Syllabus: Ph.D. Coursework
2011

Department of Physics

Institute of Science, Visva-Bharati

Syllabus for Ph.D. Coursework in Physics:

1. **Unit 101:**
    - **101A:** Research Methodology (Marks = 75, Credit Points = 6)
    - **101B:** Basic Computer Applications (Marks = 25, Credit Points = 2)

2. **Unit 102:** Marks 100, Credit Points 8

    Students have to choose any one of the following:

    - **102 A Astrophysics & Cosmology**
    - **102 B Condensed Matter Physics (Theory)**
    - **102 C Condensed Matter Physics (Experiment)**
    - **102 D Electronics**
    - **102 E Laser Physics & Quantum Optics**
    - **102 F Nuclear Physics**
    - **102 G Particle Physics**

3. **Unit 103**: Review work in the relevant field of research

Unit 101A: Research Methodology

Marks - 75, Credit Points - 6

1. Research: meaning, characteristics, types, importance and ethics
2. Defining research problem
3. Literature survey of previous works
4. Methods of data collection, qualitative and quantitative data, data interpretation, graphical representation of data
5. Technical aspects of scientific article and thesis writing: organization of materials, style, drawing figures, graphs, tables, footnotes, references, etc.
6. Scientific paper presentation: one seminar paper preparation (oral or poster) which includes text, figures, pictures, tables, references, etc., question & answer session.
7. Introduction to Patent Law, etc.: patent laws, process of patenting a research finding. copyright, cyber Laws

Unit 101B: Basic Computer Applications

Marks - 25, Credit Points - 2

The syllabus is to be framed and taught by the Department of Computer and System Studies

Unit 102A: Astrophysics & Cosmology

Marks - 100, Credit Points - 8, Lectures - 60

1. Star formation, **s**tellar evolution, late stage of stellar evolution;
2. White dwarfs, Neutron stars, Black Holes.
3. Pulsars, radio pulsars, millisecond pulsars, binary pulsars; Neutron star magnetic field, generation and decay; magnetars**,** generation of magnetic field in magnetars.
4. Introduction to cosmology
5. Hubble's Law, a brief introduction to Big Bang cosmology.
6. Friedman models and their properties.
7. Problems of standard Big Bang cosmology and their remedy by inflation.
8. Some flavour of steady state model and cyclic model cosmology.

Unit 102B: Condensed Matter Physics (Theory)

Marks - 100, Credit Points - 8, Lectures - 60

1. **Band theory**: Bloch theorem, General properties of Bloch function, The nearly free electron model, tight binding model, k.p theory, Hartree-Fock theory of free electrons, Density functional theory, Thomas Fermi approximation, Kohn Sham equation, Local density approximation. (8)

2. **Many Particle Physics**: Fock space and occupation number representation for bosons and fermions,Greens functions, Analytical properties and their relation to observable quantities, Finite temperature Greens functions, Feynman diagrams, Dyson equation, Link-cluster theorem, Random phase approximation, Electron-phonon interaction, Migdal theorem, superconductivity, Kubo formalism of electrical conductivity, Perturbation theory away from equilibrium, Keldysh formalism. (22)

3. **Magnetism**: Diamagnetism, Paramagnetism, Ferromagnetism, Antiferromagnetism, Ferrimagnetism, Exchange interaction, RKKY mechanism of exchange interaction, Mean field theory, Spin waves, Holstein Primakov approximation, Kondo effect, Hubbard model, Stoner criteria. (8)

4. **Theory of phase transition**; Landau theory of phase transition, critical fluctuations, Critical exponents, Landau coarse graining theory, renormalisation group methods: Kadanoff's Block spin renormalisation group, one and two dimensional Ising model, scaling theory, RG analysis of the ferromagnetic transition. (12)

5. **Low Dimensional Systems**: effective mass theory, density of states, Hetero-structures, quantum wells and super-lattices, Two-dimensional electron gas, one-dimensional quantum systems, quantum dots and wires, quantum Hall effect, Coulomb blockade and single electron tunnelling/transistors, quantum computers. (10)

Unit 102C: Condensed Matter Physics (Experiment)

Marks - 100, Credit Points - 8, Lectures - 60

1. **Sample Preparation**: Standard methods for the preparation of different kind of materials, nano-materials (nano-particles, nano-tubes, nano-rods etc.) thin films of nano-structured materials by chemical and physical methods (5)

2. **X-Ray Diffraction**: X-ray diffractometer, Phase identification, Calculation of lattice parameters, strain, density and grain size from x-ray diffractogram. (5)

3. **Microscopy**: Electron microscopy, Transmission electron microscope, Scanning electron microscope, Structural Characterization of materials by SEM, TEM. Atomic Force Microscopy. (8)

4. **Characterization of materials**: Experimental techniques for Optical, Electrical and Dielectric characterization of materials. (6)

5. **Heat Capacity Calorimetry:** Thermodynamics of magnetic systems; what one can learn from Heat Capacity – phase transition, lattice dimensionality, Type of Spin-Spin Interaction, Schottky Anomaly, Spin Wave Excitation, Magnetocaloric effect; Differential Scanning Calorimeter (DSC), Adiabatic Calorimeter, AC Calorimeter, Dilution Refrigerator, PPMS; Examples. (6)

6. **Magnetic Measurements**:

   - **Force Methods** – Gouy Method, Faraday Method and Alternating Force Magnetometer (AFM);
   - **Induction Methods** – AC Induction, Vibrating Sample Magnetometer (VSM), Superconducting Susceptometer (SQUID); Measureable Parameters; Calibration Materials; Examples. (6)

7. Mössbauer Spectroscopy: Theory of Mössbauer Effect, Debye-Waller factor, Lamb-Mössbauer factor, hyperfine interaction parameters (isomer shift, quadrupole shift, quadrupole splitting); Applications in Spin Transition Materials, Magnetic Materials; Examples. (6)

8. **Spectroscopic Techniques:** (18)

   - Ultraviolet-Visible Spectroscopy
   - Infrared Spectroscopy
   - Raman Spectroscopy
   - Positron Annihilation Spectroscopy:

Unit 102D: Electronics

Marks - 100, Credit Points - 8, Lectures - 60

Group-A, Theory (Marks -70, Lectures40)

1. **Scattering matrix formulation of a microwave network:** Calculation of scattering matrix for the following passive microwave components: section of a transmission line, circulator, 3-dB power divider, directional coupler, Magic Tee (8)

2. **Basics of optical Communication**: (15)

    - optical modulation and detection
    - fast optical modulator and wideband photodetector
    - optical transport of electrical signals. Optical generation of mm-wave signals
    - generation of optical comb
    - high repetition rate, short optical pulse generation.

3. **Interfacing**: Transducers - temperature-voltage, humidity-voltage, strain-voltage, displacement- voltage, etc. (4)

4. **Converters:** Analog-Digital and Digital-Analog converters: resolution and speed with simple architectures. (4)

5. **Control**: Mechanical actuator-servo motor and stepping motor-piezoelectric actuators for fine control (4)

6. **Inter-computer-communication**: RS232C, USB, IEEE-488 GPIB, Ethernet (5)

Group-B, Experiments (Marks-30, Lectures-20)

1. **Simulate and study using Pspice:**
    - V-I characteristics of a BJT
    - Frequency response of Transistor amplifier in CE configuration
    - Active Load, Darlington pair
    - Integrator and differentiator using OP-AMP
    - Integrated circuit

2. **Design of circuits using VLSI trainer kits:**

    Karnaugh simplification of arbitrary truth tables, implementation on FPGA and CPLD; implementation of flip-flops, counters, registers on FPGA and CPLD.

Unit 102E: Laser Physics & Quantum Optics

Marks - 100, Credit Points - 8, Lectures - 60

1. **Coherent states and squeezed states of the radiation field:** Light waves as classical harmonic oscillators, phasor diagrams and field quadratures, vacuum fields, coherent states, shot noise and number phase uncertainty, squeezed states, quantum noise in amplifiers, operator solution of the harmonic oscillator, number state representation, photon number states (15)

2. **Non-classical properties of radiation field:** Photon-counting statistics, Wigner function and its properties, different types of photon statistics, theory of photo detection, intensity interferometer, Hanbury Brown-Twiss experiments and classical intensity fluctuations, second order correlation function, photon bunching and anti-bunching, single photon sources. (15)

3. **Atom-photon interaction:** Two-level atom, coherent superposition states, density matrix, time-dependent Schrodinger equation, weak field limit, Einstein's B-coefficient, strong field limit, Rabi oscillaton, phenomenological damping. (10)

4. **Cold atoms:** Laser cooling: basic concept of Doppler cooling, optical molasses, sub-Doppler cooling, magneto-optical trap, experimental realization, ion-trapping – basic ideas, Bose-Einstein condensation. (10)

5. **Review of semiconductor laser:** Principle of operation, homojunction and double-heterostructure lasers, quantum well lasers, distributed feedback and distributed Bragg reflector lasers, vertical-cavity surface emitting lasers, applications – external cavity diode laser systems, frequency tuning mechanisms, application in spectroscopy. (10)

References:

1. Quantum Optics – An Introduction *by* Mark Fox (Oxford University Press).

2. Elements of Quantum Optics *by* P Meystre and M Sargent II (Springer)

3. Optical Coherence and Quantum Optics *by* L. Mandel and E. Wolf (Cambridge University Press).

4. Principles of Lasers *by* O. Svelto (Springer International Edition).

5. Laser Fundamentals *by* William T. Silfvast (Cambridge University Press).

6. Laser Spectroscopy – Basic Concepts and Instrumentation *by* W. DemtrÖder (Springer International Edition).

Unit 102F: Nuclear Physics

Marks - 100, Credit Points - 8, Lectures - 60

1. **Nuclear Model I**: Two body force, infinite nuclear matter, effective interactions (pairing + quadrupole, Skyrme etc.); single particle motion, shell model with configuration mixing, Nilsson model, Strutinsky and shell corrections. [8]

2. **Nuclear Model II**: Liquid drop model and collective motion, rotation and vibration with particle coupling, Cranking models, Hartree-Fock models, Hartree-Fock Bogoliuobov and quasi particles, pairing and BCS equations. [8]

3. **Nuclear Reactions**: Kinematics, Optical model of elastic scattering, direct and compound nuclear reaction, inelastic scattering and transfer reactions and their descriptions in Distorted-waves Born Approximation and in coupled channels formalism, resonances, break-up reactions. [8]

4. **Heavy Ion Reactions**: Special features of heavy ions scattering (Q- and L-window), semi classical models, deflection functions, quasi elastic and transfer reactions, deep inelastic scattering, complete and incomplete fusion, fission. [8]

5. **Detectors**: Energy loss of charged particles in matter; range and straggling, energy, position and time detection for charged particles with solid state detectors; gas detectors - ionization chamber, multi-wire proportional counter; interaction of radiation with matter, semi-conductor gamma detector, scintillation detector, micro-channel plates; particle identification techniques and time of flight; data reduction and error analysis, engineering drawing. [10]

6. **Accelerator Physics**: Beam optics and beam transport, ion sources; electrostatic accelerators - Cockroft-Walton, Van de Graaff, principle of tandem pelletron; pulsed accelerators - cyclotron, synchrotron, radio-frequency linear accelerators LINAC; radio-frequency quadrupole, drift tube Linac, storage rings - future trends, applications of accelerators. [8]

7. **Nuclear Electronics**: NIM, CAMAC & VME standards; general instrumentation, measurement of voltage, current, charge, frequency etc, timing measurement, leading edge and constant fraction discriminators, coincidence measurement, gates, time-amplitude converter, analog-digital conversion, pulse height analysis, digital signal processing, computations for nuclear experiments, data acquisition system. [10]

Unit 102G: Particle Physics

Marks - 100, Credit Points - 8, Lectures - 60

Field Theory: *Lectures 30, Marks 40*

1. **Introduction:** Concept of fields and field quanta, various kinds of fields and their characteristics, inadequacies of quantum mechanics and the necessity of field theory.

2. **Second Quantization:** concept of second quantization and Field operators, Quantization of real scalar field, complex scalar field, Dirac Field and Electromagnetic field; normal ordering, time ordered product, Wick's theorem.

3. **Interacting Quantum Fields**: Lagrangian formalism, concept of Feynman diagrams and rules, two-body scattering processes: electron-muon, Moeller, Bhabha, Compton; introduction to re-normalization.

4. **Gauge Theory**: Local and Global gauge transformations and their corresponding symmetry properties.

Particle Physics: *Lectures 20, Marks 30*

1. **Introduction:** Fundamental Forces, classification of particles, elementary particles

2. **Quark Model**: Isospin and strangeness, baryon and meson multiplets, concept of color; symmetry breaking; Gell-Mann-Okubo mass formula; constituent quark model – construction of wave function of hadrons, mass and magnetic moments of hadrons.

3. **Standard Model**: Spontaneous symmetry breaking and Higgs mechanism; Standard Model of electroweak interaction; weak decays; fermion mass.

4. **Beyond the Standard Model**: Unification of strong, weak and electromagnetic interaction gauge coupling unification, proton decay – implication and experimental status; hierarchy problem and supersymmetry; dark matter, R-parity.

5. **Current experiments:** LHC and Tevatron experiments, Neutrino experiments

Experimental Techniques for Particle Physics: *Lectures 10 Marks 20*

1. **Interaction of particles with matter:** Energy loss by EM interactions in matter – quantum treatment of the energy loss, fluctuations in energy loss; specific cases of electrons, positrons and photons; energy loss by hadrons, radiation length and interaction length

2. **Basic Particle Detectors:** Gaseous detectors - proportional chambers, multi-wire proportional chambers, drift chambers, resistive plate chambers; scintillation detectors - organic and inorganic; semiconductor detectors; Photon multiplication devices

Unit 103: Review Work in the Relevant Field of Research

Marks - 100, Credit Points - 8

The student will submit, after consultation with the supervising faculty member, a written review of his/her field of research work and make a public oral presentation.

Dissertation: 60, Presentation: 20, Viva Voce: 20