Ph.D. COURSE WORK

Ph.D. students at SNBNCBS are required to do course work as mandated by UGC. Relevant points from 2016 regulations of UGC are quoted below. They are also required to take additional courses as stipulated by SNBNCBS as outlined in the section 'PhD Course Work – Current Session'.

University Grants Commission (Minimum Standards and Procedure for Award of M.PHIL./PH.D. Degrees) Regulations, 2016

Course Work: Credit Requirements, number, duration, syllabus, minimum standards for completion, etc.

6.1. The credit assigned to the Ph.D. course work shall be a minimum of 08 credits and a maximum of 16 credits.

6.2. The course work shall be treated as prerequisite for Ph.D. preparation. A minimum of four credits shall be assigned to one or more courses on Research Methodology which could cover areas such as quantitative methods, computer applications, research ethics and review of published research in the relevant field, training, field work, etc. Other courses shall be advanced level courses preparing the students for Ph.D. degree.

6.3. All candidates admitted to the Ph.D. programme shall be required to complete the course work as advised by their supervisors during the initial one or two semesters.

6.4. A Ph.D. scholar has to obtain a minimum of 55% of marks or its equivalent grade in the UGC 7-point scale (or an equivalent grade/CGPA in a point scale wherever grading system is followed) in the course work in order to be eligible to continue in the programme and submit the dissertation/thesis.

PhD Course Work – Current Session

Uniform Course Structure is being formulated for all PhD scholars. The course guideline is as follows:

(i) External course requirement: As per UGC requirement, one subject is to be chosen from the list of courses approved by the University.

(ii) Internal course requirement: As per Centre's requirement, one subject is to be chosen from the approved courses by the Centre from time to time.

(iii) The scholars have to fulfill the above mentioned criteria [(i) & (ii)] which is mandatory for upgradation as Senior Research Fellow.

(iv) All JRF students including IPhD students are required to take one Centre's required course.

(v) The Centre's required courses cannot be one of IPhD semester I or II courses. However they can be one of IPhD semester III or IV courses, and any of the departmental courses that are atleast of the III Semester IPhD level.

(vi) Supervisors may however advise their PhD students to audit some of the IPhD semester I or II courses if necessary.

* Future updates regarding internal courses will be notified in our website from time to time.

Ph.D. PROGRAMME IN PHYSICAL SCIENCES

COURSE STRUCTURE & SYLLABUS

List of courses approved by the University

L=Lectures T=Tutorials P=Practicals in hours per week & C=Credit points

Course No.	Course Title	L	T	P	C
PHY 601	Research Methodology	4	-	-	4
PHY 602	Review of the topical Research	4	-	-	4
PHY 603 / 503	Condensed Matter Physics	4	-	-	4
PHY 604 / 504	Astrophysics	3	1	-	4
PHY 605 / 505	Quantum Physics (Application)	3	1	-	4
PHY 606	Computational Methods in Physics	3	1	-	4
PHY 607 / 507	Nuclear & Particle Physics	4	-	-	4
PHY 608	Classical Mechanics & Electromagnetism	4	-	-	4
PHY 609	Numerical Methods				
PHY 610 / 510	Mathematical Methods	3	1	-	4
PHY 611	High Energy Astrophysics around compact stars	4	-	-	4
PHY 614 / 514	Statistical Physics	3	1	-	4
PHY 616 / 516	Advanced Condensed Matter Physics I – Magnetism & Superconductivity	4	-	-	4
PHY 618 / 518	Non-Linear Dynamics	3	1	-	4
PHY 620 / 520	Optical Physics	3	1	-	4
PHY 622 / 522	Advanced Condensed Matter Physics II – Correlated Electrons & Disorder	4	-	-	4
PHY 624 / 524	Quantum Information Theory	3	1	-	4
PHY 626 / 526	Theory of Elementary Particles	3	1	-	4
PHY 628 / 528	Mesoscopic Physics	3	1	-	4
PHY 630 / 530	Soft Matter	3	1	-	4
PHY 632 / 532	General Relativity & Cosmology	3	1	-	4
PHY 691	Project Research (Semester - I)	-	-	8	8
PHY 692	Project Research (Continued in Semester - II)	-	-	8	8
	Total hours of contact per week	*16*			
	Total credits	*16*			

* The syllabi of the courses starting with Course Code No. 5XX are available in IPhD Course Curriculum. The syllabi for Courses with Code No. 6XX will include the syllabi of Courses with Code No. 5XX plus additional special/advanced topics that will be decided by the concerned teachers.

AMITABHA LAHIRI
SENIOR PROFESSOR & DEAN (ACADEMIC PROGRAMME)
S N BOSE NATIONAL CENTRE FOR BASIC SCIENCES

COURSE DESCRIPTION IN OUTLINE

PHY 601. RESEARCH METHODOLOGY: 4-0-0-4

1. Define Research and Methodology; Types of research methods available; Describe Experiments, Theory and Computation/ Simulation in general terms; Spell out explicitly (with a few examples) the connection among them.

2. Define Library Research, Field Research and Laboratory Research; Explain Sample Survey, Sample Collection and/or Preparation, Data Analyses, Hypothesis, Modeling, Interpretation, and Conclusion.

3. Error in Data Analyses and Ways to Report Error; Statistical Analyses of Collected Data; Importance of Error Analyses in Experimental/Numerical Study. Validity, Reliability and Reproducibility of Measured/Acquired Data.

4. Accuracy and Precision in Measurements/ Predictions. Selectivity and Specificity of a Method Developed; Generalization and External Validity; Internal Validity and Inter-relationship between measurements and the underlying theory/hypothesis.

5. Formulation of a Research Problem: Motivation, Induction, Hypothesis, Deduction, Observation and Conclusion

6. Scientific Reporting of Data/Observation/Prediction; Difference between Magazine or Newspaper Reporting, and Science Journal Reporting; Expression Skill Development and Nurturing.

7. Plagiarism – Self and External. Ethics, Attitude, Discipline and Holistic Approach to Research; Implication of Research Tenure on Personality Development. Importance of Focus, Challenge and Self-belief in Research.

8. Research and Society – Coupling and Necessary Aloofness. Relevance to "Old fashion" Indian Philosophy of High Thinking. Basic Scientific Research, Translational Research, Technology Development and Elements of Commerce.

9. Specific Experimental, Theoretical and Simulation Techniques for Decoding the Systems Around; Interconnection Between Theory and Experiments. Computer Languages Necessary for Machining a Scientific Problem, and Relevant Data Collection; Examples of a few commercially available software; Popular Numerical Techniques and Libraries (For example, MATLAB).

PHY 602. REVIEW OF THE TOPICAL RESEARCH: 4-0-0-4

Goal of the review – History of the subject – development of the subject: theoretical and experimental – alternative models and theories – pros and cons of various models and theories if any – the relevance of the topical research from the perspective of the subject – Possible ways to develop the research topic further.

PHY 603. CONDENSED MATTER PHYSICS: 4-0-0-4

- Binding and cohesion in solids. Bonds and bands.
- Crystal Structure, X-ray Diffraction, Reciprocal Lattice.
- Periodic potentials, Bloch's Theorem, Kroning Penney Model, Free electrons and nearly free electrons; tight binding approximation.
- Elementary ideas of band structure of crystalline solids.
- Concept of holes and effective mass; density of states; Fermi surface; explanation of electronic behaviour of metals, semi-conductors and insulators.
- Lattice vibrations, harmonic approximation, dispersion relations and normal modes, quantization of lattice vibrations and phonons. thermal expansion and need for anharmonicity.
- Transport properties of solids. Boltzmann transport equation. Wiedemann-Franz law. Hall effect.
- Superconductivity: Phenomenology, penetration depth, flux quantization etc. Josephson effect.
- Semiconductors: intrinsic and extrinsic, carrier mobility etc.
- Thermal properties of solids.
- Magnetism in solids.
- Optical and Dielectric Properties.

Dekker, Solid State Physics
Kittel, Introduction to Solid State Physics
Ashcroft and Mermin, Introduction to Solid State Physics.
Ziman, Principles of the Theory of Solids.

PHY 604. ASTROPHYSICS: 4-0-0-4

Basic Background and Instrumentations: Elecmentary radiative transfer equations, absorption and emission, atomic processes, continuum and line emission, Optical and radio telescopes, Fourier Transform methods, detectors and image processing, Distance measurements in astronomy, Hubble's law, modern observational techniques.

Spectral Classifications of Stars: Saha's equation, Harvard system, Luminosity effect, Absolute and apparent luminosity relation, spectroscopic parallax

Evolution of Stars: Observational basis, protostars, disks, bipolar outflows, hydrostatic equilibrium, Sources of stellar energy, Gravitational Collapse, Fusion reactions (p-p) chain, CNO Cycle, triple alpha reactions, formation of heavy elements, Hertzsprung-Russell diagram, evolution of lowmass and high mass stars, Chandrasekhar limit, Pulsars, neutron stars and black holes

The Sun: Different layers of the Sun and their properties, Solar cycles, sunspots, solar corona and solar winds, expected and observed solar neutrino spectra, Possible resolution of the solar neutrino problem.

Binary Stars: Different types of binary stars, Importance of binary systems, Accretion, spectral properties of radiations from accretion flows and identification of black holes and neutron stars.

Galaxies: Formations and classification, Density Wave Theory of the formation of spiral arms, Rotation curves, missing mass and dark matter, Quasars and active galactic nuclei magnetic fields in the galaxy.

Cosmic Rays: Extensive air shower and Fermi's theory of high energy cosmic rays; Interaction of high energy cosmic rays with the CMBR background and the GZK cutoff, Cosmic ray experiments like HiRes, AGASA, Pierre Augur Observatory.

1. *M. Zeilik and S.A. Gregory, Introductory Astronomy and Astrophysics*
2. *B. Basu, An Introduction to Astrophysics*
3. *Radiative processes in Astrophysics: G. Rybicki and A. Lightman*
4. *Accretion Power in Astrophysics, J. Frank*
5. *Physics of Astrophysics – F. Shu*
6. *General relativity with Application to Astrophysics: N. Straumann*

PHY 605. QUANTUM PHYSICS (FORMAL): 4-0-0-4

The formal structure of quantum mechanics, Schroedinger equation, matrix formulations, application to simple systems, angular momentum, perturbation theory, variational techniques, and WKB approximations.

R. Shankar, Quantum Mechanics
L.D Landau and E. M Lifshitz, Course of Theoretical Physics

PHY 606. COMPUTATIONAL METHODS IN PHYSICS: 3-1-0-4

Introduction to Fortran programming and basic numerical methods will be imparted to the students through lectures and projects based on the numerical analysis of elementary physical problems illustrating such techniques.
This course will involve lectures on advanced numerical techniques and projects based on the numerical analysis of advanced physical problems illustrating such techniques.

PHY 607. NUCLEAR & PARTICLE PHYSICS: 3-1-0-4

General properties of nuclei: 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. [4 lecture hours]

Particle accelerators: Pelletron, tandem principle, Synchrotron and synchrosyclotron, colliding beams, threshold energy for particle production. [4 lectures]

Two-body bound state: Properties of deuteron, Schr ¨odinger 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.
[4 lecture hours]

Two-body scattering: 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. [6 lecture hours]

Nuclear structure: Liquid drop model, Bethe-Weizs ¨acker binding energy/mass formula, Fermi model, Shell model and Collective model. [6 lecture hours]

Nuclear reactions and fission: 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. [6 lecture hours]

Radio Active Decays: Alpha decay, Beta decay –Energy release in beta decay–Fermi theory of beta decay–Shape of the beta spectrum –decay rate Fermi-Curie plot–Fermi & G.T Selection rules – Comparatives half-lives and forbidden decays – Gama decay-Multi pole radation – Angular momentum and parity selection rules – Internal conversion – Nuclear isomerism. [8 lecture hours]

Elementryparticle Physics: Types and characteristics of interaction between elementary particles–Hadrons and laptons–Symmetry and conservation laws – CPT theorem– Gell-Mann-Nishijima formula-classification of hadrons –Quark model - symmetry classification of elementary particles- Parity non-conservation in weak interaction. Relativistic kinematics.
[10 lecture hours]

Suggested Books:

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

PHY 608. CLASSICAL MECHANICS & ELECTROMAGNETISM: 4-0-0-4

Lagrangian treatment, Variational principle, Hamiltonian structure, Canonical transformations, Hamilton Jacobi theory, Spatial relativity, Electromagnetism from a least action principle, potential theory, retarded and advanced potentials, waves.

H. Goldstein, Classical Mechanics
J. D Jackson, Electrodynamics

PHY 609. NUMERICAL METHODS: 3-1-0-4

Basic programming in Fortran, Numerical methods of finding roots of an equation (Bisection method, Newton's method), Numerical methods of solving set of linear equations(Gauss elimination method, Thomas method), Numerical method of integration (Gregory-Newton expansion, Trapezoidal rule, Simpson's rule),Numerical method of differentiation, Numerical method of solving differential equation (Euler's method, Runge-Kutta method).

In addition to the above, some lectures at a more advanced level will be offered.

1. Programming in FORTRAN by Rajaraman.
2. Numerical Recipe by Press, Shapiro and Teukolski
3. Numerical methods for Scientists and Engineers by HM Antia

PHY 610. MATHEMATICAL METHODS – I: 3-1-0-4

- Vector analysis, Green, Gauss and Stokes theorems.
- Linear vector spaces and linear operators. Matrices & eigenvalue problem.
- Theory of complex variables, Cauchy-Riemann conditions, Cauchy integral theorem, Taylor- Laurent expansion, classification of singularities, analytic continuation, theorem of residues and evaluation of definite integrals and series.
- Ordinary differential equations and series solution. Sturm-Liouville problem and orthogonal functions, special functions.
- Green's functions for self-adjoint differential operators and eigenfunction expansion. (Laplace, Poisson, Diffusion, Wave equation etc to be discussed).

In addition to the above, some lectures at a more advanced level will be offered.

G. Arfken, Mathematical Methods for Physicists
I.N. Sneddon, Special Functions of Mathematical Physics & Chemistry
P.K. Chattopadhyay, Mathematical Physics
E. Kreyszig, Advanced Engineering Mathematics
Mathews and Walker, Mathematical Physics
P. Dennery & A. Kryzwicki, Mathematics for Physicists
C.M. Bender & S.A. Orszag, Advanced Mathematical Methods for Scientists & Engineers
E. Butkov, Mathematical Physics
R.W. Churchill & J.W. Brown, Com

PHY 611. HIGH ENERGY ASTROPHYSICS AROUND COMPACT STARS: 4-0-0-4

Astrophysics of compact stars: Black Holes, Neutron Stars and White Dwarfs;
Accretion processes on these objects: Transonic Flows, Outflows and origin, acceleration and collimation of jets; Radiative Properties of the accretion flows; Observational Evidence for compact stars.
Data Analysis: Observations of high energy radiation from compact objects; satellite data and their analysis

1. *Accretion Power in Astrophysics - J. Frank*
2. *Theory of Transonic Astrophysical Flows – S. K. Chakrabarti*
3. *Accretion Processes in Astrophysics – (Physics Reports) S.K. Chakrabarti*
4. *Black Holes, Neutron Stars and White Dwarfs: Physics of Compact Objects by Shapiro and Teukolsky*

PHY 614. STATISTICAL PHYSICS: 3-1-0-4

Foundations, micro-canonical, canonical and grand canonical ensembles, non-interacting systems, interacting systems, phase transitions, quantum statistics, BEC, Quantum Hall, magnetism, superconductivity.

PHY 616. ADVANCED CONDENSED MATTER PHYSICS I

– MAGNETISM & SUPERCONDUCTIVITY: 4-0-0-4

Generalized Hamiltonian of Condensed Matter Physics and origin of various "effective theories"; Introduction to phenomenon of Superconductivity; Experimental features; Various phenomenological theories; Cooper's one pair problem; Gateway to microscopic theories---BCS Fermion pairing theory and BSB Bose Condensation theory; BCS ground state; Mean field treatment of BCS Hamiltonian; Gap equation and its solution; Equation for critical temperature; Brief applications of BCS theory to various experiments; Brief introduction to exotic phenomena like interplay of superconductivity and magnetism, high temperature superconductivity etc.

In addition to the above, some lectures at a more advanced level will be offered.

(i) "Theory of Superconductivity" by J.R. Schrieffer.
(ii) "Solid State Physics" by N. Ashcroft and N.D. Mermin.
(iii) "Introduction to Solid State Physics" by C. Kittel.
(iv) "Quantum Theory of Solids" by C. Kittel.
(v) "Quantum Theory of Many Particle Systems" by G.D. Mahan.
(vi) "Elementary Excitations" by D. Pines

PHY 622. ADVANCED CONDENSED MATTER PHYSICS II
– CORRELATED ELECTRONS & DISORDER: 4-0-0-4

- **Physics of Materials:**

Metals (M) and Insulators (I)
A. BAND INSULATORS vs CORRELATED INSULATORS
- Breakdown of independent electron description
- Mott transition
- Hubbard model
- Limiting cases of Hubbard models - band limit & atomic limit, Hubbard sub-bands
- Mott transitions in transition metal oxides
- Mott insulators & charge transfer insulator, Zaanen-Sawatzky-Allen classification

B. LARGE-U LIMIT
- Canonical transformation
- t-J model, Super-exchange
- Half-filled band : Heisenberg spin model
- Antiferromagnetic Heisenberg model : spin waves, strange world of D=1

C. SOME INTERESTING SYSTEMS
- Band-width-control M-I transition systems: V2O3, RNiO3, NiS etc
- Filling control M-I transition systems: R_{1-x}A_{x}Ti(V)O3
- High Tc super-conducting cuprates
- Quasi one-dimensional systems: Cu-O chain & ladder compounds
- Double-exchange systems: R_{1-x}A_{x}MnO3

D. DISORDER INDUCED INSULATORS
- Anderson Localization
- Scaling theory
- Electron-electron interaction & disorder

References:

1. Patrik Fazekas -- Lecture notes on Electron Correlation & Magn.
2. Imada, Fujimori, Tokura -- Metal-Insulator Transitions, Review. Mod. Phys. vol 70, pg 1039 (1998)
3. P.A. Lee & T.V. Ramakrishnan -- Disordered electronic system, Review. Mod. Phys. vol 57, pg 287 (1985)
4. Fulde -- Electron correlation in Molecules and Solids

- **Electronic Structure of Materials**

A. BASICS
1. Electrons in periodic potentials
- Bloch's theorem
- Kronig-Penney model
- concept of energy bands

2. Density of states
- Green's function
- Tridiagonal matrices & Continued fractions
- Singularities in DOS

3. Reciprocal lattice & Brillouin zone
- Special k-points in BZ sampling

<u>B. EL-ION PROBLEM</u>
4. Adiabatic approximation (Born-Oppenheimer).
5. Classical nuclei approximation (Ehrenfest Theorem).
6. Hellman-Feynman force on nuclei.
<u>C. MANY-ELECTRON PROBLEM</u>
7. Hartree approximation
- LCAO method
8. Hartree-Fock approx.
- Slater-determinantal wavefunction & its properties
- Hartree-Fock equation
- Fock operator
- Energy of the groundstate
- Koopman's theorem
9. Going beyond Hartree-Fock (introductory)
- Absence of correlation in H-F theory
- Basics of MCI and Perturbative (Moller-Plesset) methods
10. Density Functional Theory
- Energy as a functional of density : basic concepts
- Thomas-Fermi theory
- Hohenberg-Kohn Theorem
- Kohn-Sham Eqn.
- LDA for the exchange-correlation function
<u>D. MOLECULAR DYNAMICS METHODS IN ELECTRONIC STRUCTURE</u>
11. Introduction to MD methods
- Deterministic vs. Stochastic methods
- Connection to statistical mechanics & thermodynamics
- Finite difference algorithms for solving eqns. of motion
- running and controlling MD simulations
- Limitations & errors in MD simulation
12. Tight-binding MD
- Eqn of motion in TB-MD
13. Ab-initio (Car-Parrinello) MD
- Basic concepts and effective Lagrangian
- Eqn of motion
- Iterative solution of Kohn-Sham eqn
<u>E. EXPERIMENTAL MANIFESTATION OF ELECTRONIC STRUCTURE</u>
- Theory of photoemission
- Core-levels and Final states
- Satellites
- Valance band
- Band structure
- Surface states and surface effects

1. Ashcroft & Mermin -- Solid State Physics
2. Grosso & Pastore-Parravicini -- Solid State Theory
3. Kaxiras -- Electronic Structure of Solids
4. Sutton -- Electronic Structure of Materials
5. Fulde -- Electron correlation in Molecules and Solids

PHY 691. PROJECT RESEARCH (SEMESTER - I)

Projects shall be taken up by students under the supervision of a Research Guide.

PHY 692. PROJECT RESEARCH (CONTINUED IN SEMESTER - II)

Continuation of the fifth semester project under the supervision of a Research Guide.

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