergence. Calculation of self-energy of scalar in φ^4 theory using cut-off or dimensional regularization.

6. Gauge theories (10)
   Gauge invariance in QED, non-abelian gauge theories, QCD (introduction), Asymptotic freedom, Spontaneous symmetry breaking, Higgs mechanism.

PHY 522: Advanced II
Condensed Matter Physics II

1. Symmetry in crystals (9)
   Concepts of point group; Point groups and Bravais lattices; Crystal symmetry space groups; Symmetry and degeneracy - crystal field splitting; Kramer's degeneracy; incommensurate structure; Quasicrystals: general idea, Fibonacci lattice, Higher dimensional space, approximate translational and rotational symmetry of two-dimensional Penrose tiling, Diffraction from Fibonacci lattice, Frank-Casper phase in metallic glass.

2. Lattice dynamics (10)
   Classical theory of lattice vibrations in 3-dimensions under harmonic approximation; Dispersion relation: accoustical and optical, transverse and longitudinal modes; Lattice vibrations in a monatomic simple cubic lattice; Symmetry consideration of eigen vectors; Frequency distribution function; Maxima, minima and Saddle points; Frequency variation close to the critical points, Normal coordinates and phonons; Occupation number representation of the lattice Hamiltonian, Phonon phonon interaction; Neutron diffraction by lattice vibrations; Coherent and incoherent scattering, scattering cross section for one phonon, multi phonon processes, Debye - Waller factor; Atomic displacement and melting point; Thermal conductivity in insulators; Mossbauer effect.

3. Density Functional Theory (8)
   Basics of DFT, Comparison with conventional wave function approach, Hohenberg-Kohn Theorem; Kohn-Sham Equation; Thomas-Fermi approximation and beyond; Practical DFT in a many body calculation and its reliability.

4. Electronic properties: I (6)
   The Boltzmann transport equation and relaxation time; Electrical conductivity of metals impurity scattering, ideal resistance at high and low temperatures, U processes; Thermo-electric effects; Thermal conductivity; The Wiedemann - Franz law.

5. Electronic properties: II (7)
   Electronic properties in a magnetic field; Classical theory of magneto-resistance; Hall effect and magnetoresistance in two-band model; K-space analysis of electron motion in a uniform magnetic field; magnetoresistance for open orbits, cyclotron resonance; Azbel - Kaner resonance; Energy levels and density of states in a magnetic field; Landau diamagnetism; de Haas van Alphen effect; Quantum Hall effect.

6. Optical properties of solids (10)
   Kramers - Kronig relations; Sum rules, Dielectric function for ionic lattice, Polariton dispersion, Soft mode and Ferroelectricity, Dielectric function for free electron gas; loss spectroscopy, optical properties of metals, skin effect and anomalous skin effect, Free carrier absorption in semiconductor; Interband transition - direct and indirect transition, surface and interface modes.

Laser Physics

1. Laser Spectroscopy (15)
   Physical Effects of Strong Fields on Atomic Matter: Basic concepts of light-induced effects on atomic matter, Inclusion of phenomenological aspects of population and depopulation in a two-level system. A stationary two-level atom in a standing wave, A moving two-level atom in traveling wave, A moving two-level atom in a standing wave, Lamb dip, Saturation phenomena, Hole burning, Physical significance, Three-level systems with two laser fields: concepts and approach.

2. Quantization of the radiation field (10)
   Background and importance, Lamb shift Classical electromagnetic field, Free classical field, Quantization of electromagnetic field, Photon number states and eigenvalues, Significance of creation/annihilation operators and electric field operator. Multimode electromagnetic field. Interaction picture, Atom-field interactions (first-order perturbation theory and Rabi solution), spontaneous emission, stimulated absorption and emission, Wigner-Weiskopf theory of spontaneous emission.

3. Optical fluctuations and Coherence (4)
   Coherent light: Poissonian photon statistics, Super-Poissonian light: Thermal light and chaotic light, Sub-Poissonian light. Photon antibunching: Mach-Zehnder interferometer, First-order coherence, The intensity interferometer, Hanbury-Brown Twiss experiments, Second order coherence, Photon bunching and antibunching, Coherent light, Bunched light, Antibunched light.

4. Nonlinear interactions of light and matter (7)
   Nonlinear polarization of the medium, Optical susceptibility tensor, Generation of second harmonic, Sum frequency and difference frequency generation, Optical rectification, Parametric amplifier and oscillation, Generation of third harmonic, Intensity dependent refractive index, Self-focussing, Wave equation for nonlinear optical media, Coupled wave equation for sum frequency generation, Phase matching considerations.

5. Mechanical effects of light (4)
   Dynamics of an atom in a laser field, Light forces on atoms, Radiation pressure force, Dipole force, Optical potential.

6. Laser Cooling, Trapping and Bose-Einstein Condensation (10)
   Doppler cooling, Cooling of an atomic beam, Optical molasses, Doppler cooling limit, Sub-Doppler cooling: Sisyphus cooling, Recoil cooling limit, Magneto-optic trap, Magnetic trap, Quadrupole trap, Optical trap, Experimental techniques.
   Theoretical overview of Bose-Einstein Condensate, Experimental realization, Evaporative cooling, Observation of condensate.

Materials Physics

1. Physical properties of materials (6)
   Tensor Properties of Materials; Tensor representation of electrical and thermal conductivity, Onsager's principle, heat flow in crystals; Stress and Strain – effect of crystal symmetry; Thermoelectric effect in crystals; Thermal expansion; Magnetic susceptibility; The Hall effect – axial third rank tensor, relationship to symmetry, Magnetoresistance, Kubo Greenwood formalism.

2. Phase transition in materials (9)
   Thermodynamics and phase diagrams: Kinetics vs. thermodynamics: Role of interface energy. Interfacial coherency and the shape of precipitates. The effect of interfacial curvature on equilibrium-Grain growth, Ostwald ripening. Surface energy and nanostructured materials. Diffusion in solids: activation energies and fast diffusion paths, Variation of diffusion constant with temperature. Ficks 2nd law: specific solutions to time dependent diffusion problems. Diffusion in substitutional alloys: Kirkendall effect; Homogeneous and heterogeneous nucleation; Interface controlled vs. diffusion controlled growth, Rate laws for different growth geometries and coarsening – Avrami Equation. Diffusionless transformations: Ordering, recrystallization, the martensite transformation (basics only). Spinodal decomposition: Spinodal curve, Free energy of compositional fluctuations, Kinetics of Spinodal decomposition.

3. Magneto-resistance and its application (6)
   Ordinary and anisotropic magneto-resistance, mechanism; Giant magneto-resistance (GMR): basic properties, mechanism, Application — spin valves and spin switches; Colossal magneto-resistance (CMR): basic properties and phase diagram, comparison with GMR; structure-tolerance factor, effect of doping, charge ordering; Theoretical understanding – Double exchange mechanism, crystal field

splitting and Jahn-Teller distortion, electron phonon coupling, Recent developments; Application – Magnetoresistive devices

4. Exotic solids (9)
   Aperiodic solids and Quasicrystals, Fibonacci sequence, Penrose lattices and their extensions in 3 dimensions; Special carbon solids: Fullerene, Graphene and Carbon Nano Tube – Structure, formation and characterization; Synthesis; Density of States, Elementary electronic properties and band structure; Usual properties of Graphene – Dirac Fermion, single wall and multiwall carbon nanotube, Carbon nanotubule based electronic devices.

5. Computational methods in Materials Physics (10)
   Quantum mechanical modeling of materials: Hartree Fock and Density Functional Theory. Atomic Pseudopotentials, Basis Sets: Plane Waves and Augmented Basis sets. Plane Wave based DFT calculations. Simplified Approaches to the electronic problem: Tight binding methods;
   Atomistic modeling of materials: Many body Classical potentials, Classical force fields. Monte Carlo and Molecular dynamics simulations;
   Hybrid Quamtum Mechanics Molecular Mechanics (QM-MM) method. Car-Parrinello molecular dynamics.

6. Experimental characterization techniques (10)
   Structure: X-ray diffraction (XRD) patterns, Intensities of reflections, Thermal effects on diffraction patterns, Identification of phases, Effects of disorder, Strain and crystallite size;
   Morphology: Scanning electron microscopy (SEM), Energy-dispersive and wavelength – dispersive spectrometry; Transmission electron microscopy (TEM), Selected area diffraction patterns, Diffraction contrast to image defects;
   Defect: Positron annihilation lifetime spectroscopy, defect analysis from PAL spectroscopy, defect property correlation.

Nuclear Reaction and Nuclear Astrophysics

1. Nuclear Reactions

   (a) Introduction: Survey of reactions of nuclei (2): Strong, electromagnetic and weak processes, Types of reactions and Q-values, Reaction mechanisms: Energy and time scales for direct and compound reactions, Experimental observables: Cross sections — definitions and units; Angular distributions, Excitation functions,

   (b) Models for nuclear reactions (8): Direct reactions: Optical Model: From Hamiltonian to cross sections for elastic scattering; Partial waves, Phase shifts, Scattering amplitudes, S-matrix and its symmetry and reciprocity; Angular distributions, Optical potential.
   Green functions methods: T-matrix expression, Two potential formula, Plane-wave and distorted-wave Born series.
   Connection with nuclear structure: Reference to folded potential, Nuclear density, Inelastic excitation, Electric B (Ek) and nuclear deformations, transfer reactions, Spectroscopic factors, Asymptotic normalization constant (ANC).
   Compound nuclear reactions : Statistical model.
   R-matrix methods: Dispersion theory, One level formula.

   (c) Heavy Ion collisions (6): Collisions near the Coulomb barrier: Semiclassical concepts, Elastic scattering, Coulomb excitation, Deep inelastic collisions, Fusion, Collisions near the Fermi velocity, Collisions near the speed of light: Classifications of reactions and products. Ultra relativistic nuclear collisions: Phase diagram of nuclear matter.

   (d) Nuclear Fission (4): Spontaneous fission, Mass energy distribution of fission fragments, Bohr-Wheeler theory, Fission isobars, Super-heavy nuclei.

   (e) Reactions involving exotic nuclei (1)

2. Nuclear Astrophysics

   (a) Thermonuclear reactions (5): Reaction rates. Low energy behaviour and astrophysical S-factors, Forward and reverse reactions, Nonresonant and resonant reactions, Maxwell-Boltzmann distribution of velocities, Gamow peak.

(b) Big Bang nucleosynthesis (3): He production, Be bottleneck, Abundance of light elements.

(c) Stellar structure (3): Classical stars, Degenerate stars.

(d) Nuclear burning in stars (6): H burning, He burning, Advanced nuclear burning, Core collapse.

(e) Stellar nucleosynthesis (4): Abundance of elements, Production of nuclei, r-, s- and γ-processes.

3. Experimental techniques (8)
Experimental signature of different nuclear reactions: compound nucleus and direct reaction. Charged particle: detection and identification using particle telescope and time of flight measurement, neutron detection using pulse shape discrimination technique, γ-ray detection: different detector characteristics, evaluation of level structure, lifetime measurement, polarization measurement.

Particle Physics

1. Hadron structure and QCD (15)
Elastic e-p scattering, electromagnetic form factors, electron-hadron DIS, structure functions, scaling, sum rules, neutrino production, jet production in e^+e^- collision, scaling violation.

2. Low energy weak interactions (5)
Fermi theory, calculation of decay widths of muon and π^+.

3. Electroweak Theory (9)
Gauge boson and fermion masses, neutral current, experimental tests. Calculation of FB asymmetry in $e^+e^- \to \mu^+\mu^-$ and decay widths of W and Z bosons (only at tree-level). Higgs physics. Reasons for looking beyond the electroweak theory.

4. Flavour physics (8)
Quark mixing, absence of tree-level FCNC in the Standard Model, the CKM matrix, oscillation in K and B systems, CP violation.

5. Neutrino physics (6)
Theory of two-flavour oscillation. Solar and atmospheric neutrino anomalies. Neutrino experiments. The India-based Neutrino Observatory.

6. HEP experiments (2)
Relative merits and demerits of e^+e^- and hadronic colliders, LEP, LHC, B-factories.

Solid State Electronics

1. Foundation of Solid State Electronics (8)
Boltzmann Transport Equation, expressions for mobility and diffusion constant, Einstein relation, temperature dependence of mobility, negative differential mobility; magnetotransport - Hall coefficient and magnetoresistance, Quantum Hall effect; recombination of electron hole pairs: Direct recombination, Kinetics of traps and recombination centers; surface states, pinning of Fermi level; continuity equations, space charge in semiconductors, relaxation effects; space charge neutrality, ambipolar effects; experimental determination of mobility, diffusion constant and lifetime of minority carriers, Hayens Shockley experiment.

2. Semiconductor Technology (5)
Preparation of semiconductor materials: different crystal growth methods, epitaxial growth, strain for lattice mismatch, effect of strain on band structure, pseudomorphic layer, heterostructures, synthesis - Molecular beam epitaxy; metal organic chemical vapor deposition; kinetics of growth; oxidation; diffusion and ion implantation process.

3. JFET and MESFET (5)
Family tree of FET: Basic device characteristics of FET- uniform charge distribution, arbitrary charge distribution, General characteristics- field dependent mobility, two region model and saturated velocity model, microwave performance, related field effect devices.

4. MOSFET and CCD (8)
Surface charge in MOS-capacitors; Capacitance voltage characteristics of MIS structure; Basic device characteristics, Non-equilibrium conditions, linear and saturation regions, subthreshold region, mobility behavior, temperature dependence, threshold shift, short channel effects, subthreshold current, FAMOS, VMOS; types of MOSFET. Charge coupled devices (CCD); interface trapped charge, charge storage, basic CCD structure, charge storage and frequency response, buried channel CCD.

5. Microprocessors (9)

   Introduction to microcomputers, memory-I/O interfacing devices. 8085 CPU; Architecture BUS timings, Demultiplexing the address bus generating control signals, instruction set, addressing modes, illustrative programs, writing assembly language programs: looping, counting and indexing-counters and timing delays; stack and subroutine; extension to 8086 CPU.

6. Nanostructures

   (a) Physics of Nanostructures (5)

   Different form of nanostructures, idea of 2-d, 1-d and 0-d nanostructures; Hetrostructures - Band bending, depletion width and capacitance, inversion layer, 2-d electron gas in triangular well; subband, density of states, surface electron density; exciton, quantum size effect, electron confinement - strong and weak limit; spherical well, effects of confinement; electronic properties of Graphene and amorphous silicon; experimental techniques for nanostructure characterization.

   (b) Techniques for nanostructure fabrication (4)

   Top down: UV and electron beam lithography, Ball milling; Bottom up: Atom manipulation by SPM, Dip pen nanolithography, Microcontact printing; Cluster beam evaporation, Ion beam deposition, chemical bath deposition with capping techniques, Self assembled mono layers. Synthesis of nanowires, VLS growth method, core - shell and epitaxial structures in one dimension, nanowire based devices.

7. Quantum transport in nanostructures (8)

   Ballistic transport; Phase coherence, Aharonov - Bohm effect; density of states for 1-d system; quantized conductance, Landauer formula, conductance behavior of quantum point contact; Landauer - Buttiker formula for multileads, edge states - explanation of Quantum Hall effect; Single electron transport - Coulomb blockade, Coulomb diamond, single electron transistor (SET), molecular electronics; Kondo effect in nanostructures.

PHY 523: Elective
Astrophysics and Cosmology

Part A: Astrophysics

1. Measurement techniques (3)
   Distance measurements in astronomy: Various methods. Measurement of mass through different types of binary systems. Measurement of other properties such as velocity, temperature, radius, etc.

2. Spectral Classification of Stars (3)
   Saha's equation; Harvard system of classification; Absolute and apparent luminosity; Mass luminosity relation, spectroscopic parallax.

3. Evolution of Stars (13)
   Observational basis, protostars, Jeans mass, Hydrostatic equilibrium, equations of stellar structure; Scaling relations; Sources of stellar energy: gravitational collapse, fusion reactions (p-p chain, CNO cycle, triple α reactions); stellar nucleosynthesis and formation of heavy elements; r- and s- processes; Evolution of low-mass and high-mass stars; White and brown dwarfs, Chandrasekhar limit; Pulsars, neutron stars

4. Galaxies (6)
   Types, structure and formation, interaction between galaxies; Active galactic nuclei and quasars.

Part B: Cosmology

1. Elements of General Relativity (12)
   Curved space-time; Eotvos experiment and the equivalence principle; Equation of geodesic; Christoffel symbols; Schwarzschild geometry and black holes; FRW geometry and the expanding universe; Riemann curvature; Einstein equations.

2. ΛCDM Cosmology (13)
   Hubble's observation and expanding universe; Friedmann cosmology; Red shift and expansion; Big bang theory; Constituents of the universe; Dark matter and dark energy (as a nonzero cosmological constant); Early universe and decoupling; Neutrino temperature; Radiation and matter-dominated phases;

Cosmic microwave background radiation, its isotropy and anisotropy properties; COBE, WMAP and Planck experiments; CMBR anisotropy as a hint to large scale structure formation; Flatness, horizon, and relic abundance problems; Inflation and the slow-roll model.

General Theory of Relativity

1. The Equivalence Principle (2)
   Non-inertial frames and non-Euclidean geometry; General coordinate transformations and the general covariance of physical laws.

2. Geometrical Basis (18)
   Contravariant and covariant vectors; Tangent vectors and 1-forms; Tensors: product, contraction and quotient laws; Wedge product, closed forms; Levi-Civita symbol; Tensor densities, the invariant volume element.
   Parallel transport and the affine connection; Covariant derivatives; Metric tensor, raising and lowering of indices; Christoffel connection on a Riemannian space; Geodesics; Space-time curvature; Curvature tensor; Commutator and Lie derivative; Equation for geodesic deviation; Symmetries of the curvature tensor; Bianchi identities; Isometries and Killing vectors.

3. Einstein's Equations (10)
   Energy-momentum tensor and conservation laws; Einstein's equation; Hilberts variational principle; Gravitational energy-momentum pseudotensor.
   Newtonian approximation. Linearised field equations; Gravitational waves; gravitational radiation.

4. Simple Solutions and Singularities (20)
   Static, spherically symmetric space-time; Schwarzschild's exterior solution; Motion of perihelion of Mercury; Bending of light; Gravitational red shift. Radar echo delay.
   Black holes; Kruskal-Szekeres diagram.
   Schwarzschilds interior solution; Tolman-Oppenheimer-Volkov equation; Collapse of stars; Kerr metric; Ergosphere; Reissner-Nordstrom metric; Kerr-Newman metric.
   Weyl's postulate and the cosmological (Copernican) principle; Robertson-Walker metric; Anisotropies, vorticity and shear; Raychaudhuri equation; Singularity theorems of Hawking and Penrose.

Many Body Theory

1. Introduction (5)
   Many particle Hilbert space, Creation and annihilation operators, many particle wave function, fields. Quantum ideal gases: thermodynamic properties. Schrodinger, Heisenberg and interaction pictures.

2. Zero temperature (ground state) formalism (12)
   Time ordering, Gell-Mann Low theorem. Greens functions: Lehmann representation, Wicks theorem. Feynman diagrams: coordinate space and momentum space, Dyson equation, Goldstone theorem.

3. Zero temperature Greens function in Fermi systems (15)
   Hartree-Fock approximation, Application: imperfect Fermi gas, scattering from a hard sphere in coordinate space and momentum space. Ring diagrams; Application: degenerate electron gas.

4. Greens functions for bosons (8)
   Lehmann representation. Feynman diagrams: coordinate space and momentum space, Dyson equation, Application: weakly interacting Bose gas.

5. Finite temperature formalism (elementary discussion) (10)
   Temperature Greens functions for free particles. Interaction representation, Wicks theorem. Feynman diagrams: coordinate space, transformation to momentum space.

Physics of Liquid Crystals

1. Structure and classification of mesophases (5)
   Thermotropic and lyotropic liquid crystals; Different molecular order-nematic, smectic and cholesteric phases; Recent interests in liquid crystals; X-ray analysis of unoriented and oriented liquid crystals; Measurement of nematic order parameter by NMR; Polymer liquid crystals.

2. Molecular theory of nematic liquid crystals (14)
   Symmetry and order parameter; Molecular potential; Distribution function; Nematic–isotropic (N-I) phase transitioni — Maier-Saupe theory; Generalized mean field theory; The even-odd effect — Marcelja's calculation; Hard rod model of N-I phase transition; Derivation of the Onsager equation, solution of Onsager equation in a simple case.

3. Molecular theory of smectic A liquid crystals (5)
   Symmetry, structure and order parameter; Phase diagram of homologous series, McMillan's theory.

4. Elastic continuum theory of liquid crystals (10)
   General expression of free energy of a deformed nematic liquid crystal; Franck's elastic constants; Distortion due to external electric or magnetic field; Freederickz's transition; The twisted nematic cell.

5. Numerical methods for studying liquid crystal phase transitions (4)
   Monte-Carlo simulation; Lebhwol-Lasher simulation of N-I transition; Gey-Berne potential.

6. Landau's theory of phase transition (8)
   Generalization of Landau's theory to liquid crystals; Fourth order and sixth order Landau expansion for studying N-I transition; de Gennes' Generalization to smectic phase; Critical fluctuation.

7. Liquid crystal displays (2)
   Optical properties of on ideal helix, agents influencing the pitch; Basic principle of liquid crystal displays; Advantages of liquid crystal displays; Twisted nematic crystal and cholesteric liquid crystal displays.

8. Discotic liquid crystals (2)
   Symmetry and structure, mean field description of discotic liquid crystals.

9. Lyotropic liquid crystals (5)
   Models for different phases, biomembrane.

Microwave

1. Transmission line and waveguide (10)
   Interpretation of wave equations; Rectangular wave guide — TE and TM modes, power transmission, excitation of modes; Circular waveguide — TE, TM and TEM modes, power transmission, excitation of modes. Microstrip lines — characteristic impedance, loss and Q of microstrip lines, coplanar strip lines and shielded strip lines.

2. Component (9)
   Scattering parameter and scattering matrix, properties of S-parameter; Quality factor and Q-value of a cavity resonator, Q-value of a coupled cavity; Wave guide tees, magic tee, hybrid ring, couplers; Ferrites and Faraday's rotation, gyrator, circulator, isolator and terminator; $\lambda/4$ section filter, tuner and sliding short.

3. Measurement (10)
   Smith chart, single stub and double stub matching; Microwave bridge, measurement of frequency, attenuation and phase; Measurement of dielectric parameters of amorphous solids — dielectric constant, ac conductivity, resistivity, insertion loss, return loss, shielding coefficient. Measurement of microstrip line parameters.

4. Source (10)
   Conventional sources – their limitations.
   (a) Vacuum tube sources — Klystron, reflex klystron, travelling wave tubes and switching tubes; Magnetrons, FWCFA and Gyrotrons.
   (b) Microwave transistors and FETs, Gunn, IMPATT, TRAPATT and parametric devices.
   (c) Laser — Laser processes, Pockels-Cell; Laser modulators, infrared radiation and sources.

5. Antenna (6)
   Transmitting and receiving antennas, antenna gain, resistance and bandwidth; Antenna dipoles, straight, folded and broadband dipoles; Beam width and polarisation; Antenna coupling.

6. Microwave integrated circuit (5)
   Materials and fabrication technique; MOSFET fabrication, memory construction, thin film formation, planar resistor, planar inductor and planar capacitor formation; Hybrid integrated circuit formation.

Selected Topics of Statistical Mechanics

1. Classical Ising model (18)
   (i) Definition of the Ising model, application to binary alloy and lattice gas, mean field approximation for arbitrary dimension.
   (ii) One dimensional Ising model under external field by transfer matrix method (including the two spin correlation function).
   (iii) Two dimensional Ising model under zero external field: High and low temperature expansion, expression for T by duality transformation.
   (iv) Infinite range Ising model: equivalence to mean field theory.
   (v) Ising model in the continuum limit.
   (vi) Kinetic Ising model: Stochastic Dynamics, Relaxation, Critical dynamics (introduction only), Single spin-flip Glauber model; Conserved Ising model - Kawasaki dynamics.
   (vii) Principles of computer simulation of Ising model by Monte Carlo algorithm and molecular dynamics.

2. Quantum Ising Model (5)
   Introduction. Transverse Ising Model: Duality transformation and exact solution for the energy eigenvalues.

3. Phase transitions and critical phenomena (27)

   (a) Basic themes:
   Liquid-gas and uniaxial ferromagnetic phase transitions, first order and continuous phase transitions and critical points, behaviour of thermodynamic functions near the critical point, convexity properties, critical exponents, scaling and hyperscaling relations, universality.
   Introduction to some other kinds of phase transitions: Percolating systems — geometric phase transition, self similarity and fractals; Roughening transitions in interfaces — scaling relations, exact calculations for random deposition model.

   (b) Mean field theory in ferromagnetic systems, critical exponents, breakdown of MFT for dimensions less than 4.

   (c) Beyond mean field theory: Landau theory of phase transitions, critical exponents, Landau-Ginzburg hamiltonian (φ^4 theory), Gaussian approximation for $T < T_c$ and $T > T_c$ — partition function and thermodynamics.

   (d) Block spin transformation, scaling hypothesis etc: Classical models of the cell Hamiltonian, block hamiltonian and Kadanoff transformation, correlation length and statement of scaling hypothesis, scaling dimension, scale transformation and dimensional analysis. Critical phenomena in finite systems: finite size scaling ansatz.

   (e) Renormalisation group: Real space renormalisation group (RSRG): Motivation, definition of RG, recursion relations and fixed point, relevant, irrelevant and marginal parameters, flow diagrams, scaling field, critical exponent. Alternative definition of RG: Momentum shell renormalisation group (MSRG).

   (f) Applications of RG:
   (a) Thermodynamic phase transitions: Decimation in one dimensional Ising model, MSRG in Gaussian model.
   (b) Percolation: RSRG in square and triangular lattices.

Nonlinear Dynamics

1. Introduction, Terminology and applicability (13)

   (a) General idea of dynamical system, order of dynamical system,continuous and discrete, rheonomous and autonomous systems. (b) One-dimensional systems: Flows on the line. Fixed points and stability, graphical analysis, linear stability analysis. Existence and uniqueness of solutions. Impossibility of oscillations in one dimension, Potentials, Solving on the computer. Flows on the Circle : Possibility of oscillations, Superconducting Josephson Junction, Equivalent circuit and damped, driven pendulum analogue. (c) Bifurcations in one dimensional systems and their classifications. Imperfect bifurcations and catastrophes.

2. Two-Dimensional Flows (12)

   (a) Linear Systems and classification. Nonlinear systems: linearization and Jacobian matrix, analysis in polar coordinates. Conservative systems, reversible systems. (b)Lyapunov function, gradient systems, Dulac criterion, limit cycle, Poincare-Bendixson theorem, Lienard systems. Analysis of two widely separated time-scales. (c) Bifurcations in two dimensions: Hopf Bifurcation-super and sub-critical.

3. Chaos I (10)

   One dimensional map : Stability, Liapunov exponent, chaos; Logistic map : period-doubling route to chaos, estimation of and from renormalisation arguments

4. Chaos II (12)

   Fractals : examples, similarity dimension and box dimension; Rayleigh-Benard convection : basic equations, Boussinesq aproximation; Lorenz map : Stability of fixed points and appearence of strange attractors; Baker's map; Henon map : relation with periodically kicked rotator, stability of fixed points and appearence of strange attractors.

5. Quantum Chaos (3)

   Elementary ideas of quantum chaos.

Soft Matter Physics

1. Introduction (2)

   Introduction to soft matter systems : liquid crystals, colloidal systems, biological membranes, macromolecules.

2. Liquid Crystals (20)

   Structure and classification of mesophases; Molecular theories of nematic and smectic liquid crystals; Symmetry and order parameter; Landau's theory of phase transition; Generalization of Landau's theory to liquid crystals; Polymer liquid crystals.

3. Colloidal systems (8)

   Dispersion colloids : Stability and forces, DLVO-theory, gels, emulsions and foams; Association colloids : amphiphiles, micells and critical micelle concentration in colloidal solution, lyotropic liquid crystals, biological systems.

4. Biological Membranes (6)

   Bilayer properties; Chain rotational isomerism; Marcelja's molecular field theory to study different phases and the even-odd effect; Phase diagram.

5. Macromolecules (10)

   Polymer : random walk polymer, self-avoiding random walk polymers, polymer solutions.

   DNAs : Flory's model of DNA condensation; Polymorphism of liquid crystal states by low molecular mass double stranded DNA complexes; DNA condensation in water-polymeric solution; biological activity.

6. Numerical methods for studying soft matter (4)

   Lattice models; Coarse grain models; Gaussian overlap potential; Ellipsoidal contact potential; Computational methods.

PHY 414, PHY 415 and PHY 424: General Experiments

1. Molecular absorption spectroscopy.
2. Atomic emission spectroscopy.
3. Acousto-optical effect using piezo-electric crystal and determination of the velocity of ultrasonic wave in liquids.
4. Interferometry with Michelson's and Jamin's interferometer.
5. Spectrophotometry — Absorption of biomolecules — study of melting.

6. Experiments with laser — its characteristics.
7. Experiments with optical fibers.
8. Study of Zeeman effect — determination of e/m, Lande g-factor of electrons.
9. Determination of e/m of electrons by magnetic focusing method.
10. Determination of Lande g-factor by ESR spectroscopy.
11. Study of para-ferromagnetic phase transition.
12. X-ray diffraction experiment — Laue spots — determination of Miller indices by gnomonic projection.
13. Calibration of audio oscillator by the method of propagation of sound wave and formation of Lissajous' figures.
14. Energy band gap of a semiconductor by four probe method.
15. Energy band gap of semiconductor by studying the luminescence spectra.
16. Verification of Bohr's atomic theory by Franck Hertz Experiment.
17. Hall coefficient of a semiconductor.
18. Dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibration.
19. Amplitude modulation and demodulation.
20. Magnetic parameters of a magnetic material by hysteresis loop tracer.
21. Filter circuits: passive and active filters (1st and 2nd order), Notch filter.
22. RC network and RC phase shifter.
23. Design and study of multivibrators.
24. Studies on FET and MOSFET.
25. Programming with microprocessors.
26. Calibration of a condenser and an inductor.
27. Studies on Diac, Triac and SCR.
28. Unijunction transistors, characteristics and use as saw-tooth generator.
29. Study of plasma density and plasma temperature by glowing discharge method.
30. Study of temperature variation of refractive index of a liquid using hollow prism and laser source.
31. Study of photo-conductivity of a semiconductor material.
32. Study of Gaussian and Poisson distributions and error propagation using radioactive source and GM counter.
33. Determination of phase transition temperatures of a binary liquid crystal mixture at different concentrations.
34. Determination of persistence time in a high impedance current source.

PHY 425: Computer Practical

Part A

1. Plotting of functions and data; fitting etc. using gnuplot
2. Revision of numerical methods for integration, finding roots of equation, solving simultaneous linear differential equations, least squares fitting, interpolation, solving differential equations (Euler method).
3. Use of standard subroutines :

   (i) Runge kutta method for solving differential equations (example : anharmonic oscillator)

   (ii) Matrix diagonalisation; matrix inversion (eigenvalue problem)

Part B

Monte Carlo methods. Applications in

1. Random number generation from different distributions: uniform, gaussian etc; random walk problem
2. Integration
3. Simulating Ising spin systems

PHY 515 and PHY 525: Advanced Experiments

1. Debye-Scherrer, Laue and rotational X-ray photographs.
2. Study of paramagnetic salts by Guoy's balance.
3. Study of colour centers and thermoluminiscence of alkali halides.
4. Study of p-n junction diode.
5. Magnetoresistance and Hall effect at elevated temperatures.
6. Dielectric constant of insulating and ferroelectric materials at room and elevated temperatures.
7. Growth of semiconducting and insulating materials and polycrystalline thin films and their characterization.
8. Optical constants of dielectric and metal films.
9. Photoconductivity and deep level transient spectroscopic studies of doped and undoped semiconducting materials.
10. Study of lifetime of minority carriers of a semiconductor.
11. Differential scanning calorimetry.
12. Study of materials by Mossbauer spectroscopy and positron annihilation technique.
13. Fabrication of Current controller for operation of diode laser.
14. Study of mode characteristics of near infrared diode laser and measurement of atmospheric oxygen absorption.
15. Measurement of optical properties of a glass plate by laser Fizeau interferometry.
16. Infrared spectra of Urea.
17. α particle absorption using semiconductor detectors and multichannel analyser.
18. β particle absorption using GM counting system.
19. β spectrometry with scintillation detectors and multichannel analysers.
20. γ spectrometry with scintillation detectors and single-channel analysers.
21. Energy spectrum of β rays using 180° deflection type magnetic spectrometer.
22. Experiments and design with OP AMP.
23. Experiments on digital electronics.
24. Design and study of DAC/ADC.
25. Design of circuits using 555 timer.
26. Experiments on microprocessor (8085).
27. Design of astable multivibrator using transistors.
28. Study of frequency modulation.
29. Characterization of Solar cell
30. Synthesis of thin films samples by thermal evaporation method and determination of its resistance.

31. Determination of precise lattice parameter and grain size of crystalline materials by X-Ray powder diffractometer.

Reference Books

PHY 411 : Mathematical Methods

1. G. Arfken: Mathematical Methods for Physicists
2. J. Mathews and R.L. Walker : Mathematical Methods of Physics
3. P. Dennery and A. Krzywicki: Mathematics for Physicists
4. R.V. Churchill and J.W. Brown: Complex variables and Applications
5. M.R. Spiegel: Theory and Problems of Complex Variables
6. W.W. Bell: Special Functions for Scientists and Engineers
7. A.W. Joshi: Matrices and Tensors in Physics
8. A.W. Joshi: Elements of Group Theory for Physicists
9. M. Tinkham: Group Theory and Quantum Mechanics
10. S.L. Ross: Differential Equations

PHY 412 : Classical and Relativistic Mechanics

1. H. Goldstein: Classical Mechanics
2. K.C. Gupta: Classical Mechanics of Particles and Rigid Bodies
3. S.N. Biswas: Classical Mechanics
4. N.C. Rana and P.S. Joag: Classical Mechanics
5. A.P. French: Special Relativity

PHY 413 : Quantum Mechanics I

1. S. Gasiorowicz : Quantum Physics
2. P.M. Mathews and K. Venkatesan: A Text Book of Quantum Mechanics
3. E. Merzbacher: Quantum Mechanics
4. J.J. Sakurai : Modern Quantum Mechanics

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1. J.D. Jackson: Classical Electrodynamics
2. W.K.H. Panofsky and M. Phillips: Classical Electricity and Magnetism
3. J.R.Reitz, F.J. Milford and R.W. Christy: Foundations of Electromagnetic theory
4. D.J. Griffiths: Introduction to Electrodynamics
5. L.D. Landau and E.M. Lifshitz: (i) Electrodynamics of Continuous Media (ii) Classical theory of fields
6. C.A. Brau, Modern Problems in Classical Electrodynamics
7. J.A. Bittencourt, Fundamentals of Plasma Physics

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1. L.I. Schiff: Quantum Mechanics
2. J.J. Sakurai: Modern Quantum Mechanics
3. P.M. Mathews and K. Venkatesan: A Text Book of Quantum Mechanics
4. E. Merzbacher: Quantum Mechanics
5. Messiah: Quantum Mechanics, Vol. II
6. J.D. Bjorken and S.D. Drell: Relativistic Quantum Mechanics
7. F. Halzen and A.D. Martin: Quarks and Leptons
8. W. Greiner: Relativistic Quantum Mechanics
9. A. Lahiri and P.B. Pal: A First Book of Quantum Field Theory

PHY 423 : Electronics and Instrumentation

1. J.D. Ryder: Network, Lines and Fields
2. J. Millman and C. Halkias: Integrated Electronics
3. J.D. Ryder: Electronic Fundamental and Applications

4. J. Kennedy: Electronic Communication Systems
5. J. Millman and A. Grabel: Microelectronics
6. B.G. Streetman, S. Banerjee: Solid State Electronic Devices
7. G.F. Knoll: Radiation, Detection and Measurement
8. Sedra and Smith: Microelectronic Devices
9. Taub and Schilling: Digital Integrated Electronics
10. S.Y. Liao: Microwave Devices and Circuits
11. H.J. Reich: Microwave Principles
12. P. Bhattacharyya: Semiconductor Optoelectronic Devices
13. S.M. Sze: Physics of Semiconductor Devices
14. Boylestad and Nashelski: Electronic Devices and Circuit Theory

PHY 511 : Atomic, Molecular and Laser Physics

1. B.H. Bransden and C.J. Joachain: Physics of Atoms and Molecules
2. C. Cohen-Tannoudji, B. Dier, and F. Laloe: Quantum Mechanics vol. 1 and 2
3. R. Shankar: Principles of Quantum Mechanics
4. C.B. Banwell: Fundamentals of Molecular Spectroscopy
5. G.M. Barrow: Molecular Spectroscopy
6. K. Thyagarajan and A.K. Ghatak: Lasers, Theory and Applications
7. O. Svelto: Principles of Lasers
8. B.H. Eyring, J. Walter and G.E. Kimball: Quantum Chemistry
9. W. Demtroder: Molecular Physics
10. H. Herzberg: Spectra of Diatomic Molecules
11. J.D. Graybeal: Molecular Spectroscopy
12. M.C. Gupta: Atomic and Molecular Spectroscopy
13. B.B. Laud: Lasers and Non-linear Optics
14. A. Thorne, U. Litzen and J. Johnson: Spectrophysics

PHY 512 : Statistical Mechanics

1. F. Reif: Fundamentals of Statistical and Thermal Physics
2. R.K. Pathria: Statistical Mechanics
3. K. Huang: Statistical Mechanics
4. F. Mandl: Statistical Physics
5. H.B. Callen: Thermodynamics and an Introduction to Thermostatics

PHY 513 : Nuclear and Particle Physics

1. J.S. Lilley, Nuclear Physics
2. M.K. Pal: Theory of Nuclear Structure
3. R.R. Roy and B.P. Nigam: Nuclear Physics
4. S.N. Ghoshal: Atomic and Nuclear Physics (Vol. 2)
5. D.H. Perkins: Introduction to High Energy Physics
6. D.J. Griffiths: Introduction to Elementary Particles
7. W.E. Burcham and M. Jobes: Nuclear and particle Physics

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1. N.W. Ashcroft and N.D. Mermin: Solid State Physics
2. J.R. Christman: Fundamentals of Solid State Physics
3. A.J. Dekker: Solid State Physics
4. C. Kittel: Introduction to Solid State Physics
5. H. Ibach and H. Luth: Solid State Physics: An Introduction to Theory and Experiment
6. J.P. Srivastava: Elements of Solid State Physics
7. J.P. McKelvey: Solid State and Semiconductor Physics

PHY 425 : Computer Practical

1. V. Rajaraman: Computer Programming in Fortran IV
2. V. Rajaraman: Computer Oriented Numerical Methods
3. J.M. McCulloch and M.G. Salvadori: Numerical Methods in Fortran

PHY 521 : Advanced I

A. Condensed Matter Physics I

1. D. Pines: Elementary Excitations in Solids
2. S. Raimes: Many Electron Theory
3. O. Madelung: Introduction to Solid State Theory
4. N.H. March and M. Parrinello: Collective Effects in Solids and Liquids
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A. Condensed Matter Physics II

1. M. Tinkham: Group Theory and Quantum Mechanics
2. M. Sachs: Solid State Theory
3. A.O.E. Animalu: Intermediate Quantum Theory of Crystalline Solids
4. N.W. Ashcroft and N.D. Mermin: Solid State Physics
5. J.M. Ziman: Principles of the Theory of Solids
6. C. Kittel: Introduction to Solid State Physics

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3. P. Meystre: Atom Optics
4. H. Metcalf and P. Straten: Laser Cooling and Trapping
5. P. Meystre and M. Sargent III: Elements of Quantum Optics
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C. Materials Physics

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1. G.R. Satchler: Introduction to Nuclear Reactions
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2. H.E. Stanley: Introduction to Phase Transitions and Critical Phenomena
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