PHYSICAL SCIENCES

Programme Code: PHYS05

Programme Outcome:

- Advanced Theoretical Command Demonstrate an authoritative understanding of the core pillars of physics—Classical Mechanics, Quantum Mechanics, Electromagnetism, and Statistical Mechanics—alongside specialized knowledge in Relativity, Nuclear, and Condensed Matter Physics.
- Methodological and Mathematical Mastery Apply sophisticated mathematical methods and computational techniques to model complex physical systems, bridging the gap between theoretical frameworks and observable phenomena.
- Experimental Expertise and Technical Innovation Execute advanced experimental protocols through modular, semester-specific laboratories, developing the technical proficiency required to design and calibrate state-of-the-art instrumentation for physical research.
- Research Integrity and Professional Ethics Internalize rigorous research methodologies and global standards of publication ethics, ensuring that all scientific inquiries and disseminations are conducted with high transparency and academic integrity.
- Transitional Research Synthesis Synthesize coursework into a significant Master's project, demonstrating the ability to transition from structured learning to the formulation of independent, doctoral-level research questions.
- Original Doctoral Contribution and Global Impact Execute an independent, multi-year PhD thesis that generates original knowledge in physical sciences, culminating in high-impact publications and the establishment of the student as a peer in the global scientific community.

DETAILED COURSE STRUCUTRE

Note: ***L = Lecture, P = Practical, T = Tutorial.***

Semester I					
Sl. No.	**Course Code**	**Course Name**	**L-P-T**	**No of Lectures**	**Credits**
1	PHY701	Classical Mechanics	45-0-15	60	4
2	PHY702	Mathematical Methods	45-0-15	60	4
3	PHY703	Electromagnetism	45-0-15	60	4
4	PHY741	Integrated MSc-PhD Semester I experiments: Part I	30-30-0	60	4
5	PHY742	Integrated MSc-PhD Semester I experiments: Part II	-	60	4
Semester II					
Sl. No.	**Course Code**	**Course Name**	**L-P-T**	**No of Lectures**	**Credits**
1	PHY714	Statistical Mechanics	45-0-15	60	4
2	PHY715	Quantum Mechanics	45-0-15	60	4
3	PHY706	Introduction to Condensed Matter	45-0-15	60	4
4	PHY743	Integrated MSc-PhD Semester II experiments: Part I	-	60	4
5	PHY744	Integrated MSc-PhD Semester II experiments: Part II	-	60	4
Semester III					

Sl. No.	Course Code	Course Name	L-P-T	No of Lectures	Credits
1	PHY704	Special Theory of Relativity	45-0-15	60	4
2	PHY705	Atoms, Molecules and Radiation	45-0-15	60	4
3	PHY745	Integrated MSc-PhD computational Lab	30-0-30	60	4
4	****	Elective I	45-0-15	60	4
5	****	Elective II	45-0-15	60	4

Semester IV

Sl. No.	Course Code	Course Name	L-P-T	No of Lectures	Credits
1	PHY707	Nuclei and Particle Physics	45-0-15	60	4
2	PHY797	Master Project	-	-	8
3	****	Elective I	45-0-15	60	4
4	****	Elective II	45-0-15	60	4

Semester V

Sl. No.	Course Code	Course Name	L-P-T	No of Lectures	Credits
1	PHY798	MSc Project	-	-	20

Semester VI

Sl. No.	Course Code	Course Name	L-P-T	No of Lectures	Credits
1	PHY799	MSc Project	-	-	20
2	PHY800	Research Methodology and Research Publication Ethics	45-0-15	60	4

List of Elective

Sl. No.	Course code	Course Name	L-P-T	No of Lectures	Credits
1	PHY751	Special topics in quantum mechanics	45-0-15	60	4
2	PHY752	Computational Physics	45-0-15	60	4
3	PHY753	Quantum Field theory I	45-0-15	60	4
4	PHY754	Particle Physics	45-0-15	60	4
5	PHY755	Introduction to Phase Transition and Critical Phenomena	45-0-15	60	4
6	PHY760	Nonlinear Optics	45-0-15	60	4
7	PHY757	General Theory of Relativity and Cosmology	45-0-15	60	4
8	PHY758	Soft Condensed Matter	45-0-15	60	4
9	PHY759	Applied Nuclear Physics	45-0-15	60	4
10	PHY760	Quantum many-body theory – formalism	45-0-15	60	4
11	PHY761	Introduction to Mesoscopic phenomena & quantum devices	45-0-15	60	4

12	PHY762	Introduction to Quantum Optics	45-0-15	60	4
13	PHY763	Astronomy and Astrophysics	45-0-15	60	4
14	PHY764	Plasma Physics and Magneto-hydrodynamics	45-0-15	60	4
15	PHY765	Relativistic Nucleus-Nucleus collision and Quark-Gluon Plasma	45-0-15	60	4
16	PHY766	Non-equilibrium Statistical Mechanics	45-0-15	60	4
17	PHY767	Nonlinear Dynamics and Chaos	45-0-15	60	4
18	PHY768	Quantum many-body phenomena	45-0-15	60	4
19	PHY769	Special topics & techniques in quantum condensed matter theory	45-0-15	60	4
20	PHY770	Quantum Field Theory II	45-0-15	60	4
21	PHY771	Quantum Information and Quantum Computation	45-0-15	60	4
22	PHY772	Experimental High Energy Physics	45-0-15	60	4
23	PHY773	Experimental Techniques	45-0-15	60	4
24	PHY774	Introduction to Cosmology	45-0-15	60	4

COORDINATORS

Chief Coordinators:
Convener, Post-Graduate Committee of the School, Physics
(Dr Pratap Kumar Sahoo),
Chairperson of the School of Physical Sciences (Dr. Kartikeswar Senapati)

CORE COURSES CO-ORDINATORS

Course name	Coordinators	E-mail
Classical Mechanics	Dr. Nishikanta Khandai	nkhandai@niser.ac.in
Mathematical Methods	Dr. Victor Roy	victor@niser.ac.in
Electromagnetism	Dr. Joydeep Bhattacharjee	jbhattacharjee@niser.ac.in
Integrated MSc-PhD Semester I experiments: Part I	Dr. Pratap Kumar Sahoo & Prof. Subhankar Bedanta & Dr. Kartikeswar Senapati	pratap.sahoo@niser.ac.in & sbedanta@niser.ac.in & kartik@niser.ac.in
Integrated MSc-PhD Semester I experiments: Part II	Dr. Pratap Kumar Sahoo & Prof. Subhankar Bedanta & Dr. Kartikeswar Senapati	pratap.sahoo@niser.ac.in & sbedanta@niser.ac.in & kartik@niser.ac.in
Statistical Mechanics	Dr. Sumedha	Sumedha@niser.ac.in
Quantum Mechanics	Dr. Nishikanta Khandai	nkhandai@niser.ac.in
Introduction to Condensed Matter	Dr. Joydeep Bhattacharjee	jbhattacharjee@niser.ac.in

Integrated MSc-PhD Semester II experiments: Part I	Dr. Tapan Mishra	mishratapan@niser.ac.in
Integrated MSc-PhD Semester II experiments: Part II	Dr. Ajaya Kumar Nayak	ajaya@niser.ac.in
Special Theory of Relativity	Dr. Yogesh Kumar Srivastava &	yogeshs@niser.ac.in & bshamik@niser.ac.in
	Dr. Shamik Banerjee	-
Atoms, Molecules and Radiation	Dr. Chetan N. Gowdigere	chetan.gowdigere@niser.ac.in
Integrated MSc-PhD computational Lab	Dr. Subhasish Basak	sbasak@niser.ac.in
Nuclei and Particle Physics	Dr. Narayan Rana	narayan.rana@niser.ac.in
Master Project	Dr. Kartikeswar Senapati	kartik@niser.ac.in
Research Methodology and Research Publication Ethics	Dr. Pratap Kumar Sahoo	pratap.sahoo@niser.ac.in

ELECTIVE COURSES CO-ORDINATORS

Course name	name/s	emails
Special topics in quantum mechanics	Dr. Anamitra Mukherjee	anamitra@niser.ac.in
Computational Physics	Dr. Colin Benjamin	colin@niser.ac.in
Quantum Field theory I	Dr. Yogesh Kumar Srivastava	yogeshs@niser.ac.in
Particle Physics	Dr. Sanjay Kumar Swain	sanjay@niser.ac.in
Introduction to Phase Transition and Critical Phenomena	Dr. A. V. Anil Kumar	anil@niser.ac.in
Nonlinear Optics	Dr. Ashok Mohapatra	a.mohapatra@niser.ac.in
General Theory of Relativity and Cosmology	Dr. Yogesh Kumar Srivastava	yogeshs@niser.ac.in
Soft Condensed Matter	Dr. Sumedha	sumedha@niser.ac.in
Applied Nuclear Physics	Dr. Sanjay Kumar Swain	sanjay@niser.ac.in
Quantum many-body theory – formalism	Dr. V. Ravi Chanda & Dr. Anamitra Mukherjee	ravi@niser.ac.in & anamitra@niser.ac.in
Introduction to Mesoscopic phenomena & quantum devices	Dr. Colin Benjamin & Dr. Satyaprasad P Senanayak	colin@niser.ac.in & satyaprasad@niser.ac.in
Introduction to Quantum Optics	Dr. Ashok Mohapatra	a.mohapatra@niser.ac.in

Astronomy and Astrophysics	Dr. Nishikanta Khandai & Dr. Luke Robert Chamandy	nkhandai@niser.ac.in & lchamandy@niser.ac.in
Plasma Physics and Magneto-hydrodynamics	Dr. Amaresh Kumar Jaiswal	a.jaiswal@niser.ac.in
Relativistic Nucleus-Nucleus collision and Quark-Gluon Plasma	Dr. Amaresh Kumar Jaiswal & Dr. Victor Roy	a.jaiswal@niser.ac.in & victor@niser.ac.in
Non-equilibrium Statistical Mechanics	Dr. A. V. Anil Kumar	anil@niser.ac.in
Nonlinear Dynamics and Chaos	Dr. A. V. Anil Kumar & Dr. Sumedha	anil@niser.ac.in & sumedha@niser.ac.in
Quantum many-body phenomena	Dr. Kush Saha & Dr. Anamitra Mukherjee	kush.saha@niser.ac.in & anamitra@niser.ac.in
Special topics & techniques in quantum condensed matter theory	Dr. V. Ravi Chanda & Dr. Ashis Kumar Nandy	ravi@niser.ac.in & aknandy@niser.ac.in
Quantum Field Theory II	Dr. Chethan N. Gowdigere and Dr. Yogesh Kumar Srivastava	chethan.gowdigere@niser.ac.in & yogeshs@niser.ac.in
Quantum Information and Quantum Computation	Dr. V. Ravi Chandra	ravi@niser.ac.in
Experimental High Energy Physics	Dr. Prolay Kumar Mal & Prof. Sanjay Kumar Swain	prolay@niser.ac.in & sanjay@niser.ac.in
Experimental Techniques	Dr. Pratap Kumar Sahoo & Prof. Subhankar Bedanta & Dr. Kartikeswar Senapati	pratap.sahoo@niser.ac.in & sbedanta@niser.ac.in & kartik@niser.ac.in
Introduction to Cosmology	Dr. Tuhin Ghosh	tghosh@niser.ac.in

CORE COURSES

PHY701 Classical Mechanics (60 Lecture Hrs)

Coordinators: Dr. Nishikanta Khandai
nkhandai@niser.ac.in

Course Details:

- Two-body Central force problem (reduced mass), planet orbits, Virial theorem.
- Collisions and scattering, CM and lab frames, scattering cross section.
- Motion in non-inertial frames, Coriolis force.
- Principle of virtual work, constraints, D Alemberts principle.
- Generalized coordinates, velocities and momenta, Lagrange's formulation.
- Principle of list action, formulation by Maupertuls, Euler, Hamilton, Liouvilles theorem.
- Hamilton's equations, poisson brackets.
- Canonical transformation, Hamilton-Jacobi equation, Generating functions, Symetries and conservation laws.
- Small oscillations, Normal modes.
- Rigid body dynamics, Euler angles, Euler equations.

Course Outcomes:

- Students are expected to understand the basic principles of mechanics, apply them to their research field, and develop the ability to solve unknown problems encountered during their research.

References:

1. H. Goldstein - Classical mechanics
2. Morion and Thorton - Introduction to classical mechanics.
3. Landau & Lifshitz - Mechanics
4. John R Taylor - Classical Mechanics

Suggested References: Relevant research articles with updates in knowledge as decided by the instructor.

PHY702 Mathematical Methods (60 Lecture Hrs)

Coordinators: Dr. Victor Roy
victor@niser.ac.in

Course Details:

- Vectors and Tensors (index notation, vector analysis in curvilinear coordinates. Cartesian tensors and four vectors, General tensors).
- Review of Linear Algebra with emphasis on applications to physical problems (linear transformations + Matrix representations, Eigen values + Eigen Vectors, Inner product spaces).
- Review of complex analysis with applications (Cauchy-Riemann equations, Complex integration, Cauchy theorems, Contour integration, Branch points and branch cuts, Applications to integrals, series etc.)
- Hilbert Space methods, special functions (Hilbert space, Orthonormal series expansions in Hilbert space, especially Fourier series, Special functions.
- Ordinary and partial differential equations (Analysis of second order OFE's Sturm-Liouville system, Boundary value problems for Laplace, Diffusion (Heat), and wave equations)
- Integral transforms, its applications and generalized functions (Laplace and Fourier transform, Dirac delta and other generalized functions, Green's functions of ODE and PDE)
- Group theory (introduction using various groups occurring in physics, its algebra, Representation of groups, Characters)
- Probability and Statistics (probability distributions, Stochastic processes like Brownian motion, Error analysis for experiments, Statistical inference)

Course Outcomes:

- Students are expected to understand the basic principles of mathematical methods, apply them to their research field, and develop the ability to solve unknown problems encountered during their research.

References:

1. Arfken and Weber - Mathematical Methods
2. C.Harper - Mathematical methods
3. T L Chow - Mathematical method for physicists

Suggested References: Relevant research articles with updates in knowledge as decided by the instructor.

PHY703 Electromagnetism (60 Lecture Hrs)

Coordinators: Dr. Joydeep Bhattacharjee
jbhattacharjee@niser.ac.in

Course Details:

- Electrostatics in vacuum, force, field, potentials, and energy.
- Electrostatic boundary conditions and conductors.
- Solution of Laplace's equation in one, two, and three dimensions, uniqueness theorem, methods of images, separation of variables, multipole expansion.
- Dielectrics.
- Current distributions, magnetic fields and magnetostatic boundary conditions.
- Motion of charges in E & B fields, energy and momentum of electromagnetic fields.
- Maxwell's equations, EM waves and their propagation in free space and in media.
- Potential formulation, Coulomb and Lorentz gauge, radiation from an accelerated charge, dipole radiation.

Course Outcomes:

- Students are expected to understand the basic principles of electromagnetism, apply them to their research field, and develop the ability to solve unknown problems encountered during their research.

References:

1. David Griffith - Introduction to electrodynamic
2. Reitz, Milford, Christy - Foundation of electromagnetic theory
3. J. D. Jackson - Classical Electrodynamics
4. M. H Nayfeh, M. K. Brussel - Electricity and magnetism

Suggested References: Relevant research articles with updates in knowledge as decided by the instructor.

PHY741 Integrated MSc-PhD Semester I experiments: Part I (60 Lab Hrs)

Coordinators: Dr. Pratap Kumar Sahoo & Prof. Subhankar Bedanta & Dr. Kartikeswar Senapati
pratap.sahoo@niser.ac.in & sbedanta@niser.ac.in & kartik@niser.ac.in

Course Details:

- **PART I (Theory) (28 Lectures)**
  - Introduction to basic electronics equipment
  - R-L, R-C and LCR circuits.
  - Bipolar junction transistors, constant current source, constant voltage source, field effect transistors, basic differential amplifier circuit.
  - Basic of Operational amplifiers, feedback circuits and simple mathematical operations and Schmitt trigger.
  - Op-amp based differentiator, integrator and phase shift oscillator
  - Digital electronics, gates, universality of certain gates.
  - Boolean expressions, other ways of realizing logic functions.
  - Multiplexers, flip-flops and latches, counters, sequential circuits – master slave flip-flop (S-R), edge triggered flip-flops
  - Counters and Shift registers
  - DAC and ADC converting circuits and sampling rate.

- **PART II (Experiments) (14 x 2 classes)**
  - Training of using equipment and identifying components.
  - RL and RC circuits LCR circuits
  - Diode, Transistor I-V characteristics
  - Amplifier and other applications of transistors.
  - Operational amplifier circuits and mathematical operations using Operational amplifiers
  - Schmitt trigger, Comparator and active Filters using Operational amplifiers
  - Phase shift Oscillator
  - Digital circuits using GATES and Boolean operations
  - Adder and subtractor circuits using GATES
  - Flipflop circuits
  - Counter circuits
  - Shift Registers
  - Astable, monostable and bistable multivibrator using IC 555

- ADC and DAC converting circuits

Course Outcomes:

- This course provides training on electronics for physics experiments instrumentation with the necessary theory and basic training on design of circuits for lab applications.

References:

1. The art of electronics by Paul Horowitz and Winfield Hill, Cambridge University Press
2. Electronics by Allan R. Hambley, Prentice Hall
3. Electronics Fundamentals by Thomas L. Floyd, Prentice Hall
4. Introduction to Electronics by Earl Gates, Cengage Learning
5. Op-amps and linear integrated circuits by R.A. Gayakwad, Prentice Hall of India
6. Microelectronics by Millman, Grabel, McGraw-Hill

PHY742 Integrated MSc-PhD Semester I experiments: Part II (60 Lab Hrs)

Coordinators: Dr. Pratap Kumar Sahoo & Prof. Subhankar Bedanta & Dr. Kartikeswar Senapati
pratap.sahoo@niser.ac.in & sbedanta@niser.ac.in & kartik@niser.ac.in

Course Details:

- Coefficient of linear expansion by Fizeu's method
- Young's modulus of glass by Cornu's method
- Magnetic susceptibility of a paramagnetic material by Quincke's method
- Specific charge of electron (e/m)
- Magnetic Hysteresis
- Dielectric constant of different materials
- Electron spin resonance and estimation of Lande 'g' factor in DPPH and magnetic resonance with a compass
- Measurement of elementary charge by Millikan oil drop method
- Emission and absorption spectra of various elements and Absorption spectra in Iodine vapour
- Normal and Anomalous Zeeman effect and determination of Bohr magnetic moment
- Study of Hydrogen spectra (Balmer Series)
- Study of Lock-in amplifier
- Frank-Hertz experiment
- Verification of Coulomb's law / Velocity of light/Ramseur-Townsend Effect

Course Outcomes:

- This course provides training on modern physics experiments instrumentation with the necessary theory and basic training on design of circuits for lab applications.

References:

1. Lab Manuals as references as prescribed by the instructors

PHY714 Statistical Mechanics (60 Lecture Hrs)

Coordinators: Dr. Sumedha
Sumedha@niser.ac.in

Course Details:

- Review of thermodynamics, thermodynamic potentials, thermodynamic equilibrium and stability
- Gibbs distribution: Ensembles, classical and quantum free particles, systems with continuous and discrete spectrum, degenerate Fermi systems, Bose-Einstein condensation.
- Interacting system: Cluster and Virial expansions, radial distribution function.
- Introduction to response, fluctuation and noise, Einstein's formula.
- Phase transition: phenomenology of first order and continuous phase transitions, order parameters, 1D Using model, Universality and scaling, Ginzburg-Wilson theory, Spontaneous symmetry breaking.
- Fundamentals of statistical mechanics: phase space, Liouville theorem, statistical distribution theorem.
- Probability theory: Probability densities, cumulants and correlations, central limit theorem, laws of large numbers.
- Brownian motion, Langevin equation, Markov process, and Fokker-Planck equation.

Course Outcomes:

- Students are expected to understand the basic principles of statistical mechanics, apply them to their research field, and develop the ability to solve unknown problems encountered during their research.

References:

1. Kerson Huang - Introduction to statistical mechanics
2. Reif - Statistical physics
3. M. Kardar- Statistical physics of particles
4. H. E. Stanley - Introduction to phase transitions and critical phenomena

Suggested References: Relevant research articles with updates in knowledge as decided by the instructor.

PHY715 Quantum Mechanics (60 Lecture Hrs)

Coordinators: Dr. Nishikanta Khandai
nkhandai@niser.ac.in

Course Details:

- Hilbert space (states, operators, evolution)
- One dimensional problems & Harmonic oscillator, delta & periodic pots
- Bound states vs scattering states
- The central force problem
- The hydrogen atom, hard and soft sphere
- Time-independent perturbation theory, WKB approximation, variational method
- Time-dependent perturbation theory, Heisenberg and interaction representations
- Dirac equation
- Scattering theory/semi-classical theory of radiation/identical particles/ angular momentum/ path integrals

Course Outcomes:

- Students are expected to understand the basic principles of quantum mechanics, apply them to their research field, and develop the ability to solve unknown problems encountered during their research.

References:

1. R. Sankar - Principles of Quantum Mechanics
2. Cohen-Tannoudji, Diu and Laloe - Quantum Mechanics I & II
3. J. J Sakurai - Modem Quantum mechanics
4. David Griffiths - Introduction to Quantum Mechanics
5. Stephen Gasiorowicz - Quantum Physics
6. Eugen Merzbacher-Quantum mechanics
7. Bransden and C. J. Joachain - Quantum mechanics

Suggested References: Relevant research articles with updates in knowledge as decided by the instructor.

PHY706 Introduction to Condensed Matter Physics (60 Lecture Hrs)

Coordinators: Dr. Joydeep Bhattacharjee
jbhattacharjee@niser.ac.in

Course Details:

- General introduction, Drude' and Sommerfeld model
- Crystal structure; x-ray diffraction
- Cohesive energy
- Bloch's theorem; Band theory nearly free electrons; tight binding approximation; semi-classical dynamics of electrons in a band; motion of electrons in super-lattices
- Semiconductors
- Thermal properties of insulators; phonons
- Landau levels - de Haas van alphen effect and integer quantum hall effect
- Introduction to Magnetism and Superconductivity.

Course Outcomes:

- This is the first course in condensed matter physics and draws on quantum and statistical mechanics to provide a foundation in basic concepts and techniques required to tackle advanced courses in the area of solid state physics.

References:

1. Introduction to Solid State Physics by C. Kittel
2. Solid State Physics by N. Ashcroft and N. D. Mermin,
3. Solid-State Physics by M. N. Rosenberg
4. Solid State Physics by G. Burns

PHY743 Integrated MSc-PhD Semester II experiments: Part I (60 Lab Hrs)

Coordinators: Dr. Tapan Mishra
mishratapan@niser.ac.in

Course Details:

- Basics of Geiger Muller counter: Characteristics and counting statistics
- Application of GM counter (range of beta particles, attenuation of Bremsstrahlung, half-life measurement)
- Rutherford Alpha scattering
- Gamma Ray spectroscopy
- Compton Scattering
- Gamma-Gamma coincidence
- Photomultiplier tube characteristics
- Interfacing with pocket Geiger detectors and Arduino
- Microcontroller boards (Raspberry pi pico), writing interfacing code and nuclear instrumentation using detectors with silicon photomultipliers

Course Outcomes:

- This course provides training on nuclear physics experiments and basic training on design of instrumentations for lab applications.

References:

5. Lab Manuals as references as prescribed by the instructors

PHY744 Integrated MSc-PhD Semester II experiments: Part II (60 Lab Hrs)

Coordinators: Dr. Ajaya Kumar Nayak
ajaya@niser.ac.in

Course Details:

- Estimation of resistance in metals and semiconductors, two probe and four probe methods, Resistivity as a function of temperature, PID controller and estimation of band gap
- Measurement of indirect and direct band gap of semiconductors with UV-Vis spectroscopy
- Phonon vibrations, realization of monoatomic and diatomic lattices with inductors and capacitors
- Measurement of Hall voltage in p-type and n-type Ge, Hall voltage as a function of temperature in p type Ge, Types of charge carriers, mobility and concentration of charge carriers
- Estimation of Resistance in presence of magnetic field strength (Magneto-resistance) in semi metals and semiconductors
- Study of Paraelectric-Ferroelectric phase transition to determine Curie temperature
- Study of Antiferromagnetic to Paramagnetic phase transition to determine Neel temperature
- I-V and C-V solar cell characteristics
- Instrumentation using Hall sensor, photodiode, phototransistor, strain guage and sound sensors with SEELab3 (versatile multi-purpose measurement hardware tool) along with data collection, control and feedback using SEELab3 by writing code with python language

Course Outcomes:

- This course provides training on advanced physics experiments and basic training on design of instrumentations for lab applications.

References:

1. Lab Manuals as references as prescribed by the instructors

PHY704 Special Theory of Relativity (60 Lecture Hrs)

Coordinators: Dr. Yogesh Kumar Srivastava & Dr. Shamik Banerjee
yogeshs@niser.ac.in & bshamik@niser.ac.in

Course Details:

- Review of Newtonian Mechanics. Special theory of relativity. prelude to general relativity, historical developments
- 4-Vectors and 4-tensors, examples from physics
- Principle of Equivalence, Equations of motion, gravitational force
- Tensor analysis in Riemannian space, Effects of gravitation, Riemann-Christoffel curvature tensor, Ricci Tensor, Curvature Scalar
- Einstein Field Equations, Experimental tests of GTR
- Schwarzschild Solution, gravitational lensing
- Gravitational waves: generation and detection
- Energy, momentum and angular momentum in gravitation
- Cosmological principle, Robertson-Walker metric, Redshifts
- Big-Bang Hypothesis, CMB
- Issues in Quantum gravity

Course Outcomes:

- This course teaches the students advanced concepts and methods in general relativity crucial for the stu- dent for building their background for research work in general relativity and cosmology.

References:

1. A first course in General Relativity by Bernard Schutz
2. Gravity by James B. Hartle
3. The Classical Theory of Fields by L. D. Landau and E. M. Lifshitz
4. Gravitation and Cosmology by Steven Weinberg
5. Introducing Einstein's Relativity by Ray D'Inverno
6. General Relativity by P. Dirac

PHY705 Atoms, Molecules and Radiation (60 Lecture Hrs)

Coordinators Dr. Chetan N. Gowdigere
chetan.gowdigere@niser.ac.in

Course Details:

- Addition of angular momenta and Clebsch-Gordan coefficient; Scalar, vector and irreducible tensor operators; Wigner-Eckart theorem
- The Schrödinger equation for one-electron atoms; The eigenfunctions of the bound states in spherical and parabolic coordinates; Fine and Hyperfine structure of one-electron atoms; Interaction of one-electron atoms with external electric and magnetic fields (Stark and Zeeman effect)
- Interaction of one-electron atoms with electromagnetic radiation; The dipole approximation, selection rules; Spontaneous and stimulated emissions, stimulated absorption; Lifetimes of excited states; Line shapes and widths (Pressure broadening, Doppler broadening etc)
- The Schrödinger equation for two-electron atoms, Para and ortho states; Spin wave functions and role of Pauli exclusion principle; Ground and excited states of two-electron atoms; Doubly excited states of two-electron atoms
- The H2 Molecule; Molecular Orbital Approximation; Electronic States of Diatomic Molecules; Electronic Angular Momenta, Electron Spins, Multiplicity and Fine Structure Splitting; Rotation and Vibration of Diatomic Molecules; The Born-Oppenheimer Approximation; The Influence of the Electron Motion; Vibrations of Diatomic Molecules.
- Experimental Techniques in Atomic and Molecular Physics; Basic Principles of Spectroscopic Techniques; Spectroscopic Instruments such as Spectrometers, Interferometers and Detectors, Infrared Spectroscopy, Absorption Spectroscopy, Raman Spectroscopy; Time-Resolved Measurements of At- oms and Molecules such as Lifetime Measurements and Fast Relaxation Processes in Atoms and Molecules. (Optional)

Course Outcomes:

- Important topics in atomic physics, selection rules, atomic and molecular spectroscopy are taught. The training is imperative to work in the area of applied solid state physics and optics.

References:

1. Elementary Atomic Structure by G. K. Woodgate
2. Atomic Physics by C. J. Foot
3. Atoms, Molecules and Photons by W. Demtroeder
4. The Theory of Atomic Spectra by E. U. Condon and G. H. Shortley
5. Topics in Atomic Physics: C. E. Butkhardt and J. L. Leventhal
6. Physics of Atoms and Molecules by B.H. Bransden and C. J. Joachain

PHY745 Integrated MSc-PhD computational Lab (60 Lab Hrs)

Coordinators Dr. Subhasish Basak
sbasak@niser.ac.in

Course Details:

- Introduction to C/C++ or Python
- Representation of numbers on the computer, integers and floating point number, finite precision
- Statistical description of data: Mean, Variance etc. Statistical inference, Error propagation
- Curve fitting : Introduction to least squares, Straight line fitting, General linear and non-linear function fitting
- Numerical Differentiation
- Numerical Integration
- Random number generators and random walk
- Differential equations - Euler and Runge Kutta methods
- Introduction to solving Partial Differential Equations
- Finding roots of polynomials and transcendental equations
- Minimisation of functions - golden section search, multivariable minimisation, gradient descent, conjugate gradient methods for quadratic and general functions
- Solving system of linear equations using matrix algebra
- Fast Fourier Transforms
- Monte Carlo – Markov chain, Metropolis algorithm, Ising Model

Course Outcomes:

- The course provides a basic training in numerical and statistical methods used in all branches of physics through programming and hands-on tutorial sessions.

References:

1. Learning Python, 5th Edition by Mark Lutz, O'Reilly Publications
2. The C++ Programming Language 4th Edition by Bjarne Stroustrup, Addison-Wesley Professional
3. An Introduction to Computational Physics by Tao Pang, Cambridge University Press
4. A Guide to Monte Carlo Simulations in Statistical Physics, by David P. Landau and Kurt Binder, Cam- bridge University Press.
5. Numerical Recipes in C++: The Art of Scientific Computing by William H. Press, Saul A. Teukolsky, Cambridge University Press

PHY707 Nuclei and Particle Physics (60 Lecture Hrs)

Coordinators: Dr. Narayan Rana
narayan.rana@niser.ac.in

Course Details:

- Nuclear systematics and stability (masses, sizes, spins, magnetic moments, quadrupole moments, energetics and stability against particle emission, beta decay)
- Nucleon-nucleon interaction, space-time symmetries, conservation laws, iso-spin symmetry, low energy interactions (effective range, shape independence, meson exchange picture)
- Liquid drop model, compound nucleus and fission, nuclear vibrations and rotations
- Shell model, Nuclear spin and magnetic moments
- Direct nuclear reactions
- Mesons and baryons, resonances, SU(3) classification, iso-spin and strangeness, quark model, colour
- Weak interactions (nuclear and particle decays, neutrinos)

Course Outcomes:

- Provides training in basic concepts and methods in nuclear physics, stability of nucleons and classification of interactions. The course prepares the student to begin working in experimental and theoretical high energy physics.

References:

1. Introduction to Nuclear Physics by R. R. Roy and B. P. Nigam
2. Structure of Nucleus by M. A. Preston and R. K. Bhaduri
3. Introduction to Particle Physics by D. J. Griffith
4. Introduction to Particle Physics by D. J. Perkins

PHY800 Research Methodology & Research Publication Ethics (60 Lecture Hrs)

Coordinators: Dr. Pratap Kumar Sahoo
pratap.sahoo@niser.ac.in

Course Details:

- Introduction to Research Methodology (8 hours), Meaning, objectives, and types of research (basic, applied, qualitative, quantitative, mixed methods). Research process and design. Identification and formulation of research problems. Review of literature: sources, strategies, and tools (including databases, citation managers).
- Research Design & Methods (8 hours), Data collection methods: surveys, experiments, interviews, observations. Instrument design, reliability, and validity. Data analysis basics: descriptive and inferential statistics. Introduction to statistical software (SPSS, R, Python).
- Research Ethics (6 hours) Academic integrity and responsible conduct of research. Plagiarism: definition, types, and prevention (Turnitin, iThenticate). Fabrication, falsification, and misrepresentation. Ethical clearance, consent, and confidentiality in human/animal research. Case studies on research misconduct.
- Publication Ethics (8 hours), Authorship criteria and contribution statements. Open access, predatory journals, and impact factor metrics. Retraction, corrections, and copyright issues.
- Research Communication Skills (6 hours), Writing research proposals, thesis, and dissertations. Abstract writing, figures, and tables. Conference presentations and posters.
- Digital Tools & Data Management (6 hours), Research data management and repositories. Bibliographic tools: Mendeley, Zotero, EndNote. ORCID, ResearcherID, Scopus Author ID, Google Scholar. Altmetrics and research visibility.
- Tutorials / Practical Sessions (16 hours), Literature search exercises (Scopus/Web of Science). Plagiarism check and interpretation.

Course Outcomes:

- Students are expected to understand the fundamentals of research design, methodology, and ethics, and gain the skills to conduct rigorous research and publish with academic integrity.

References:

1. Kothari, C.R. Research Methodology: Methods and Techniques, New Age International.
2. Creswell, J.W. Research Design, Sage Publications.
3. Day, R.A., & Gastel, B. How to Write and Publish a Scientific Paper, Cambridge University Press.
4. COPE (Committee on Publication Ethics) Guidelines.
5. UGC Research and Publication Ethics (Two Credit Course Guidelines).

ELECTIVE COURSES

PHY751 Special Topics in Quantum Mechanics (60 Lecture Hrs)

Coordinators: Dr. Anamitra Mukherjee
anamitra@niser.ac.in

Course Details:

- **PART I : Quantum entanglement & applications :**
  - Density matrices
  - Tensor product and entangled states coherent and squeezed states; Bell basis
  - Quantum teleportation
  - EPR and Bells inequalities
  - Shannon entropy: Qbits, introduction to quantum computing principles; measurement and decoherence
- **PART II: Introduction to many particle QM:**
  - Creation/ Annihilation operators; Symmetization/Antisymmetrization; many body operators, Boson/Fermion coherent states, Grassmann algebra and Gaussian integrals using coherent states.
  - Dynamical variables and dynamics of identical particles
  - Applications to many body systems: Angular momentum of system of identical particles, first order perturbation in many body systems, introduction to Hartree-Fock methods.
- **PART III: Symmetries in QM :**
  - Group representation, Point group symmetry, Lie Groups; Schur lemma, orthogonality theorems, irreducible representations, accidental degeneracies; Irreducible tensor operators and direct product representations, Wigner Eckart theorem;
  - Applications including molecular orbitals, space time symmetries of Bloch states; normal model of vibrations; characters of angular momentum states; SU(2), SU(3) representations

Course Outcomes:

- This course teaches advanced topics in quantum mechanics which provides the much needed background in concepts and techniques in present day research in the interface of the area of quantum mechanics, many body physics and information theory.

References:

For Part I :

1. Entangled systems by Jurgen Audretsch
2. Density Matrix Theory and Applications by Karl Blum
3. Quantum Mechanics by Leonard Susskind
4. Modern Quantum Mechanics by J. J Sakurai

For Part II:

1. Quantum Mechanics Merzbacher (Chapters 21 and 22)
2. Quantum many particle systems J. W. Negele and H. Orland (Chapter 1)
3. Quantum Mechanics Schiff (Chapter 14)
4. Elements of Advanced Quantum Theory by J. M. Ziman (Chapters 1,2 and 5)
5. Modern Quantum Mechanics by J. J Sakurai

For Part III:

1. Group Theory by M Tinkham
2. Group Theory by Hamermesh
3. Lie Algebras in Particle Physics: from Isospin To Unified Theories by Howard Geogie
4. Group theory and Chemistry by Bishop
5. Topics in Condensed Matter Theory by Michele Cini
6. Elements of Advanced Quantum Theory by J. M. Ziman (chapters 7)
7. Solid State Physics by Ashcroft and Mermin

PHY752 Computational Physics (60 Lecture Hrs)

Coordinators: Dr. Colin Benjamin
colin@niser.ac.in

Course Details:

- Introduction to theory of computation and Random numbers.
- Monte Carlo: Importance sampling, Markov chain, Metropolis algorithm, Ising Model and other appli- cations.
- Molecular Dynamics: Integration methods (e.g Verlet and Leap frog algorithms), extended ensembles, molecular system.
- Variational methods for Schrodinger Equation, Hartree and Hartree-Fock methods.
- Quantum Monte Carlo methods.
- Special Topics Like: QMD, Ideal fluids, matrix inversions, Numerical solution of Poisson's equation: Finite difference method. Particle-Mesh Methods, radiative transfer etc.

Course Outcomes:

- This course provides training in computation tools required in research across a wide variety of fields including condensed matter, high energy phenomenology and lattice field theories.

References:

1. Computational Physics by Joseph Marie Thijssen, Cambridge University Press
2. An Introduction to Computational Physics by Tao Pang, Cambridge University press
3. Computer Simulation of Liquid by M. P. Allen and D. J. Tildesley, Clarendon press
4. A Guide to Monte Carlo Simulations in Statistical Physics by L. Landau and K. Binder
5. Quantum Monte Carlo Methods by M. Suzuki (Editor) Springer-Verlag
6. New Methods in Computational Quantum Mechanics by I. Prigogine and Stuart A. Rice
7. Understanding Molecular Simulation by D. Frankel and B. Smit, Second edition, academic press.
8. Computational Methods in Field Theory by H. Gausterer and C.B. Lang (Lecture notes in physics 409)
9. Density Functional Theory of Atoms and Molecules by R. G. Parr and W. Yang
10. F. Jensen, introduction to Computational Chemistry by F. Jensen
11. Essentials of Computational Chemistry by C. J. Crammer
12. Dynamical mean field theory by Jean-Marc Robin
13. Quantum Monte Carlo Methods by James Gubernatis, Naoki Kawashima, Philipp Werner
14. Computer Simulations using Particles - R. W. Hockney and J. W. Eastwood

PHY753 Quantum Field Theory I (60 Lecture Hrs)

Coordinators: Dr. Yogesh Kumar Srivastava
yogeshs@niser.ac.in

Course Details:

- Lagrangian formulation of Klein-Gordon, Dirac and Maxwell equations, Symmetries (Noether's theorem), Gauge fields
- Relativistic quantum mechanics - Klein-gordon equation, Dirac equation, Free- particle solutions
- Canonical quantization of scalar and Dirac field
- Path-integral formulation of quantum mechanics
- Path-integral for scalar fields, generating functional, connected Green's functions, Feynman rules, Tree and loop diagrams
- Grassmann variable, Path-integral for Dirac field
- Path-integral and Feynman rules for QED
- S-Matrix, cross-section and decay rate for tree level processes of QED, Symmetries and Ward identity
- If time permits, Renormalization of scalar field theory

Course Outcomes:

- This first course on quantum field theory prepares the student for tackling future advanced courses in the area of high energy physics.

References:

1. An Introduction to Quantum Field Theory by M. Peskin and D. V. Schroeder
2. Quantum Field theory: From Operators to Path Integrals, 2nd edition by Kerson Huang
3. Quantum Field Theory by Mark Srednicki
4. Quantum Field Theory by Claude Itzykson and Jean Bernard Zuber
5. Notes from Sidney Coleman's Physics 253a, arXiv: 1110.5013

PHY754 Particle Physics (60 Lecture Hrs)

Coordinators: Dr. Sanjay Kumar Swain
sanjay@niser.ac.in

Course Details:

- Elementary particles, discrete symmetries and conservation laws.
- Symmetries and Quarks.
- Klein-Gordon equation, concept of antiparticle.
- Lorentz symmetry and scalar / vector / spinor fields.
- Dirac equation
- Scattering processes of spin-1/2 particles, Feynman's rules as thumb rule, QFT course, propagators.
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- Current-current interactions, weak interaction, Fermi theory.
- gauge symmetries, spontaneous symmetry breaking, Higgs mechanism
- Electroweak interaction, Glashow-Salam-Weinberg model.
- Introduction to QCD, structure of hadrons form factors, structure functions, parton model, Deep inelastic scattering.

Course Outcomes:

- This course teaches the basics of particle physics and allows the student to start beginning research work in high energy phenomenology

References:

1. Gauge Theories in Particle Physics, Vol I & II by Aitchison and Hey
2. Foundations of Quantum Chromodynamics by T. Muta
3. Modern Particle Physics by Mark Thomson
4. Introduction to Elementary Particle by David Griffiths
5. Quarks and Leptons by F. Halzen and A.D. Martin
6. Introduction to High Energy Physics: D.H. Perkins
7. Introduction to Elementary Particle Physics: A. Bettini
8. Particle Physics by B. R. Martin and G. Shaw

PHY755 Introduction to Phase Transitions and Critical phenomena (60 Lecture Hrs)

Coordinators: Dr. A. V. Anil Kumar
anil@niser.ac.in

Course Details:

- Introduction to critical phenomena and first order phase transition. Survey of experimental results and scaling hypothesis, introduction to critical exponents and universality.
- Review of thermodynamic potentials, introduction to order parameters and response functions.
- Introduction to interacting systems: study of one dimensional Ising model via transfer matrix, lack of phase transition in one dimension, study of Ising model in two dimensions, XY and Heisenberg model.
- Mean field theory: calculation of order parameter, response functions and correlation functions using
- Curie-Weiss mean field theory and Landau-Ginzberg theory, calculation of critical exponents for mean field systems, range of validity of mean field theory.
- Introduction to re-normalization group (RG): Kadanoff block spins and real space RG methods, Perturbative RG in momentum space: Wilson-Fisher RG and epsilon expansion, broken continuous symmetry: Mermin Wagner theorem, Goldstone modes and Kosterlitz Thouless phase transition, introduction to non-linear sigma models, quantum critical phenomena and quantum phase transitions, introduction to 1D Transverse Field Ising Model and introduction to Bose- Hubbard model.

Course Outcomes:

- This course teaches the students advanced concepts and methods in statistical mechanics crucial for the student to take up basic research work.

References:

1. Introduction to phase Transitions and Critical phenomena by H. Eugene Stanley
2. Modern approach to Critical phenomena by Igor Herbut
3. Statistical physics: Statics, Dynamics and Renormalization by Leo p. Kadanoff
4. The Theory of Critical Phenomena by J. J. Binney, a. J. Fisher, M. E. J. newman
5. Modern Theory of Critical phenomena by Shang-keng Ma
6. Statistical Mechanics of phase Transitions by J. Yeomans
7. Field Theory, the Renormalisation group and Critical phenomena by Daniel J. Amit

PHY760 Nonlinear Optics (60 Lecture Hrs)

Coordinators: Dr. Ashok Mohapatra
a.mohapatra@niser.ac.in

Course Details:

- Overview of non-linear Optics, nonlinear polarization, nonlinear optical susceptibility, Symmetry consideration.
- Wave propagation in nonlinear media.
- Electro optical and magneto optical effects, Faraday effect, Kerr effect, Pockel's effect and Birefrin- gence.
- Higher harmonic generations, phase matching and quasi phase matching, Sum and difference fre- quency generation, Optical parametric amplification and oscillation.
- Cross-Phase Modulation, Self-phase modulation, Multi-photon processes, Self-focusing, Four-Wave Mixing.
- Laser Spectroscopy, wave front conjugation, Stimulated Raman Scattering, Stimulated Brillouin Scattering, Optical solitons and Optical pulse compression.
- Introduction to ultrafast nonlinear phenomena at femtosecond timescales, Intense pulses and higher harmonic generation, Introduction to attosecond pulse generation and spectroscopy.

Course Outcomes:

- This course teaches the students advanced concepts and methods in modern topics in and nonlinear optics necessary for the student to take up basic research work in nonlinear and ultrafast optics.

References:

1. Lasers by A. E. Siegman
2. Principles of Lasers by Orazio Svelto
3. The Principles of Nonlinear Optics by Y. R. Shen
4. Nonlinear Optics by Robert W. Boyd
5. Nonlinear Optics: Basic Concepts by D. L. Mills
6. Optical waves in crystals by Amnon Yariv and Pochi Yeh

PHY757 General Theory of Relativity and Cosmology (60 Lecture Hrs)

Coordinators: Dr. Yogesh Kumar Srivastava
yogeshs@niser.ac.in

Course Details:

- Review of Newtonian Mechanics. Special theory of relativity. prelude to general relativity, historical developments
- 4-Vectors and 4-tensors, examples from physics
- Principle of Equivalence, Equations of motion, gravitational force
- Tensor analysis in Riemannian space, Effects of gravitation, Riemann-Christoffel curvature tensor, Ricci Tensor, Curvature Scalar
- Einstein Field Equations, Experimental tests of GTR
- Schwarzschild Solution, gravitational lensing
- Gravitational waves: generation and detection
- Energy, momentum and angular momentum in gravitation
- Cosmological principle, Robertson-Walker metric, Redshifts
- Big-Bang Hypothesis, CMB
- Issues in Quantum gravity

Course Outcomes:

- This course teaches the students advanced concepts and methods in general relativity crucial for the stu- dent for building their background for research work in general relativity and cosmology.

References:

1. A first course in General Relativity by Bernard Schutz
2. Gravity by James B. Hartle
3. The Classical Theory of Fields by L. D. Landau and E. M. Lifshitz
4. Gravitation and Cosmology by Steven Weinberg
5. Introducing Einstein's Relativity by Ray D'Inverno
6. General Relativity by P. Dirac

PHY758 Soft Condensed Matter (60 Lecture Hrs)

Coordinators Dr. Sumedha
sumedha@niser.ac.in

Course Details:

- Introduction: Basic phenomenology of soft condensed matter systems, intermolecular forces, viscoe-elasticity, ordering in soft matter, glass transition, phase separation
- Diffusion processes: Fick's laws, Diffusion Equation, Random walks, Brownian motion, Langevin and Fokker-Plank equations
- Colloids: Stability of colloidal systems, Poisson-Boltzmann theory, DLVO theory, Depletion interactions, Electro-kinetic effects
- Polymers: model systems and chain statistics, polymers in solvents and melts, viscoelasticity, gelation
- Liquid crystals: Introduction, liquid crystal phases and transitions, Distorted nematic ordering, response to electric and magnetic fields
- Amphiphiles: Introduction, microphase separation in block copolymers and in solutions of amphiphiles, aggregation and self-assembly of amphiphiles

Course Outcomes:

- This course teaches the students advanced concepts and methods in soft matter physics, with the aim to build their background for future research work in this area.

References:

1. Principles of Condensed Matter Physics by P. M. Chaikin and T. C. Lubensky
2. Soft Condensed Matter by R. A. L. Jones
3. Structured Fluids: Polymers, Colloids, Surfactants by T. Witten
4. Introduction to Soft Matter: Polymers, Colloids, Amphiphiles and Liquid Crystals by I. W. Hamley
5. Soft Matter Physics by M. Klemanand and O. D. Lavrentovich
6. Colloidal Dispersions by W. B. Russel, D. A. Saville and W. R. Showalter
7. Dynamics of Colloids by J. K. G. Dont
8. Intermolecular and Surface Forces: With Applications to Colloidal and Biological Systems by J. Israe- lachvili
9. Introduction to Liquid Crystals by P. J. Collings and M. Hird
10. Polymer solutions -- an introduction to physical properties by I. Teraoka

PHY759 Applied Nuclear Physics (60 Lecture Hrs)

Coordinators: Dr. Sanjay Kumar Swain
sanjay@niser.ac.in

Course Details:

- Basis of nuclear structure and reactions
- Radioactivity and radioactive decays: Detecting nuclear radiations, Alpha decay, beta decay, gamma decay
- Passage of charged particles through matter.
- Detectors and accelerators.
- Applications: Effects of radiation on biological systems and Nuclear medicine, Industrial Application
- Power from Fission and Fusion: Characteristics of Fission, Nuclear Reactors, Thermonuclear fusion

Course Outcomes:

- This course teaches the students advanced concepts and methods in applied nuclear physics, with the aim to build their background for future research work in this area.

References:

1. Nuclear Physics: Principles and Applications, John Lilley, Wiley Publications
2. The Atomic Nucleus, Robley D. Evans, Tata McGraw-Hill Publishing.
3. Fundamentals of Nuclear Reactor Physics, Elmer Lewis, Elsevier Publishing.
4. An Introduction to the Passage of Energetic Particles through Matter, N. J. Carron, CRC Press
5. Accelerator Physics, S. Y. Lee, World Scientific

PHY760 Quantum many-body theory – formalism (60 Lecture Hrs)

Coordinators: Dr. V. Ravi Chanda & Dr. Anamitra Mukherjee
ravi@niser.ac.in & anamitra@niser.ac.in

Course Details:

- Second quantisation and Fock space formalism for bosons & fermions
- Canonical Transformation: Interacting fermion & boson lattice models Jordan-Wigner, Bogoliubov- Valetin, Schrieffer-Wolf
- Green's function formalism at zero & finite temperatures and relation to observables.
- Linear Response theory and collective excitations: screening and plasma oscillations, spin waves and magnons.
- Diagrammatic perturbation theory for Green function for bosons & fermions
- Interacting fermions: Hartree-Fock, Random phase and ladder approximation, Goldstone theorem, Lut- tinger-Ward identities, skeleton approximations
- Interacting bosons: Bose condensation, interacting bosons and condensate depletion.
- Green's function equation of motion for Anderson, formation of local moments and Kondo screening
- (Time permitting) Exact solutions: Bethe ansatz for spin chains and 1D interacting fermions, Kitaev and spin-orbital flux-lattice models

Course Outcomes:

- This course teaches the students basic theoretical concepts and methods in quantum many body physics, with the aim to build their background for future research work condensed matter theory.

References:

1. Advanced Quantum Mechanics F. Schwabl
2. Quantum Theory of Many body particle systems by Fetter & Walecka
3. Introduction to Many-Body Physics by Piers Coleman
4. Feynman Diagram techniques in Condensed Matter Physics Radi A. Jishi
5. Green's Function for Solid State Physics by S. Doniach & E.H. Sondheimer
6. Elementary Excitations in Solids by D. Pines
7. The Kondo problem to heavy fermions A.C. Hewson
8. Quantum many particle systems J. W. Negele and H. Orland

PHY761 Introduction to Mesoscopic phenomena & quantum devices (60 Lecture Hrs)

Coordinators: Dr. Colin Benjamin & Dr. Satyaprasad P Senanayak
colin@niser.ac.in & satyaprasad@niser.ac.in

Course Details:

The course will cover the basics material. Elements from the theoretical & experimental topics can be cho- sen by the as required. The degree of focus of theory or experiment will be at the instructor's discretion.

- **Basics**
  - Introduction of quantum devices and active electronic devices at nano scale.
  - Effects of magnetic fields: The Aharonov Bohm effect; 2D electron gas; Landau levels; Transverse modes in 2D quantum wire; Shubnikov de Haas oscillations; Magnetic edge states; integer Quantum Hall effect, Fractional Quantum Hall effect
  - Electron transport: Boltzmann semiclassical transport; Onsager reciprocity relations; Conventional Hall effect; Drude conductivity; Einstein relation; Electronic states in quantum confined systems;
  - [Note: both options modules below have 32 lectures each. The instructor is free to teach any one module or a mix of both]

- **Topic I: Theory of quantum devices**
  - Conductance from transmission; Ballistic transport; Quantum of conductance; Landauer formula; Lin- ear response
  - Quantum point contact; T-matrices; S-matrix and Green functions; Current operator; Landauer Buttiker formalism;
  - Nonequilibrium green's function approach to transport; Breit Wigner and Fano resonance; Delay time for resonances; Friedel sum rule; Levinson's theorem; Single electron tunnelling: Coulomb blockade and Kondo effect
  - Disordered conductors: Weak localization; Mesoscopic fluctuations; Random Matrices; Anderson localization; Quantum Chaos; Dephasing; Decoherence

- **Topics II: Realization of quantum devices**
  - Fabrication and characterization methods for nano-electronics
  - The field effect transistor FET: size limits and alternative forms
  - Devices based on electron tunnelling, resonant tunnel diodes, single electron transistors, molecular electronics, hybrid electronics
  - Devices based on electron spin and ferromagnetism
  - Quantum dot based devices
  - Qubits vs. binary bits in a quantum computer, applications of nano-electronic technology to energy is- sues

- Spin qubits.
- Quantum information: Josephson Junctions and Qubits; Metastable states and escape dynamics

Course Outcomes:

- This course is an introduction to the area of mesoscopic physics and nano-electronic devices.

References:

1. Electronic Transport in Mesoscopic Systems by S. Datta, Cambridge University press.
2. Introduction to Mesoscopic Physics by Y. Imry
3. Mesoscopic Electronics in Solid State Nanostructures by T. Heinzel
4. Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations by P. Mello and
5. N. Kumar
6. Quantum nano-electronics: An Introduction to Electronic Nanotechnology and Quantum Computing by Edward L.Wolf
7. Quantum Electronics by Amnon Yariv
8. Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience by Edward L. Wolf
9. Fundamentals of Nanoelectronics by George Hanson

PHY762 Introduction to Quantum Optics (60 Lecture Hrs)

Coordinators: Dr. Ashok Mohapatra
a.mohapatra@niser.ac.in

Course Details:

- Electromagnetic field quantization: Quantum fluctuation and Quadrature operators of a single mode field, Thermal fields, Vacuum fluctuation and zero-point energy, Quantum phase.
- Coherent and squeezed states of radiation field: Properties and phase space picture of coherent state, Generation of a coherent state, Squeezed state physics, generation and Detection of squeezed light, Schrodinger cat states, Multi-mode squeezing, Broadband squeezed light, Squeezing via non-linear pro- cess.
- Atom-field interaction: Rabi model (Semi-classical model for atom-field interaction), Jaynes-Cum- mings model (fully quantum mechanical model for atom-field interaction).
- Quantum coherence function: photon detection and quantum coherence functions, First-order coher- ence and Youngs type double source experiment, Second order coherence, physics of Hanbury-Brown- Twiss effect, Experiments with single photon, Quantum mechanics of beam splitter, interferometry with single photon.
- Optical test of quantum mechanics: photon sources: spontaneous parametric down-conversion, Hong- Ou-Mandel interferometer, Superluminal tunneling of photons, EpR paradox and optical test of Bell's the- orem.

Course Outcomes:

- This course teaches the students important concepts and methods in quantum optics, with the aim to build their background for future research work in this area.

References:

1. Introductory Quantum Optics by C. C. Gerry and P. L. Knight, Cambridge University press
2. Quantum Optics by M. O. Scully and M. S. Zubairy, Cambridge University press
3. Quantum Optics by M. Fox, Oxford Master series in atomic, Optical and Laser physics
4. Quantum Theory of Light by R. Loudon, Oxford science publication

PHY763 Astronomy and Astrophysics (60 Lecture Hrs)

Coordinators: Dr. Nishikanta Khandai & Dr. Luke Robert Chamandy
nkhandai@niser.ac.in & lchamandy@niser.ac.in

Course Details:

- **Part I: Introduction and Tools**
  - Tools - astronomical objects, multiwavelength astronomy, scales, distance ladder, astrometry, magni- tude scale
  - Gravity - Kepler's laws, Virial theorem
  - Radiation physics - radiative flux, transfer function, absorption, scattering and emission, Einstein coef- ficient, local thermodynamic equilibrium, source function and line formation, concept of opacities
- **Part II: Minor planets, Planets and Brown dwarfs**
- **Part III : Stars and their Remnants**
  - Stellar atmospheres
  - Stars and stellar structures - stellar spectra, HR diagram, Equilibrium in stars, binary stars
  - Star formation and Protostars
  - Stellar evolution
  - White dwarfs, neutron stars, black holes
- **Part IV: Galaxies**
  - Interstellar medium
  - Milky way Galaxy - distribution of matter, differential rotation, spiral arms
  - Morphological classification of galaxies and tuning fork diagram
  - Evidence for dark matter
  - Active Galactic Nuclei
  - Special Topics: [If time permits]
- **Part V : Magnetic fields**
  - Astrophysical phenomena where magnetic fields are critical
  - Galactic magnetic fields - dust and synchrotron polarization, Faraday rotation, Zeeman measurements
- **Part VI: Gravitational Lensing**
- **Part VII: Galaxy groups, Clusters and Superclusters**
- **Part VIII: Expanding Universe**

Course Outcomes:

- This course teaches the students important concepts and methods in astronomy and astrophysics, with the aim to build their background for future research work in this area.

References:

1. Astrophysics for Physicists – Arnab Rai Choudhuri
2. Astrophysics: Decoding the Cosmos, 2nd edition - Judith Irwin
3. Introduction to Modern Astrophysics - B. W. Carroll and D. A. Ostlie
4. An invitation to Astrophysics - T. Padmanabhan
5. Astrophysical Concepts - Martin Harwit
6. Introductory Astronomy and Astrophysics - Zelike and Gregory
7. Universe - Roger Freedman
8. Physical Universe - F. Shu
9. Astrophysics Processes by Hale Bradt
10. Radiative processes in Astrophysics by Rybicki and Lightman

PHY764 Plasma Physics and Magneto-hydrodynamics (60 Lecture Hrs)

Coordinators: Dr. Amaresh Kumar Jaiswal
a.jaiswal@niser.ac.in

Course Details:

- Introduction to plasmas, applications: in fusion, space and astrophysics, semi- conductor etching, microwave generation, characterisation of the plasma state, Debye shielding.
- Plasma and cyclotron frequencies, collision rates and mean-free paths, atomic processes, adiabatic in- variance, orbit theory, magnetic confinement of single charged particles.
- Two-fluid description, magneto-hydrodynamic waves and instabilities, heat flow, diffusion, kinetic description, and Landau damping
- Ideal magneto-hydrodynamic (MHD) equilibrium, MHD energy principle, ideal and resistive MHD stability, drift-kinetic equation, collisions, classical and neoclassical transport, drift waves and low- frequency instabilities, high frequency micro instabilities, and quasi-linear theory

Course Outcomes:

- This course teaches the students important concepts and methods in plasma physics and magnetohydrodynamics, with the aim to build their background for future research work in this area.

References:

1. Plasma physics by Peter Andrew Sturrock
2. Principles of Magnetohydrodynamics by J. P. Hans Goedbloed, Stefaan Poedts
3. Hydrodynamic and Hydromagnetic Stability by S. Chandrasekhar
4. The Physics of Plasmas by T. J. M. Boyd, J. J. Sanderson
5. Fundamentals of Plasma Physics by Paul M. Bellan,
6. Introduction to Plasma Physics by R. J. Goldston, P. H. Rutherford
7. An Introduction to Magnetohydrodynamics by P. A. Davidson
8. An Introduction to Plasma Astrophysics and Magnetohydrodynamics by M. Goossens

PHY765 Relativistic Nucleus-Nucleus collision & Quark-Gluon Plasma (60 Lecture Hrs)

Coordinators: Dr. Amaresh Kumar Jaiswal & Dr. Victor Roy
a.jaiswal@niser.ac.in & victor@niser.ac.in

Course Details:

- Introduction to high energy heavy ion collisions and Quark-Gluon-Plasma, comparison of big bang and the little bang
- Thermodynamics: Relativistic gas (hadrons, quarks and gluons) and its statistical and thermodynamical properties, MIT Bag model, Hagedorn gas, phase diagram of QCD
- Relativistic Kinematics: four vectors notation, rapidity variables, pseudo rapidity variables, light cone variables, relativistic invariants, Dalitz plot, cross sections
- Collision Dynamics: initial state of nuclear collisions, fluid dynamical evolution, kinetic transport model, freeze-out and particle production
- Experiments: a general overview of different experimental setup related to search for QGP and relevant observables
- Signatures of QGP: collective flow, J/Ψ suppression, strangeness enhancement, jet quenching, electromagnetic probes, Hanbury-Brown-Twiss measurement
- Recent progress

Course Outcomes:

- This course provides the basic background for relativistic nuclear scattering processes and physics of quark gluon plasma.

References:

1. Hadrons and QGP by Letterssier and Rafelski
2. Introduction to High Energy Heavy Ion Collisions by C. Y. Wong
3. Phenomenology of Ultra Relativistic Heavy Ion Collisions by W Florkowski
4. Ultra relativistic heavy ion collisions by R. Vogt
5. Introduction to relativistic heavy ion collisions, by L. P. Csernai
6. A Short Course On Relativistic Heavy Ion Collision by A. K. Chaudhuri
7. Extreme states of matter in strong interaction physics by Helmut Satz
8. Relativistic Hydrodynamics by L. Rezzolla and O. Zanotti
9. Finite Temperature Field Theory by J. I. Kapusta and C. Gale
10. The Early Universe by Kolb and Turner
11. Fantastic Realities by Frank Wilczek
12. Research Reports in Physics, Quark Gluon Plasma, Invited lectures of Winter School, Published by Springer Verlag, Editors - B. Sinha, S. Pal and S. Raha
13. The Physics of Quark Gluon Plasma, Introductory lectures, Lecture Notes in Physics 785, Publisher - Springer, Editor - S. Sarkar, H. Satz and B. Sinha
14. Quark Gluon Plasma - From big bang to little bang, K. Yagi, T. Hatsuda, Y. Miake, Cam- bridge Monograms on Particle Physics, Nuclear Physics and Cosmology
15. Quark Gluon Plasma: Theoretical Foundations, An annotated reprint collection - J. Ka- pusta, B. Muller and J. Rafelski, Publisher - Elsevier Science

PHY766 Non-equilibrium Statistical Mechanics (60 Lecture Hrs)

Coordinators: Dr. A. V. Anil Kumar
anil@niser.ac.in

Course Details:

- Kinetic theory of gases, Boltzmann distribution and its implications.
- Boltzmann equation, H Theorem, Conservations laws and Hydrodynamics
- Linear response, fluctuation dissipation theorem,Green-Kubo formula
- Markov Processes: Conditional probabilities, Markov processes, Chapman-Kolmogorov equation, Master equation, Fokker Planck equation, Random walk processes,Ising Glauber Model
- Stochastic differential equations: Langevin equation, stochastic integration, Ito calculus, Stratonovich integrals
- Diffusion equations, first passage problems, driven diffusive systems
- Applications: Aggregation,Fragmentation,Phase ordering Kinetic,Exclusion processes

Course Outcomes:

- This course provides the basic background of non-equilibrium statistical mechanics and out of equilibrium dynamics.

References:

1. Stochastic Methods by C. Gardiner
2. A Kinetic View of Statistical Physics by P. L. Kaprivsky, S. Redner and E. Ben Naim
3. Statistical Physics 2- Nonequilibrium Statistical Mechanics by R. Kubo, M. Toda and N. Hashitsume
4. Stochastic Processes in Physics and Chemistry by N. G. Van Kampen.
5. Theory and Applications of Stochastic Processes by Z. Schuss
6. A Guide to First Passage Processes by S. Redner

PHY767 Nonlinear Dynamics and Chaos (60 Lecture Hrs)

Coordinators Dr. A. V. Anil Kumar & Dr. Sumedha
anil@niser.ac.in & sumedha@niser.ac.in

Course Details:

- **General introduction and motivation:**

  examples of linearity and nonlinearity in physics and the other sciences; modelling systems using iterated maps or differential equations, nonautonomous systems

- **General features of dynamical systems :**

  Systems of differential equations with examples; control parameters; fixed points and their stability; phase space; linear stability analysis; numerical methods for nonlinear systems; properties of limit cycles; nonlinear oscillators and their applications; the impossibility of chaos in the phase plane; bifurcations: their classification and physical examples; spatial systems, pattern formation and the Turing mechanism; strange attractors and chaotic behaviour

- **The logistic map:**

  Linear and quadratic maps; graphical analysis of the logistic map; linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; chaotic behaviour and the determination of the Lyapunov exponent; universality and the Feigenbaum numbers; other examples of iterated maps

- **Hamiltonian Systems:**

  Phase space; Constants of motion and integrable Hamiltonians; Nonintegrable systems, the KAM theorem and period-doubling;

  applications

- **Fractal geometry:**

  dimension of an object, Mandelbrot set, Julia set, iterated function systems

- **Spatio-temporal dynamics:**

  Spatio-temporal chaos

- **Quantum Chaos:**

  Quantum analogies to Chaotic behaviour, Correlations in wave functions, chaos and Semi-classical approaches to Quantum mechanics

Course Outcomes:

- This course teaches the students important concepts and methods in classical nonlinear dynamics, with the aim to build their background for future research work in this area.

References:

1. Nonlinear Dynamics and Chaos: With Applications in Physics, Biology, Chemistry and Engineering by S. H. Strogatz
2. Chaos and Nonlinear Dynamics by Robert C. Hilborn
3. Exploring Chaos: Theory and Experiment by Brian Davies
4. An Introduction to Dynamical Systems by K. T. Alligood, T. D. Sauer and J. A. Yorke, Chaos
5. Chaos in Dynamical Systems by Edward Ott

6. Chaos and Integrability in Nonlinear Dynamics: An Introduction by M. Tabor

PHY768 Quantum many-body phenomena (60 Lecture Hrs)

Coordinators: Dr. Kush Saha & Dr. Anamitra Mukherjee
kush.saha@niser.ac.in & anamitra@niser.ac.in

Course Details:

- **Fermi liquid theory:**

  phenomenology, self-energy and quasiparticle, spectral function properties and metal to insulators transitions, measuring Fermi surfaces, and spectral functions. Instabilities of Fermi liq- uids.

- **Superconductivity:**

  Meissner Effect & London equations, types of superconductors, Ginzburg Landau phenomenology, Josephson effect, Conventional and un-conventional superconductors Cooper instability, Electron phonon interaction & BCS wave function, gap equation, thermodynamics and magnetic response. (time permitting) Nambu-Gorkov formalism, BEC and idea of BCS-BEC crossover.

- **Magnetism:**

  Metallic and insulating magnets mean field theory, spin wave theory for ferro and antiferro- magnets. Heisenberg Model: ground state, Holstein-Primakoff expansion, and variational approaches to magnetism. Hubbard Model: itinerant exchange, phenomenology of quantum phase transitions.

Course Outcomes:

- This course introduces phenomena resulting from collective behavior of many-quantum degrees of freedom, their phenomenology and basic microscopic theoretical framework. The course aims to build a basic theoretical background for understanding a wide range of quantum many-body phenomena.

References:

1. Advanced Solid State Physics by P. Philips
2. Introduction to Many-Body Physics by P. Coleman
3. Lecture Notes on Electron Correlation and Magnetism by P. Fazekas
4. Condensed Matter Physics by M. P. Marder
5. Theory of Superconductivity by J. R. Schrieffer
6. Superconductivity of Metals and Alloys by P. G. De Gennes
7. Introduction to Superconductivity by M. Tinkham
8. Quantum Theory of Magnetism by R.M. White
9. The theory of Magnetism by D. C. Mattis

PHY769 Special topics & techniques in quantum condensed matter theory (60 Lecture Hrs)

Coordinators: Dr. V. Ravi Chanda & Dr. Ashis Kumar Nandy
ravi@niser.ac.in & aknandy@niser.ac.in

Course Details:

- **Basic topic:**
  - Review of first and second quantized approaches to Green's function-based perturbation, Wannier functions to tight binding Hamiltonians, Density matrices and bi-partite entanglement. Review of band theory.
  - Note: All optional modules below have 32 lectures each. The instructor is free to teach any one module or a mix.

- **Module -I Density functional theory**
  - QM of electrons and nuclei, Born-Oppenheimer approximation, Hartree and HF theory, CI & many-body and Moller-plesset theory, complete active space methods, coupled cluster theory, time-dependent approach to all the above formalisms.
  - Foundations of Density Functional Theory (DFT): Hohenberg-Kohn (HK) theorem, degenerate ground states, variational DFT, N − and v− representability problem, Levy-Lieb constrained search, fractional particle number & derivative discontinuity, spin polarized systems, Excited states part i: Effective Single particle picture: Kohn-Sham (KS) construction, non-interacting v− representability, degenerate KS DFT, KS equations for spin polarized systems, interpretation of KS eigenvalues
  - Exchange-Correlation (XC) Energy Functional: exact exchange formalism within DFT, exact representations of the energy functional, LDA, GGA, meta-GGA, weighted density approximation, self-interaction correction (SiC), virial theorems, exact exchange formalism (OpM, KLi, HS), where DFT goes wrong, strengths of DFT, strong correlation: DFT+U, RPA, GW, DFpT, DMFT, orbital free DFT, DFT- hybrid
  - Crossover to Excited-States: time-dependent DFT: Runge-gross theorem, time- dependent KS equations, adiabatic LDA & TD XC potentials, linear response TDDFT, Excited states part ii, spin polarized TDDFT, frequency dependent XC kernel, TDCDFT, TDOEp, relativistic DFT, molecular orbital theories

- **Module-II: Computational many body techniques:**
  - Green's function in imaginary time and coherent state path integrals, many-particle partition function and perturbation theory in path integral approach
  - Exact and Lanczos based diagonalization of large fermion and spin lattice models: Incorporating symmetry for block diagonalizations idea of shift inversion and spectral-fold techniques: applications to lattice models ground state and few body excitations; ED of quantum Hall systems (time permitting); Diagonalization of bosonic systems: applications for Bose-Hubbard model.
  - Dynamical mean field theory with iterated perturbation theory and exact diagonalization-based solver. Mott transition, local moment formation.
  - Density matrix renormalization group, MPS PEPS, Time-evolving Block Decimation, introduction to standard DMRG/Tensor network libraries.

- **Module III: Theory of Band Topology**
  - Berry phase and Berry Curvature
  - Electric Polarization and Topology in one dimension
  - Su-Schreiffer-Heeger model and winding number
  - Kitaev Chain and topological superconductor
  - Thouless Charge pumping and Laughlin argument
  - Z2 Invariant of 3D topological insulators and applications
  - Elements of topological field theory
  - Interaction effects in topological systems.

Course Outcomes:

- The course introduces contemporary topics and techniques in the field of condensed matter theory. Given the wide range of research directions the course is divided into modules. Each module is focused on a specific technique or topic, including introduction to standard libraries used in the research. At any time, any module will be covered in detail in the course. A subset of topics from the basic topics are to be covered as required by the modules, before specializing to a module. The aim of the course is to provide a solid background in cutting-edge research techniques.
- (Being a Ph.D. student centric elective, the students should discuss with the instructor before registering)

References:

For module-I

1. Density Functional Theory of Atoms and Molecules by Robert G. Parr and Weitao Yang
2. Density Functional Theory by R.M. Dreizler and E.K.U. Gross
3. Density Functional Theory by Eberhard Engel
4. Primer in Density Functional Theory by C. Fiolhais, F. Nogueira, Miguel and A. L. Marques
5. Fundamentals of TDDFT by Miguel A. L. Marques et al.
6. Time-dependent Density Functional Theory by Miguel A. L. Marques et al.
7. Time-dependent Density Functional Theory by Carsten Ullrich
8. Quantal Density Functional Theory I & II by Viraht Shani
9. Recent advances in Density Functional Methods (Part I, II & III) by Delano P Chong
10. Atomic and Electronic Structure of Solids by Ethimios Kaxiras
11. Electronic Structure: Basic Theory and Practical Methods by Richard M. Martin
12. Many-Body Quantum Theory in Condensed Matter Physics by H. Bruus and K. Flensberg
13. Quantum Theory of the Electron Liquid by Gabriele Giuliani and Giovanni Vignale
14. Molecular Electronic Structure Theory by T. U. Helgaker, P. Jorgensen and J. Olsen
15. Electronic Structure Calculations for Solids and Molecules by J. Kohanoff
16. Methods of Electronic Structure Calculations by M. Springborg
17. Self-Consistent Fields in Atoms by Norman March
18. Computational Materials Science by J. G. Lee
19. Density Functional Theory in Quantum Chemistry by Takao Tsuneda
20. Material Modeling using DFT by Feliciano Giustino

For module-II

1. Computational Many-Particle Physics Lecture Notes in Physics (LNP, volume 739) Editors: H. Fehske, R. Schneider, A. Weiße
2. Shift-invert diagonalization of large many-body localizing spin chains SciPost Phys. 5, 045 (2018) Package: https://bitbucket.org/dluitz/sinvert_mbl.
3. Dynamical Mean Field Theory Jean-Marc Robin
4. Dynamical Mean-Field Theory for Strongly Correlated Materials Volodymyr Turkowski
5. Dynamical mean-field theory of strongly correlated fermion systems and the limit of infinite dimen- sions Rev. Mod. Phys. 68, 1996
6. The density-matrix renormalization group Ulrich Schollwoeck Rev. Mod. Phys. 77, 259 (2005)
7. Matrix product states and projected entangled pair states: Concepts, symmetries, theorems Rev. Mod. Phys. 93, 045003 (2021)
8. Density-Matrix Renormalization - A New Numerical Method in PhysicsLectures of a Seminar and Workshop held at the Max-Planck-Institut für Physik komplexer Systeme: Ingo Peschel, Matthias Kaulke, Xiaoqun Wang, Karen Hallberg Lecture Notes in Physics (LNP, volume 528)

For Module-III

1. Topological Insulators, by Marcel Franz, Laurens Molenkamp
2. Topological Insulator, Shun-Qing Shen
3. Topological Insulators and Topological Superconductors, A. Bernevig

PHY770 Quantum Field Theory II (60 Lecture Hrs)

Coordinators: Dr. Chethan N. Gowdigere and Dr. Yogesh Kumar Srivastava
chethan.gowdigere@niser.ac.in & yogeshs@niser.ac.in

Course Details:

- Radiative corrections - self-energy, vacuum polarization and vertex correction in QED
- 2.1PI effective action and Coleman-Weinberg Potential
- Classical Non-Abelian Gauge theory, Wilson Loop
- Path Integral quantisation of non-Abelian gauge theory, BRST symmetry
- Feynman rules for QCD and asymptotic freedom
- Callan-Symanzik equation and its solution, fixed points of renormalisation group flow, relevant, irrele- vant and marginal operators, anomalous dimension, brief introduction to Wilsonian renormalisation group [11 L]
- If time permits, Anomalies.

Course Outcomes:

- This course teaches the students important concepts and methods in advanced quantum field theory, with the aim to build their background for future research work in this area.

References:

1. An Introduction to Quantum Field Theory by M. Peskin and D. V. Schroeder
2. Quantum Field theory:From Operators to Path Integrals, 2nd edition by Kerson Huang
3. Quantum Field Theory by Mark Srednicki
4. Quantum Field Theory by Claude Itzykson and Jean Bernard Zuber
5. Notes from Sidney Coleman's Physics 253a, arXiv: 1110.5013

PHY771 Quantum Information & Quantum Computation (60 Lecture Hrs)

Coordinators: Dr. V. Ravi Chandra
ravi@niser.ac.in

Course Details:

- Introduction to Classical information: Shannon entropy, Mutual Information
- Quantum Information I: Hilbert space, density matrices, quantum entropy and Holevo bound
- Quantum Information II: Entanglement, Teleportation, super dense coding & Bell inequalities
- Quantum dynamics:Two level systems, decoherence and Rabi oscillations
- Quantum computation: single qubit gates-phase, swap, Hadamard, two qubit gates-CNOT
- Quantum algorithms: Deutsch, Grover, Introduction to Shor's algorithm
- Quantum error correction
- Applications: Quantum simulation and Adiabatic quantum computation
- Solid state quantum information & computation: Introduction to entanglement in nanostructures, quantum computation with superconducting devices and topological quantum computation

Course Outcomes:

- This course teaches the students important concepts and methods in quantum information and computation, with the aim to build their background for future research work in this area.

References:

1. Introduction to Quantum Information Science by V. Vedral (Oxford U. Press)
2. Quantum Information & Computation by M. A. Nielsen & I. L. Chuang (Cambridge U. Press)
3. An Introduction to quantum computing Kaye by P. R. Laflamme and A. M. Mosca (Oxford U. press)

PHY772 Experimental High Energy Physics (60 Lab Hrs)

Coordinators: Dr. Prolay Kumar Mal & Prof. Sanjay Kumar Swain
prolay@niser.ac.in & sanjay@niser.ac.in

Course Details:

- The interaction of high-energy particles with matter: specific applications related to EHEP. Relativistic kinematics: Detailed derivation of kinematic variables and their transformations whenever needed. Decay kinematics. Rapidity, pseudo-rapidity, space-like and time-like. Some examples where relativistic kinematics play an important role for understanding of data.
- Detectors in High Energy physics: general concept of building a HEp experiment, coverage and option
- Gas detectors; Semiconductor detector; Scintillator and Cerenkov detectors Specific to EHEP
- Calorimeter and Pre-shower detectors: principle of electromagnetic and hadronic shower generation. Detector Simulation: need of simulation, various techniques, MC, some general
- Concepts. Data analysis in HEp: general approach of data cleanup, calibration, track reconstruction, reconstruction of events Error analysis in EHEp. Computing in EHEp: Basics of OO programming using C++, few applications in EHEpdata analysis.

Course Outcomes:

- This course teaches the students important concepts and methods in experimental high energy physics, with the aim to build their background for future research work in this area.

References:

1. Relativistic Kinematics; a guide to the kinematic problems of High Energy physics by R. Hagedorn
2. The Experimental Foundations of Particle Physics by R. N. Cahn and G. Goldhaber
3. Techniques for nuclear and particle physics experiments: a How to approach by W. R. Leo (Springer)
4. Experimental Techniques in Hugh Energy Nuclear and Particle physics by T. Ferbel (World Scientific)
5. Introduction to Experimental particle physics by R. C. Fernow
6. Data Reduction and Error analysis for the physical sciences by P. Bevington and D. K. Robinson
7. Data analysis Techniques for High Energy physics by R. Frunwirth, M. Regler, R. K. Bock and H. Grote

PHY773 Experimental Techniques (60 Lab Hrs)

Coordinators: Dr. Pratap Kumar Sahoo & Prof. Subhankar Bedanta & Dr. Kartikeswar Senapati
pratap.sahoo@niser.ac.in & sbedanta@niser.ac.in & kartik@niser.ac.in

Course Details:

- **Mechanical drawing and designs:**

  Mechanical drawing tools, basic principles of mechanical drawing, dimensions, tolerances, from design to working drawings

- **Basics tools:**

  hand tools, machines for making holes, lathe & milling machines, grinders, casting

- **Vacuum technology:**

  gases, gas flow, pressure and flow measurement, vacuum pumps, pumping mechanisms, ultrahigh vacuum, leak detection

- **Optical systems:**

  optical components, optical materials, optical sources

- **Charge particle optics:**

  electrostatic lenses, charged-particle sources, energy and mass analyzer

- **Detectors:**

  optical detectors, photoemission detectors, particle and ionizing radiation detectors, signal to noise ratio detection, surface barrier detector, Particle detector: interactions of charged particles and photons with matter; gaseous ionization detectors, scintillation counter, solid state detectors

- **Electronics:**

  electronic noise, survey of analog and digital I/Cs, signal processing, data acquisition and control systems, data analysis evaluation

- **Nano- and micro-fabrication:**

  various lithography techniques such as photolithography, nanoimprint lithography, e-beam lithography, ion-ball milling

- **SEM, TEM, X-ray diffraction, SQUID Magnetometry, Magnetotransport, PL/CL time resolved spectroscopy, Rutherford Backscattering spectrometry (RBS), RBS-Channeling, UV-ViS-iR spectrometry.**

Course Outcomes:

- This course teaches the students important concepts and methods in experimental techniques, with the aim to build their background for future research work in this area.

References:

1. The art of Measurement, by Bernhard Kramer (V. C. H. Publication)
2. Building Scientific Apparatus by J. H. Moore et al.
3. Experiments in Modern Physics, Second Edition by Adrian C. Melissinos and Jim Napolitano

4. The art of Experimental Physics by Daryl W. Preston,
5. Vacuum Technology by A. Roth (North-Holland publisher)
6. Charge particle Beams by Stanley Humphries (John Wiley and Sons)
7. Principles of Charged Particles Acceleration, by Stanley Humphries (John Wiley and Sons)
8. Radiation Detection and Measurements by G. Knoll (3rd Edition)
9. Techniques for Nuclear and Particles Physics Experiments by W. R. Leo (2nd edition, Springer)

PHY774 Introduction to Cosmology (60 Lecture Hrs)

Coordinators: Dr. Tuhin Ghosh
tghosh@niser.ac.in

Course Details:

- The cosmic history and inventory
- A sketch of general Relativity and observational Cosmology
- The expanding Universe
- Friedmann Equations and Cosmological Models
- The Standard cosmological model.
- The inflationary Universe.
- Primordial nucleosynthesis and the thermal history of the Universe.
- Perturbations in an expanding Universe.
- Growth of perturbations

- **Special Topics: [If time permits]**
  - Dark matter Halos, Statistical description of gravitational
  - clustering, Lensing, Cluster Cosmology, The Lyman-alpha Forest, Reionization, Halo Model, Redshift Space Distortions, CMB Physics and observations

Course Outcomes:

- This course teaches the students the basic concepts of cosmology required as a foundation to build their background for future research work in this area.

References:

1. Introducing Einstein's general Relativity - Ray D'inverno
2. The Early Universe - Kolb and Turner
3. Introduction to Cosmology - Barbara Ryden
4. Modern Cosmology - Scott Dodelson
5. Large Scale Structure of the Universe - P.J.E. peebles
6. Structure Formation in the Universe - T. padmanabhan
7. Fundamentals of Cosmology - James Rich
8. General Relativity - Hobson, Efstathiou and Lasenby
9. An introduction to Cosmology - J. V. Narlikar