PHYSICAL SCIENCES

Programme Code: PHYS13

Programme Outcome:

- Scientific Foundation & Interdisciplinarity - Apply comprehensive knowledge of the fundamental sciences to solve complex problems by systematically integrating concepts across Physics, Chemistry, Biology, and Mathematics.
- Advanced Disciplinary Expertise - Achieve in-depth competence and mastery in a physical sciences through core coursework starting from the second year. Demonstrate a profound understanding of the fundamental frameworks of physics, including Classical Mechanics, Quantum Mechanics, Electromagnetism, and Statistical Mechanics, through advanced mathematical modeling.
- Research Independence & Critical Thinking - Acquire in-depth knowledge and research-ready expertise in key contemporary areas such as Condensed Matter Physics, Nuclear and Particle Physics, Optics, Magnetism, and Atomic, Molecular, and Radiation physics.
- Technical Proficiency & Digital Literacy - Demonstrate proficiency in modern scientific tools and "state-of-the-art" technologies relevant to experimental and theoretical research in physics. Develop advanced technical skills in diverse experimental setups—ranging from Electronics and Optics to Solid State and Nuclear Physics—alongside the computational capability to simulate and analyze complex physical systems.
- Effective Communication Communicate complex physical concepts and research findings through professional science writing while evaluating the socio-economic and environmental impact of scientific advancements.

DETAILED STRUCTURE OF COURSE

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

Year/Semester	Course	Name of the Course	L-P-T	No of Lectures	Credits
1/Semester I	PHY101	Physics I	28-0-14	42	3
1/Semester II	PHY102	Physics II	28-0-14	42	3
	PHY141	Physics Laboratory	0-28-0	28	2
2/Semester III (20 Credits)	PHY201	Classical Mechanics I	42-0-14	56	4
	PHY203	Mathematical Methods I	42-0-14	56	4
	PHY205	Electromagnetism I	42-0-14	56	4
	PHY241	Electronics: Theory + Laboratory	28-0-28	56	4
	HSS1***	Elective from HSS	42-0-14	-	2
	HSS102	Elective from HSS	42-0-14	-	2
2/Semester IV (20 Credits)	PHY202	Quantum Mechanics I	42-0-14	56	4
	PHY204	Mathematical Methods II	42-0-14	56	4
	PHY206	Electromagnetism II	42-0-14	56	4
	PHY242	Optics: Theory + Laboratory	28-0-28	56	4

	HSS***	Elective from SHSS	42-0-14	-	2
	HSS***	Elective from SHSS	42-0-14	-	2
3/Semester V (20 Credits)	PHY301	Statistical Mechanics	42-0-14	56	4
	PHY303	Quantum Mechanics II	42-0-14	56	4
	PHY341	Computational Physics Laboratory	28-0-28	56	4
	PHY343	General Physics Laboratory	0-28-0	28	2
	PHY345	Modern Physics Laboratory	0-28-0	28	2
	***	Out of Stream Elective I	42-0-14	56	4
3/Semester VI (20 Credits)	PHY302	Classical Mechanics II	42-0-14	56	4
	PHY304	Introduction to Condensed Matter Physics	42-0-14	56	4
	PHY306	Nuclear and Particle	42-0-14	56	4
	PHY342	Nuclear Physics Laboratory	0-28-0	28	2
	PHY344	Solid State Physics Laboratory	0-28-0	28	2
	***	Out of Stream Elective II	42-0-14	56	4
4/Semester VII (20 Credits)	PHY401	Atoms, Molecules and Radiation	42-0-14	56	4

	PHY441	Integrated Physics Laboratory I	-	56	4
	***	Elective 2	42-0-14	56	4
	***	Out of Stream Elective 3	42-0-14	56	4
4/Semester VIII (20 Credits)	PHY442	Integrated Physics Laboratory II	-	56	4
	PHY499	Physics Project I	-	-	4
	***	Elective 3	42-0-14	56	4
	***	Elective 4	42-0-14	56	4
	***	Out of Stream Elective 4	42-0-14	56	4
5/Semester IX (20 Credits)	PHY598	Physics Dissertation Project	-	-	4
	***	Elective 5	42-0-14	56	4
	***	Elective 6 (Out of Stream Elective 5)	42-0-14	56	4
5/Semester X (20 Credits)	PHY599	Physics Dissertation Project	-	-	12
	***	Elective 7	42-0-14	56	4
	***	Elective 8 (Out of Stream Elective 6)	42-0-14	56	4

Minor in Physics

Sl. No.	Course Code	Name of the Course			Credits
1	PHY201	Classical Mechanics I	42-0-14	56	4
2	PHY202	Quantum Mechanics I	42-0-14	56	4
3	PHY203	Mathematical Methods I	42-0-14	56	4
4	PHY205	Electromagnetism I	42-0-14	56	4
5	PHY###	Any one of the other theory courses in Physics	42-0-14	56	4
Total					**20**

List of Elective

Sl. No.	Year/Semester	Course Code	Course Name	L-P-T	No of Lectures	Credits
1	4&5/Semester all	PHY451	Special topics in quantum mechanics	42-0-14	56	4
2	4&5/Semester all	PHY452	Computational Physics	42-0-14	56	4
3	4&5/Semester all	PHY453	Quantum Field theory I	42-0-14	56	4
4	4&5/Semester all	PHY454	Particle Physics	42-0-14	56	4
5	4&5/Semester all	PHY455	Introduction to Phase Transition and Critical Phenomena	42-0-14	56	4
6	4&5/Semester all	PHY456	Nonlinear Optics	42-0-14	56	4

7	4&5/Semester all	PHY457	General Theory of Relativity and Cosmology	42-0-14	56	4
8	4&5/Semester all	PHY458	Soft Condensed Matter	42-0-14	56	4
9	4&5/Semester all	PHY459	Applied Nuclear Physics	42-0-14	56	4
10	4&5/Semester all	PHY460	Quantum many-body theory – formalism	42-0-14	56	4
11	4&5/Semester all	PHY461	Introduction to Mesoscopic phenomena & quantum devices	42-0-14	56	4
12	4&5/Semester all	PHY462	Introduction to Quantum Optics	42-0-14	56	4
13	4&5/Semester all	PHY463	Astronomy and Astrophysics	42-0-14	56	4
14	4&5/Semester all	PHY464	Plasma Physics and Magneto-hydrodynamics	42-0-14	56	4
15	4&5/Semester all	PHY465	Relativistic Nucleus-Nucleus collision and Quark-Gluon Plasma	42-0-14	56	4
16	4&5/Semester all	PHY466	Non-equilibrium Statistical Mechanics	42-0-14	56	4
17	4&5/Semester all	PHY467	Nonlinear Dynamics and Chaos	42-0-14	56	4
18	4&5/Semester all	PHY468	Quantum many-body phenomena	42-0-14	56	4
19	4&5/Semester all	PHY469	Special topics & techniques in quantum condensed matter theory	42-0-14	56	4
20	4&5/Semester all	PHY470	Quantum Field Theory II	42-0-14	56	4
21	4&5/Semester all	PHY471	Quantum Information and Quantum Computation	42-0-14	56	4
22	4&5/Semester all	PHY472	Experimental High Energy Physics	42-0-14	56	4

23	4&5/Semester all	PHY473	Experimental Techniques	42-0-14	56	4
24	4&5/Semester all	PHY474	Introduction to Cosmology	42-0-14	56	4

COORDINATORS

Chief Program Coordinators:

Dr. Ashis Kumar Nandy, Convener, Undergraduate Committee of the School of Physical Sciences.
Dr. Kartikeswar Senapati, Chairperson, School of Physical Sciences

CORE COURSES COORDINATOR

Course name	**Coordinators**	**E-mail**
Introductory Physics I	Prof. Subhankar Bedanta & Dr. Luke Chamandy	sbedanta@niser.ac.in & satyaprasad@niser.ac.in
Introductory Physics II	Dr. Prolay K Mal & Dr. Luke Chamandy	prolay@niser.ac.in & lchamandy@niser.ac.in
Physics Laboratory-I	Dr. Ashis Kumar Nandy & Dr. Satyaprasad Senanayak	aknandy@niser.ac.in & ajaya@niser.ac.in
Classical Mechanics I	Dr. Nishikanta Khandai	nkhandai@niser.ac.in
Mathematical Methods I	Dr. Ashis Kumar Nandy	aknandy@niser.ac.in
Electromagnetism-I	Dr. Joydeep Bhattacharjee	jbhattacharjee@niser.ac.in
Electronics: Theory + Laboratory	Dr. Ajaya Kumar Nayak	ajaya@niser.ac.in
Quantum Mechanics I	Dr. Chetan N. Gowdigere	chetan.gowdigere@niser.ac.in

Mathematical Methods II	Dr. Victor Roy	victor@niser.ac.in
Electromagnetism-II	Dr. Najmul Haque	nhaque@niser.ac.in
Optics: Theory + Laboratory	Dr. Shovon Pal	shovon.pal@niser.ac.in
Statistical Mechanics	Dr. A. V. Anil Kumar	anil@niser.ac.in
Quantum Mechanics II	Dr. Shamik Banerjee	bshamik@niser.ac.in
Computational Physics Laboratory	Dr. Subhasish Basak	sbasak@niser.ac.in
General Physics Laboratory	Dr. Kartikeswar Senapati	kartik@niser.ac.in
Modern Physics Laboratory	Dr. Kartikeswar Senapati	kartik@niser.ac.in
Classical Mechanics - II	Dr. Victor Roy	victor@niser.ac.in
Introduction to Condensed Matter Physics	Dr. Joydeep Bhattacharjee	jbhattacharjee@niser.ac.in
Nuclei and Particles	Dr. Narayan Rana	narayan.rana@niser.ac.in
Nuclear Physics Laboratory	Prof. Sanjay Kumar Swain	sanjay@niser.ac.in
Solid State Physics Laboratory	Dr. Subhankar Bedanta	sbedanta@niser.ac.in
Atoms, Molecules and Radiation	Dr. Chetan N. Gowdigere	chetan.gowdigere@niser.ac.in

Integrated Physics Laboratory I	Dr. Kartikeswar Senapati	kartik@niser.ac.in
Integrated Physics Laboratory II	Dr. Kartikeswar Senapati	kartik@niser.ac.in

ADVANCED COURSES COORDINATOR

Course name	name	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 &	ravi@niser.ac.in &
	Dr. Anamitra Mukherjee	anamitra@niser.ac.in
Introduction to Mesoscopic phenomena & quantum devices	Dr. Colin Benjamin &	colin@niser.ac.in & satyaprasad@niser.ac.in

	Dr. Satyaprasad P Senanayak	
Introduction to Quantum Optics	Dr. Ashok Mohapatra	a.mohapatra@niser.ac.in
Astronomy and Astrophysics	Dr. Nishikanta Khandai &	nkhandai@niser.ac.in & lchamandy@niser.ac.in
	Dr. Luke Robert Chamandy	
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 &	anil@niser.ac.in &
	Dr. Sumedha	sumedha@niser.ac.in
Quantum many-body phenomena	Dr. Kush Saha &	kush.saha@niser.ac.in & anamitra@niser.ac.in
	Dr. Anamitra Mukherjee	
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 & 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 &	prolay@niser.ac.in &
	Prof. Sanjay Kumar Swain	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 COURSE

PHY101 : Physics I (42 Hrs (28 Lectures + 14 Tutorial))

Semester I

Coordinators: Prof. Subhankar Bedanta & Dr. Luke Chamandy
sbedanta@niser.ac.in & satyaprasad@niser.ac.in

Course Details:

- **Mechanics**
  - Newton laws, work-energy theorem, line integrals, conservative forces
  - Simple harmonic motion, forced oscillator, damping, resonance
  - Rotational motion
  - General properties of matter (Elasticity, viscosity, surface tension)
- **Kinetic theory of gases**
- **Thermodynamics**
  - Principles of thermodynamics, thermodynamic states, extensive/intensive variables
  - Heat, work, internal energy and first law of thermodynamics
  - Heat engines, second law of thermodynamics, entropy
  - Thermodynamic potentials

Course Outcomes:

- Builds understanding of basic classical mechanics and thermodynamics.

References:

1. Introduction to mechanics by Daniel Kleppner & Robert Kolenkow. New York: McGraw-Hill Book Co., Inc.
2. Heat and thermodynamics: an intermediate textbook by Mark W. Zemansky & Richard H. Dittman. 7th ed., New York: McGraw-Hill Book Co., Inc., 1997
3. Fundamentals of Physics by David Halliday, Robert Resnick, & Jearl Walker. 8th ed., New Jersey: John Wiley, 2008
4. University Physics by Francis W. Sears, Mark Zemansky, & Hugh D. Young. 7th ed. Massachusetts: Addison Wesley, 1987
5. Mechanics by Keith R. Simon. 3rd ed. Massachusetts: Addison Wesley Pub. Co., 1971
6. Thermodynamics, kinetic theory, & statistical thermodynamics by Francis W. Sears, & Gerhard L. Salinger. 3rd ed., Norosa 1998
7. Mechanics by Charles Kittel, Walter D. Knight & Melvin A. Ruderman. 2nd ed., New York: McGraw-Hill Book Co., Inc., 1973

PHY102 : Physics II (42 Hrs (28 Lectures + 14 Tutorial))

Semester II

Coordinators: Dr. Prolay K Mal & Dr. Luke Chamandy
prolay@niser.ac.in & lchamandy@niser.ac.in

Course Details:

- **Overview of Electromagnetism**
  - Coulomb’s law, Gauss law
  - Biot-Savart law, Ampere law
  - Lorentz force, Faraday law
  - Maxwell’s equations in vacuum and EM wave equation

- **Introduction to relativity**
  - Michelson Morley experiment, Bradley & Fizeau experiment (ether-drag hypothesis)
  - Galilean non-invariance of EM wave equation; postulates of SR
  - Lorentz transformation: length contraction / time dilation / simultaneity
  - Discussion of muon-decay problem

- **Introduction to quantum physics**
  - Black body radiation, photo-electric effect, Compton effect, atomic spectra, Planck postulate, Bohr atom
  - de Broglie hypothesis and Davisson-Germer experiment, Franck-Hertz experiment
  - 1D Schrödinger equation, particle in an infinite potential well
  - entropy
  - Thermodynamic potentials

Course Outcomes:

- Builds basic understanding of electromagnetism, special theory of relativity and quantum physics.

References:

1. Concepts of Modern Physics, Sixth Ed. By Arthur Beiser
2. Fundamentals of Physics by David Halliday, Robert Resnick & Jearl Walker, 8th ed. New York: John Wiley & Sons Inc., 2008
3. Foundations of Electromagnetic theory by John R. Reitz, Fredrick Milford & Robert Christy. 4th ed. Massachusetts: Addison Wesley, 1993
4. Electricity and magnetism (Berkeley Physics Course; vol.2) by Edward M. Purcell. 2nd ed. New York:

McGraw Hill Book Company Inc.
5. Introduction to Electrodynamics by David J. Griffiths, 3rd ed. New Jersey: Prentice Hall
6. Introduction to Quantum Mechanics 2nd ed. by David J. Griffiths

PHY141 : Physics Laboratory (28 Lab Hrs)

Semester II

Coordinators: Dr. Ashis Kumar Nandy & Dr. Satyaprasad Senanayak
aknandy@niser.ac.in & ajaya@niser.ac.in

Course Details:

- Training on Error Analysis
- Compound pendulum
- Moment of Inertia
- Young's modulus
- Soft massive spring and standing waves
- Velocity of Sound
- Viscosity
- Surface tension by capillary rise
- Measurement of Thermal Conductivity
- Study of Electromagnetic Damping
- Magnetic field variation along the axis of a circular coil and a Helmholtz coil
- Young's double slit interference
- Planck's constant by Photoelectric Effect

Laboratory courses are open to inclusion of new experiments in place of old ones.

Course Outcomes:

- Introduces the students to basic methods in experimental techniques, statistics and error analysis. The focus is on basic mechanics, properties of matter, heat and thermodynamics, electromagnetism, optics and modern physics.

References:

1. Classical Electrodynamics by J.D. Jackson (3rd Edition)
2. Classical Electromagnetic Radiation by Mark Heald & J. B. Marion
3. Foundations of Electromagnetic Theory by J. R. Reitz, F. J. Milford & R. W. Christy
4. Classical Theory of Fields by L. Landau and E. Lifshitz
5. Introduction to Electrodynamics by D. J. Griffiths (3rd Edition)

PHY201 : Classical Mechanics I (56 Hrs (42 Lectures + 14 Tutorials))

Semester I

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

Course Details:

- Review of Newtonian mechanics, Two-body central force problem, Collisions and scattering, scattering cross section, Virial Theorem.
- Generalized coordinates and velocities; Lagrangian formulation.
- Principle of least action; Symmetries and Noether's Theorem
- Motion in non-inertial frames; Coriolis force
- Small oscillations; normal modes
- Hamilton's equations; Poisson bracket; Liouville's theorem

Course Outcomes:

- Training in basic classical mechanics, prepares the student for advanced mechanics courses

References:

1. Classical Mechanics, by Keith R. Symon, Pearson Education Dorling Kinderslay, 3rd ed.
2. Classical Mechanics, by W. B. Kibble & F. H. Berkshire, Imperial college press, 5th Ed. By Kibble
3. Classical Mechanics by N. C. Rana & P. S. Joag, Mc Graw Hill Education
4. Classical Mechanics by H. Goldstein, C. P. Poole, J. Safko, Pearson Education Dorling Kinderslay, 3rd Ed.
5. Course of Theoretical Physics, Volume I: Mechanics, L.D. Landau and E.M. Lifshitz

PHY203 : Mathematical Methods I (56 Hrs (42 Lectures + 14 Tutorials))

Semester I

Coordinators: Dr. Ashis Kumar Nandy
aknandy@niser.ac.in

Course Details:

- Vector Calculus, curvilinear coordinates
- Linear vector spaces, Linear operators, linear vector spaces, Hermitian, Projection and Unitary operators, Normal matrices and Diagonalisation, Hilbert Space
- Fourier series, Fourier and Laplace transforms
- Sturm-Liouville Theory, 1st & 2nd order differential equations, Power series solution, Special functions (Hermite, Legendre, Bessel, Laguerre, hypergeometric)

Course Outcomes:

- Provides training in basic mathematical methods needed in all areas of physics

References:

1. Mathematical Methods in the Physical Sciences by M. L. Boas
2. Mathematical Methods for Physicists by G. B. Arfken and H. J. Weber
3. Mathematical Methods for Physics by H. W. Wyld
4. Mathematical Methods by J. Mathews and R. L. Walker
5. Mathematical Physics I and II by S. D. Joglekar
6. Introduction to Mathematical Physics by C. Harper
7. Mathematical Methods for Physics and Engineering by K. F. Riley, M. P. Hobson & S. J. Bence

PHY205 : Electromagnetism I (56 Hrs (42 Lectures + 14 Tutorials))

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

Course Details:

- Introduction to electrostatics and Green function formalism
- Laplace and Poisson equations, boundary value problems
- Dielectrics, Polarization, Electric displacement
- Steady currents, Lorentz force; Magnetostatic (including vector potentials), Magnetic materials
- Time-varying fields, Faraday's law, displacement current
- Maxwell's equations

Course Outcomes:

- Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces to the idea of energy momentum tensor and Gauge invariance.

References:

1. Classical Electrodynamics by J. D. Jackson (3rd Edition)
2. Classical Electromagnetic Radiation by Mark Heald, J. B. Marion
3. Introduction to Electrodynamics by D. J. Griffiths (3rd Edition)
4. Foundations of Electromagnetic Theory by J. R. Reitz, F. J. Milford & R. W. Christy
5. Electricity and magnetism (Berkeley Physics Course; vol.2) by Edward M. Purcell (2nd Edition)

PHY241 : Electronics Theory and Laboratory (56 Hrd (28 Lectures + 28 Tutorials))

Semester I

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

Course Details:

- **PART I (Theory)**
  - Introduction to basic electronics equipment
  - R-L, R-C and LCR circuits
  - Diodes and diode circuits, power supply – rectifiers, half wave and full wave rectifier, Bipolar junction transistors, common 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-amps based differentiator, integrator and phase shift oscillator
  - Digital electronics, gates, universally of certain gates.
  - Boolean expressions, laws of realizing logic functions.
  - Multiplexers, flip-flops and latches, counters, sequential circuits – master slave flip-flop (S-R), edge triggered flip-flops
  - DAC and ADC converting circuits.
- **PART II (Experiments)**
  - Familiarising and using equipment with exercises
  - Passive RC filters and phase shifting network, LCR series resonance circuit
  - Half wave and full wave rectifier circuit, Zener regulated power supply
  - Transistor characteristics and its applications as an amplifier
  - Study of basic configuration of OPAMP (IC-741), simple mathematical operations and its use as comparator and Schmitt trigger
  - Differentiator, integrator circuits and Phase shift oscillator using OPAMP (IC-741)
  - Study of Boolean logic operations using ICs, adder and subtractor
  - Design and study of JK flip-flop and counter circuits
  - DAC and ADC converter circuits

Course Outcomes:

- Trains the student in detailed computations involved in electrostatics and magnetostatics, solving Maxwell's equations. Introduces the ideas of energy, momentum tensor and Gauge invariance.

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-amp and linear integrated circuits by R. G. Gayakwad, Prentice Hall of India
6. Microelectronics by Millman, Grabel, McGraw-Hill

PHY202 : Quantum Mechanics I (56 Hrs (42 Lectures + 14 Tutorials))

Semester II

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

Course Details:

- Schrödinger equation, one-dimensional problems
- Central potentials, Hydrogen atom
- Stern-Gerlach Experiment and spin, Hilbert space formalism, Time dependence in QM, Different Pictures (Not interaction)
- Operator method for simple harmonic oscillator
- Variational Methods and WKB Approximation

Course Outcomes:

- First in-depth introduction of basic ideas and methods in quantum mechanics. This is necessary across almost all advanced modern physics courses.

References:

1. Introduction to Quantum Physics by A. P. French & Edwin F. Taylor
2. Quantum Mechanics by L. L. Schiff
3. Introduction to Quantum Mechanics by D. J. Griffiths
4. Principles of Quantum Mechanics by R. Shankar
5. Modern Quantum Mechanics by J. J. Sakurai
6. Quantum Mechanics by N. Zettili

PHY204 : Mathematical Methods II (56 Hrs (42 Lectures + 14 Tutorials))

Semester II

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

Course Details:

- Functions of a complex variable, analytic functions, residue theorem and applications, conformal mapping, Taylor and Laurent series, analytic continuation, special analytic functions, Gamma functions, method of steepest descent
- Partial differential equations, separation of variables
- Greens functions
- Cartesian tensors, 4-vectors and 4-tensors
- Elements of Group theory

Course Outcomes:

- Prepares the student in important advanced mathematical concepts and tools. This is needed for advanced physics courses such as applications of quantum mechanics in solid state physics quantum field theory and particle phenomenology

References:

1. Mathematical Methods for Physicists by G. B. Arfken & H. J. Weber
2. Complex Variables and Applications (9th Edition) by James Ward Brown, Ruel V. Churchill
3. Mathematical Methods for Physics by H.W. Wyld
4. Mathematical Methods of Physics by J. Mathews and R. L. Walker
5. Mathematics for Physicists by P. Dennery and A. Krzywicki

PHY206 : Electromagnetism II (56 Hrs (42 Lectures + 14 Tutorials))

Semester II

Coordinators: Dr. Najmul Haque
nhaque@niser.ac.in

Course Details:

- Electromagnetic Waves, Poynting’s theorem
- Wave propagation in conductors and dielectrics, Reflection, Refraction, Polarization, Total internal reflection, Attenuation of waves in metals, Brewster’s angle, Wave-guides
- Introduction to Special Theory of Relativity and Covariant Formulation of Electrodynamics, Electromagnetic Energy Momentum tensor
- Lienard-Wiechert potentials, Radiation from an accelerated charge, Larmor formula, Multipole radiation

Course Outcomes:

- Provides training in advanced concepts and methods for understanding advanced electromagnetic phenomena. Important concepts of radiation retardation, multipole expansions, covariant formulation of classical mechanics and relativistic kinematics are taught.

References:

1. Classical Electrodynamics by J. D. Jackson (3rd Edition)
2. Classical Electromagnetic Radiation by Mark Heald & J. B. Marion
3. Foundations of Electromagnetic Theory by J. R. Reitz, F. J. Milford & R. W. Christy
4. Classical Theory of Fields by L. Landau and E. Lifshitz
5. Introduction to Electrodynamics by D. J. Griffiths (3rd Edition)

PHY206 : Optics theory and Laboratory (56 Hrs (28 Lectures + 28 Tutorials))

Semester II

Coordinators: Dr. Shovon Pal
shovon.pal@niser.ac.in

Course Details:

- **Part 1 (Theory):**
  - Plane waves, Spherical waves, wave optics.
  - Interference: Single & multiple-beam interference, Fabry-Perot, Mach-Zehnder, Michelson interferometer, Spatial & temporal coherence.
  - Diffraction: Introduction to Fourier transform, Fresnel and Fraunhofer integral, Fourier analysis and angular spectrum. Examples of single-slit, multiple-slit, circular aperture.
  - Polarization of light, linear, circular and elliptical, Jones matrix formalism.
  - Gaussian Beam propagation.
  - Basic introduction to lasers. (optional)
- **Part 2 (Laboratory):**
  - Michelson Interferometer / Mach-Zehnder Interferometer / Fabry-Perot Interferometer
  - Diffraction of laser light using single slit, thin wire and double slits
  - Splitting of Sodium D-lines using grating
  - Study of polarization of light
  - Study of Gaussian beam propagation using lenses of different focal length

Course Outcomes:

- Provides introduction to basic and slightly advanced topics in classical optics. The course also helps build up basics for experimental work in advanced laboratories.

References:

1. Fundamentals of Photonics (2nd Edition) by B. E. A. Saleh, Malvin Carl Teich
2. Optics by Ajoy Ghatak (5th Edition), Tata McGraw Hill
3. Optics by Eugene Hecht (5th Edition), Pearsons
4. Modern Optics by B. D. Guenther (2nd Edition), Oxford University Press
5. Lasers by P. W. Milonni and J. H. Eberly

PHY301 : Statistical Mechanics (56 Hrs (42 Lectures + 14 Tutorials))

Semester I

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

Course Details:

- Basics of Probability theory: Probability distribution, cumulants, central limit theorem; laws of large numbers
- Fundamentals of statistical mechanics: Phase space and Liouville theorem; microscopic definition of entropy, ergodic hypothesis, Kinetic Theory of Gases
- Ensembles theory: Microcanonical, canonical and grand canonical ensembles
- Gibbs Paradox, Energy and density fluctuations. Application to ideal gases, spin and non-interacting systems.
- Laws of thermodynamics and entropy, Thermodynamic potentials and thermodynamic stability.
- Quantum Statistical Mechanics: Ideal quantum gases; Bose and Fermi distribution; phonons, photons; Fermi sea; density matrix formulation. Examples: electrons in metal, black body radiation, Bose-Einstein condensation and white dwarf.
- Deviations from ideal gas law behavior: Van der Waals equation, liquid-gas transition, Maxwell construction, phase diagram of water.

Course Outcomes:

- The course trains the student in basics of statistical mechanics, introduces important concepts like the density matrix, different kinds of quantum statistics and the idea of fluctuation dissipation theorem.

References:

1. Statistical Physics by F. Reif
2. Introduction to Statistical Physics by Kerson Huang
3. Statistical Mechanics by R. K. Pathria and P. D. Beale
4. Statistical Physics of Particles by M. Kardar
5. Introduction to Modern Statistical Mechanics by D. Chandler
6. Statistical Mechanics by R. P. Feynman
7. Statistical Physics (Vol. I) by L. Landau and E. Lifshitz

PHY303 : Quantum Mechanics II (56 Hrs (42 Lectures + 14 Tutorials))

Semester I

Coordinators: Dr. Shamik Banerjee
bshamik@niser.ac.in

Course Details:

- General treatment of angular momentum, Spin, Addition of angular momentum, Vector and Tensor operators
- Discrete Symmetries (Parity and Time-Reversal)
- Approximation methods: Time-independent perturbation theory, degenerate perturbation theory; Time-dependent perturbation theory
- Density Matrix
- Identical particles, Pauli exclusion principle
- Scattering theory

Course Outcomes:

- Prepares the student in the intermediate level of quantum mechanics needed across many advanced disciplines. Introduces important concepts for time evolution in quantum mechanics, propagators and path integrals and relativistic quantum mechanics.

References:

1. Modern Quantum Mechanics by J. J. Sakurai
2. Principles of Quantum Mechanics by R. Shankar
3. Quantum Mechanics by E. Merzbacher
4. Quantum Mechanics (volumes 1 and 2) by A. Messiah
5. Quantum Mechanics (Vol. I & Vol. II) by C. Cohen-Tannoudji, B. Diu & F. Laloe

PHY341 : Computational Physics Laboratory (56 Hrs (28 Lectures + 28 Tutorials))

Semester I

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

PHY343 : General Physics Laboratory (28 Lab Hrs)

Semester I

Coordinators: Dr. Kartikeswar Senapati
kartik@niser.ac.in

Course Details:

- Coefficient of linear expansion by Fizeau's method
- Young's modulus of glass by Cornu's method
- Study of Newton's ring
- Diffraction by ultrasonic waves in liquids
- Magnetic susceptibility of a paramagnetic material
- Young's modulus of glass by Cornu's method
- Specific charge (e/m) of electron
- Magnetic hysteresis
- Dielectric constant
- Study of Coulomb's law
- Laboratory courses are open to inclusion of new experiments in place of old ones

Course Outcomes:

- Expands the training of the students, building on PI41 to train them further in experimental methods.

References:

1. Lab manuals

PHY345 : Modern Physics Laboratory (28 Lab Hrs)

Semester I

Coordinators: Dr. Kartikeswar Senapati
kartik@niser.ac.in

Course Details:

- Franck-Hertz Experiment
- Emission spectra of metals and absorption spectra of Iodine
- Balmer series with hydrogen spectra
- Millikan oil drop experiment
- Electron spin resonance of DPPH
- Zeeman effect
- Lock in Amplifier

Laboratory courses are open to inclusion of new experiments in place of old ones

Course Outcomes:

- This course provides further experience to the students in experiments in modern quantum mechanics.

References:

1. Lab manuals

PHY302 : Classical Mechanics II (56 Hrs (42 Lectures + 14 Tutorials))

Semester II

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

Course Details:

- Rigid body dynamics; Euler angle, Euler equations (should solve up to nutation of a top).
- Canonical transformations, Generating functions, Hamilton-Jacobi equation, Symmetries in the Canonical formulation
- Continuous Systems and Fields, Strings and Membranes
- Fluids: Newton's second law for an ideal fluid, continuity equation, Euler equation, Bernoulli's theorem, sound waves in fluids
- Viscous Fluids: Concept of stress tensor, Navier Stokes equation, examples of incompressible flow

Course Outcomes:

- This is an advanced course introducing the students to concepts and techniques in mechanics of continuous media. It prepares them to tackle a variety of problems in many areas such as fiber optics, fluid dynamics and structural stability of materials.

References:

1. Classical Mechanics by N. C. Rana & P. S. Joag
2. Classical Mechanics by H. Goldstein, C. P. Poole, J. Safko
3. Classical Mechanics by A. L. Fetter and J. D. Walecka
4. Fluid Mechanics by L. Landau and E. Lifshitz

PHY304 : Introduction to Condensed Matter Physics (56 Hrs (42 Lectures + 14 Tutorials))

Semester II

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

PHY306 : Nuclei and Particles (56 Hrs (42 Lectures + 14 Tutorials))

Semester II

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. Griffiths
4. Introduction to Particle Physics by D. J. Perkins

PHY342 : Nuclear Physics Laboratory (28 Lab Hrs)

Semester II

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

Course Details:

- Basics of GM: 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
- Analog to digital conversion and digital to analog conversion

**Laboratory courses are open to inclusion of new experiments in place of old ones

Course Outcomes:

- This course teaches the students about basic experimentation in nuclear physics. It in conjunction with the theory course on nuclear physics P307 builds a background to carry out basic research in the field of experimental particle physics.

References:

1. Lab manuals

PHY344 : Solid State Physics Laboratory (28 Lab Hrs)

Semester II

Coordinators: Dr. Subhankar Bedanta
sbedanta@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, Ohmic contact and Schottky barrier
- Study of Paraelectric-Ferroelectric transition to determine Curie temperature
- Study of Antiferromagnetic to Paramagnetic phase transition to determine Neel temperature
- Experiments with SEELab and basic instrumentation using Python

Course Outcomes:

- In this course the student is introduced to a variety of basic experiments in solid state physics. This prepares them for taking up more challenging experiments.

References:

1. Lab manuals

PHY401 : Atoms, Molecules and Radiation (56 Hrs (42 Lectures + 14 Tutorials))

Semester I

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

Course Details:

- Addition of angular momentum 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 and 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 H_2 Molecule; Molecular Orbital Approximation; Electronic States of Diatomic Molecules; Electronic Angular Momentum, Electron Spins, Multiplicity and Fine Structure; Vibration 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 Atoms 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 by C. E. Burkhardt and J. J. Leventhal
6. Physics of Atoms and Molecules by B. H. Bransden and C. J. Joachain

PHY441 : Integrated Physics Laboratory I (56 Lab Hrs)

Semester I

Coordinators: Dr. Kartikeswar Senapati
kartik@niser.ac.in

Course Details:

Any two experiments out of the following or any new viable proposals for experiment by students.

- Measurement of Muon life time
- Proportional counter, Geiger and pocket Geiger counters
- Experiments with Arduino and FPGA for nuclear physics experiments
- Alpha particle ranges and Alpha gamma coincidence
- SQUID and Superconductivity using LC Circuit
- Vibration sample magnetometer and solid-state experiments
- Study of Faraday effect in DC and AC magnetic fields
- Raman spectroscopy and Electron diffraction
- Capacitance Voltage profiling of Schottky diode, solar cell and FET using data interfacing cards and LabView
- Topological circuits with lock in amplifier and Magnetostriction
- Hall effect, Resistivity and other characterization of thin film samples with temperature
- Study of various experiments with Microwaves
- Study of Earth Field Nuclear Magnetic Resonance
- Study of Coupled Oscillators
- Noise Fundamentals: Study of Johnson noise and Schottky noise

Laboratory courses are open to inclusion of new experiments in place of old ones

Course Outcomes:

- In this course the student is introduced to a variety of advanced experiments on different topics in an open ended environment.

References:

1. Open literature and lab manuals

PHY442 : Integrated Physics Laboratory II (56 Lab Hrs)

Semester II

Coordinators: Dr. Kartikeswar Senapati
kartik@niser.ac.in

Course Details:

Any two experiments out of the following or any new viable proposals for experiment by students.

- LIGO analogy experiment
- Quantum optics experiments, single photon interference
- Study of Holography
- Fourier optics, spatial filtering and phase contrast microscopy
- Alignment of He-Ne Laser and study of spectral and spatial properties of the beam
- Study of Nd-YAG laser
- Experiments with Optical fiber
- Study of Laser Doppler Anemometry
- Study of Geometric phase
- Surface Plasmon resonance and Tamm modes
- Study of Negative group delay in electronics circuit
- Study of Nonlinear circuits: Feigenbaum, Chua and Lorentz oscillator
- Double pendulum and study of chaos in other systems
- Na-I(H) line and 21 cm Radio antenna experiments and antenna characteristics
- Metamaterials at acoustic frequencies

Laboratory courses are open to inclusion of new experiments in place of old ones

Course Outcomes:

- In this course the student is introduced to a variety of advanced experiments on different topics in an open ended environment.

References:

1. Open literature and lab manuals

ELECTIVE COURSES

PHY451 : Special Topics in Quantum Mechanics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 Hammermesh
3. Lie Algebras in Particle Physics: from Isospin To Unified Theories by Howard Georgi
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

PHY452 : Computational Physics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 applications.
- Molecular Dynamics: Integration methods (e.g Verlet and Leap frog algorithms), extended ensembles, molecular system.
- Variational methods for Schrödinger 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 Liquids 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. Frenkel 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. Cramer
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

PHY453 : Quantum Field Theory I (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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
- Finite 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: 115013

PHY454 : Particle Physics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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, OFT course, propagators.
- 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

PHY455 : Introduction to Phase Transitions and Critical Phenomena (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 mean field.
- Curie-Weiss mean field theory and Landau-Ginzburg theory, calculation of critical exponents from mean field systems, range of validity of mean field theory.
- Introduction to renormalization 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. [14 L]

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

PHY456 : Nonlinear Optics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 Birefringence.
- 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 optics 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

PHY457 : General Theory of Relativity and Cosmology (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 student 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

PHY458 : Soft Condensed Matter (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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

Course Details:

- Introduction: Basic phenomenology of soft condensed matter systems, intermolecular forces, visco-elasticity, ordering in soft matter, glass transition, phase separation

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- Diffusion processes: Fick's laws, Diffusion Equation, Random walks, Brownian motion, Langevin and Fokker-Planck 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 W. Hamley
5. Soft Matter Physics by M. Kleman and O. D. Lavrentovich
6. Colloidal Dispersions by W. B. Russel, D. A. Saville and W. R. Schowalter
7. Dynamics of Colloids by J. K. G. Dhont
8. Intermolecular and Surface Forces: With Applications to Colloidal and Biological Systems by J. Israelachvili
9. Introduction to Liquid Crystals by P. J. Collings and M. Hird
10. Polymer solutions – an introduction to physical properties by I. Teraoka

PHY459 : Applied Nuclear Physics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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

PHY460 : Quantum many-body theory – formalism (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 bosons: Hartree-Fock, Random phase and ladder approximations, Goldstone theorem, Lee, 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 in condensed matter theory.

References:

1. Advanced Quantum Mechanics E. 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 Radhika A. Ishit
5. Green's Function for Solid State Physics by 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

PHY461 : Introduction to Mesoscopic phenomena & quantum devices (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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

Course Details:

The course will cover the basic material. Electives from the theoretical or experimental topics can be chosen as per the request. The degree of focus of theory or experiment will be at the discretion of the instructor.

- **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; Transport under magnetic field; Shockley-de Haas oscillations; Magnetic edge states; Integer Quantum Hall effect; Fractional Quantum Hall effect.
  - Electron transport: Ballistic semiclassical transport; Onsager reciprocity relations; Conventional Hall effect; Drude conductivity; Einstein relation; Electrostatics in quantum confined systems.

Note: both options modules below may be taken whereas the instructor is free to teach any one module or mix of both.

- **Topic I: Theory of quantum devices**
  - Conductors: from macroscopic, ballistic transport, Quantum dots, conductance, Landau-Büttiker formula.
  - Quantum point contacts: T-matrices; S-matrix and Green functions; Current operator; Landauer Büttiker formalism.
  - Nanostructures: Quantum wells, Quantum dots, Single electron transistors; Field effect transistors; High electron mobility transistors; Coulomb blockade and Kondo effect.
  - Disorder and conductors: Weak localization; Mesoscopic fluctuations; Random Matrices; Anderson localization; Quantum Chaos; Dephasing; Decoherence.

- **Topic II: Realization of quantum devices**
  - Fabrication and characterization methods for nano-electronics
  - The field effect transistor FET: size limits and alternative forms
  - Defects in nanostructures; Imaging and modification methods
  - Electron tunneling, molecular electronics, hybrid electronics
  - Quantum dot based devices
  - Qubits: binary bits vs quantum bits, applications of nano-electronic technology to energy issues

- Spin qubits
- Quantum information: Josephson junctions and Qubits; Metastable states and energy dissipation

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 Y. Meir and N. S. Wingreen
5. Quantum nano-electronics: An introduction to Mesoscopic Physics by Dragos V. Averin and Klaus Likharev
6. Nanotechnology and Quantum Transport by Edward L. Wolf
7. Quantum Nano-electronics: An Introduction to Modern Concepts by Stefano Datta
8. Fundamentals of Nanotechnology by George Hanson

PHY462 : Introduction to Quantum Optics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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: Properties and phase space picture of coherent state, Generation of a coherent state, Squeezed state physics, generation and Detection of squeezed light, Schrödinger cat states, Multi-mode squeezing, Broadband squeezed light, Squeezing via non-linear processes. [10L]
- Atom-field interaction: Rabi model (Semi-classical model for atom-field interaction), Jaynes-Cummmings model (fully quantum mechanical model for atom-field interaction).
- Quantum coherence function: photon detection and quantum coherence functions, First-order coherence 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 theorem.

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

PHY463 : Astronomy and Astrophysics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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, astronomy, magnetic field
  - Gravity: Kepler's laws, virial theorem
  - Radiation physics – radiative flux, transfer function, absorption, scattering and emission, Einstein coefficients, local thermodynamic equilibrium, source function, line formation, concept of opacities
- **PART II: Stars and Planets**
  - 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 III: 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
- **PART IV: Cosmology**
  - 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
- **PART VI: Measurements**
  - Particle astrophysics
- **PART VII: Gravitational lensing**

- **PART VIII: Expanding Universe and Superclusters**

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 – Zelik and Gregory
7. Universe – Roger Freedman
8. Astrophysics – E. E. Shapiro
9. Astrophysics Processes by Hale Brady
10. Radiative processes in Astrophysics by Rybicki and Lightman

PHY464 : Plasma Physics and Magneto-hydrodynamics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 invariance, 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, Stefan 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

PHY465 : Relativistic Nucleus–Nucleus collision & Quark–Gluon Plasma (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 vector 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 Letessier 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 Relativistic Heavy Ion by Wick
12. Research Report in Physics, Quark Gluon Plasma, invited lectures of Winter School, Published by Springer Verlag, Editors – S. Bihlsa, 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. Kapusta, B. Muller and J. Rafelski, Publisher – Elsevier Science

PHY466 : Non-equilibrium Statistical Mechanics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 Kinetics, 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: Non-equilibrium 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

PHY467 : Nonlinear Dynamics and Chaos (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 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
5. Chaos in Dynamical Systems by Edward Ott
6. Chaos and Integrability in Nonlinear Dynamics: An Introduction by M. Tabor

PHY468 : Quantum many-body phenomena (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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

PHY469 : Special topics & techniques in quantum condensed matter theory (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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, variational 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 Molller-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, degeneracy ground states, variational DFT, N → 1 representability problem, Levy-Lieb constrained search, fractional particle number & derivative discontinuity, spin polarized systems, excited states, non-integer particle number, Kohn-Sham (KS) constructions, perturbative G-GP expansion, degeneracy and symmetry, spin-polarized systems, interpretation of KS eigenvalues.
  - Exchange-Correlation (XC) Energy Functional: exact exchange formalism within DFT, exact exchange TDDFT, range-separated functionals, LDA, 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, DFT-DMFT, orbital free DFT.
  - Crossover of Excited-States: time-dependent DFT, Runge-gross theorem, time-dependent KS equations, adiabatic LDA & TD XC potentials, linear response TDDFT, excited states part I, spin polarized TDDFT, frequency dependent XC kernel, TDDFT, TDDFT-B, 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 low energy excitations; DQMC techniques for interacting lattice fermion models: applications to 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-Schrieffer-Heeger model and winding number
  - Kitaev Chain and topological superconductor
  - Thouless Charge pumping and Laughlin argument
  - 2Z 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 standing board discusses 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 M. 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. Quantum Density Functional Theory I & II by Virath Shankar
9. Recent advances in Density Functional Methods (Part I, II & III) by Delano P. Chong
10. Atomic and Electronic Structure of Solids by Efthimios 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. Jørgensen and J. Olsen
15. Electronic Structure Calculations for Solids and Molecules by J. Kohanoff

16. Methods of Electronic Structure Calculations by M. P. 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://github.com/javiersant
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 dimensions Rev. Mod. Phys. 68, 1996
6. The density-matrix renormalization group Ulrich Schollwöck 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 Physics Lectures of a Seminar and Workshop held at the Max-Planck-Institute für Physik komplexer Systeme: Ingo Peschel, Matthias Kaulke, Xiaoguang 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

PHY470 : Quantum Field Theory II (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

Coordinators: Dr. Chethan N. Gowdigere & 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
- IPI 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, irrelevant and marginal operators, anomalous dimension, brief introduction to Wilsonian renormalisation group
- Finite 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: 115013

PHY471 : Quantum Information & Quantum Computation (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 by P. R. Laflamme and A. M. Mosca (Oxford U. Press)

PHY472 : Experimental High Energy Physics (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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 kinematics variables and their transformations whenever needed. Decay kinematics. Rapidity, pseudo-rapidity, space-like and time-like. Some examples where relativistic kinematics plays an important role for understanding of data.
- Detectors in High Energy physics: general concept of building a HEP experiment, coverage and option [5L]
- Gas detectors; Semiconductor detector; Scintillator and Cerenkov detectors
- Calorimeter and Pre-shower detectors: principle of electromagnetic and hadronic shower generation. Detector Simulation: of various techniques, MC, some generation
- Concepts, Data analysis in HEP: general approach of data cleanup, calibration, track reconstruction, construction of events Error analysis in EHEP. Computing in EHEP: Basics of OO programming using C++, few applications in EHEP data 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 High 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. Fruwirth, M. Regler, R. K. Bock and H. Grote

PHY473 : Experimental Techniques (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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
- Basic 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 detectors, 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 Darryl 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)

PHY474 : Introduction to Cosmology (56 Hrs (42 Lectures + 14 Tutorials)

Semester I / II

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