

Dhanamanjuri University
Manipur
Department of Physics

DHANAMANJURI UNIVERSITY

RR. No. : 8307

Date : 30/5/26

To,
The Registrar
Dhanamanjuri University Manipur.

[Through the Dean School of Mathematical and Physical Sciences]

Subject: Course structures and syllabus of The One-Year PG Programme for Physics.

Sir,

In reference to the order number 1/43/2024-DMU/NEP/Misc/1285 dated 27th April 2026, I, the undersigned, herewith submit the course structures and syllabus of The One-Year PG Programme for Physics.

With regards,

Yours sincerely,



M. Shomananda Singh
HOD, Department of Physics DM
University.

Head
Department of Physics
Dhanamanjuri University, Manipur

Place: Imphal
Date: 30/05/2026

*Forwarded for favourable
and message - a.s.m.*

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Dean
School of Mathematical and Physical Sciences
Dhanamanjuri University, Manipur

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**DEPARTMENT OF PHYSICS
DHANAMAJURI UNIVERSITY**

Imphal 795001

SYLLABUS FOR ONE YEAR M.Sc. (Physics) COURSE

In the present syllabus for the M.Sc. Course in Physics, the Department adopts the choice-based credit system. The course content is distributed over two semesters. The course structure is given below.

Course structure of 1-year PG Programme in Physics
(2-SEMESTER PG PROGRAMME)

Semester I

Paper Code	Type	Title	Internal Assessment Mark		Practical	End semester marks	Total marks	Number of credits
			Class Test	Seminar				
PHY 613	Discipline Specific Core	Atomic and Molecular Physics	10	10		80	100	4
PHY 614	Discipline Specific Core	Nuclear and Particle Physics	10	10		80	100	4
A. PHY 621 B. PHY 622	Discipline Specific Elective I	A. Advanced Condensed Matter Physics I	5	10	25	60	100	4
		B. General Relativity and Cosmology	10	10		80		
A. PHY 631 B. PHY 632	Discipline Specific Elective II	A. Advanced Nuclear Physics B. Quantum Field Theory	10	10		80	100	4
PHY 615	Lab	Practical based on PHY 613 and PHY 614					100	4
Total							500	20

NB: The students may opt any one of the subjects of **Discipline Specific Elective I**, and also any one of the subjects in **Discipline Specific Elective II** on the availability of the teachers in the faculty.

Semester II

Paper Code	Type	Title	Internal Assessment Mark		Practical	End semester marks	Total marks	Number of credits
			Class Test	Seminar				
PHY 617	Discipline Specific Core	Computational Physics	10	10	—	80	100	4
A. PHY 623 B. PHY 624 C. PHY 625 D. PHY 633 E. PHY 634 F. PHY 641 G. PHY 642	Discipline Specific Elective III	A. Fabrication of Integrated Devices B. Non-linear Dynamics C. Nanoscience D. Particle Physics E. Experimental Techniques for Material Characterization F. Advanced Condensed Matter Physics II G. Astrophysics	10	10	—	80	100	4
PHY 618	Lab	Practical based on PHY 617					100	4
PHY 619	Academic Project/Dissertation	Academic Project/Dissertation					150	6
PHY 620	Research Methodology/Theory	Research Methodology	10			40	50	2
AEC XXX	VAC/AEC					50	50	2
Total							550	22

NB: a) The students may opt any one of the subjects of **Discipline Specific Elective III**. b) There will be no internal assessment for the Dissertation paper. However, the paper shall consist of two components: Evaluation of Dissertation (100) and Viva-voce (50) marks.

Semester I

PHY 613: Atomic and Molecular Physics

100 Marks/4 Credits

Objective:

To build a solid foundation in atomic and molecular physics along with laser principles, enabling students to understand quantum states, spectra, coupling mechanisms, molecular bonding, and laser operation with applications.

Course Learning Outcomes:

- Explain quantum states, hydrogen atom spectrum, Pauli's principle, fine structure, and coupling schemes in one- and two-electron systems.
- Analyse Zeeman, Paschen-Back, Stark effects, hyperfine structure, and line broadening mechanisms.
- Apply molecular models such as Heitler-London and molecular orbital theory, Born-Oppenheimer approximation, and LCAO to describe bonding and valence.
- Interpret electronic, vibrational, and rotational spectra of diatomic molecules, apply selection rules, and analyse vibrational progressions using the Franck-Condon principle.
- Understand Raman spectroscopy and its applications in molecular analysis.
- Describe laser fundamentals, Einstein coefficients, optical pumping, and conditions for population inversion and laser oscillation.
- Differentiate between three-level and four-level laser systems, and explain the working principles of He-Ne, CO₂, Ruby, and semiconductor lasers.

Syllabus:

Unit 1. Atomic Physics

Quantum states of one electron atoms, Atomic orbitals, Hydrogen spectrum, Pauli's exclusion principle, Spectra of alkali elements, Spin-orbit interaction and fine structure in alkali spectra, Equivalent and non-equivalent electrons, spectral terms, Normal and anomalous Zeeman effect, Paschen Back effect, Stark effect, Two electron systems, interaction energy in LS and JJ couplings, Hyperfine structure (qualitative discussion only), Line broadening mechanisms (general ideas).

35 Marks

Unit 2. Molecular Physics

Hydrogen molecular ion, hydrogen molecule, Heitler-London method, molecular orbital, Born-Oppenheimer approximation, bonding, directed valence, LCAO.

Electronic, vibrational and rotational spectra of diatomic molecules, selection rules, term schemes, applications to electronic and vibrational problems, progressions and sequences of vibrational bands, Frank Condon principle, Raman spectroscopy.

35 Marks

Unit 3. Lasers

Basic elements of laser, properties of laser light, spontaneous and stimulated emissions – Einstein coefficients, optical pumping, light amplification, population inversion, threshold condition for laser oscillations, three level and four level laser systems, He-Ne laser, CO₂ laser, Ruby laser and Semiconductor laser.

30 Marks

References

1. *Physics of Atoms and Molecules*: B. H. Bransden and C. J. Joachain (Pearson, 2003)
2. *Introduction to the Quantum World of Atoms and Molecules*: Jens P. Dahl (World Scientific, 2001)
3. *Fundamentals of Molecular Spectroscopy*: Colin N. Banwell and Elaine M. McCash (McGraw Hill, 1994)

4. *Introduction to Molecular Spectroscopy*: Gordon M. Barrow (McGraw Hill, 1962)
5. *Quantum Chemistry*: I. N. Levine (Prentice Hall, 2016)
6. *Molecular Quantum Mechanics*: Peter Atkins and Ronald Friedman (Oxford University Press, 2012)
7. *Atomic Physics*: C. J. Foot (Oxford University Press, 2005)
8. *Modern Spectroscopy*: J. M. Hollas (Wiley-Blackwell, 2003)
9. *Spectra of atoms and molecules*: P. F. Bernath (Oxford University Press, 2005)
10. *Introduction to Atomic spectra*: H. E. White (McGraw Hill, 1934)
11. *Laser Fundamentals*: W. T. Silfvast (Cambridge University Press, 2004)

PHY 614: Nuclear and Particle Physics

100 Marks/4 Credits

Objective:

To develop an in-depth understanding of nuclear forces, nuclear models, beta decay processes, and elementary particle physics, fostering the ability to analyse experimental evidence and theoretical frameworks leading to the Standard Model.

Course Learning Outcomes:

- *Explain deuteron structure, nucleon–proton scattering, effective range theory, and spin dependence of nuclear forces including exchange, tensor, and meson theories.*
- *Apply concepts of charge independence, charge symmetry, and isospin formalism to nuclear interactions.*
- *Describe liquid drop and shell models of the nucleus, Bohr–Wheeler theory of fission, and interpret magnetic moments with Schmidt lines.*
- *Analyse beta decay using Fermi's theory, Kurie plots, selection rules, and distinguish allowed/forbidden transitions, including parity violation and Gamow–Teller transitions.*
- *Classify elementary particles and interactions, apply conservation laws, and use isospin, strangeness, and Gell-Mann–Nishijima relations for particle assignments.*
- *Explain quark model classification, mass formulas for hadron multiplets, and discuss properties of quarks leading to the Standard Model framework.*

Syllabus:

Unit 1

Deuteron problem, Nucleon – proton scattering, Effective range theory, Spin dependence of nuclear forces (ortho and para – hydrogen), Exchange forces and tensor forces, Charge independence and charge symmetry of nuclear forces, Isospin formalism, Meson theory of nuclear forces.

25 Marks

Unit 2

Liquid drop model, Bohr – Wheeler theory of fission, Evidence for shell structure, single –particle Shell model and its limitations, Magnetic moments and Schmidt lines.

25 Marks

Unit 3

Fermi's theory of beta decay, Kurie plot, Comparative half – lives, Allowed and forbidden transitions, Selection rules, Fermi and Gamow – Teller transitions, Parity violation in beta – decay.

25 Marks

Unit 4

Classification of elementary particles, fundamental interactions, conservation laws, Spin and Parity assignments, isospin, strangeness, Gell – Mann – Nishijima formula, C, P and T invariance, Quark

model, Gell – Mann – Okubo mass formula for octet and decuplet hadrons, Properties of quarks and their classification, Introduction to Standard model.

25 Marks

References

1. *Introductory Nuclear Physics*: Kenneth S. Krane (Wiley, 1988)
2. *Atomic and Nuclear Physics, Vol. 2*: S. N. Ghoshal (S Chand & Company, 1997)
3. *Nuclear Physics*: R. Roy and B. P. Nigam (Wiley – Eastern India Ltd., 1983)
4. *Introduction to High Energy Physics*: D. H. Perkins (Addison – Wesley, 1982)
5. *Introduction to Elementary Particles*: David Griffiths (Wiley – VCH, 1987)
6. *Concepts of Nuclear Physics*: Bernard L. Cohen (McGraw Hill, 2017)

Objective:

To provide students with theoretical and conceptual understanding of lattice vibrations, transport phenomena, electron-phonon interactions, superconductivity, and nanostructure physics, preparing them to analyse and apply solid-state physics principles in modern research and technology.

Course Learning Outcomes:

- Explain lattice vibrations using Born–Oppenheimer approximation, derive dispersion relations, and distinguish between acoustic and optical phonon modes in 1D, 2D, and 3D lattices.
- Analyse transport properties including phonon–phonon interactions, thermal expansion, electrical/thermal conductivity, Hall effect, magnetoresistance, and transport in composite materials.
- Understand electron–phonon interactions, polarons, and mechanisms of superconductivity, including Cooper pairing, BCS theory, Ginzburg–Landau theory, Josephson effect, vortices, and high-temperature superconductors.
- Apply the concept of quantum confinement to quantum wells, wires, and dots, and discuss how size affects density of states and material properties.
- Describe methods of synthesizing nanomaterials and characterize them using TEM, STM, and AFM techniques.

Syllabus:

Unit 1. Lattice vibrations: The Born–Oppenheimer Approximation, one-dimensional lattice, classical two-atom lattice with periodic boundary conditions, classical Diatomic lattice vibration, optic and acoustic modes, three-dimensional lattices, calculations of dispersion relations, phonons.

15 Marks

Unit 2. Transport properties: Phonon-phonon interactions, thermal expansion, thermal conductivity. The Boltzmann transport equation, motivation for solving the Boltzmann equation, scattering processes, the relaxation – time approximation, electrical conductivity for metals, theory of Hall effect, magnetoresistance, Effect of open orbit on magnetoresistance, giant magnetoresistance. Transport coefficients, electrical conductivity, Peltier coefficient, thermal conductivity, transport and material properties in composites.

35 Marks

Unit 3. Electron phonon interaction: Interaction of electrons with acoustic and optical phonons, polarons, superconductivity, Cooper pairing due to phonons, BCS theory of superconductivity, Ginzburg–Landau theory and application to Josephson effect, macroscopic quantum interference, vortices and type II superconductor, high temperature superconductivity (elementary)

30 Marks

Unit 4. Physics of nanostructures: Quantum confinement and its consequences, density of states, energy of charge carriers in quantum wells, wires and dots. Physical and chemical methods of synthesizing nanomaterials, Transmission electron microscopy, scanning tunnelling microscopy and atomic force microscopy, size dependent properties of nanostructures.

20 Marks

References:

1. *Introduction to Solid State Theory*, O. Madelung (Springer, 2004).
2. *Soild – State Theory*, James D. Patterson and Bernard C. Bailey (Sringer, 2009)
3. *Solid State Theory*, W.A. Harrison (Dover Publications, 1980)
4. *Condensed Matter Physics*, M.P.Marder (Wiley- Interscience, 2000).

Semester I

PHY 622: Elective I (B) General Relativity and Cosmology

100 Marks/4 Credits

Objective:

To provide a comprehensive understanding of Special and General Relativity, spacetime geometry, Einstein's field equations, and cosmology, enabling students to analyse physical phenomena from fundamental principles to modern applications in astrophysics and cosmology.

Course Learning Outcomes:

- Understand the principles of Special Relativity, spacetime diagrams, and the formulation of electrodynamics in four-dimensional language.
- Learn the principle of equivalence, equality of inertial and gravitational mass, and the concept of gravitation as spacetime curvature.
- Gain proficiency in tensor analysis, Riemannian geometry, metric tensor, covariant derivatives, curvature tensors, and the mathematical framework for physics in curved spacetime.
- Apply Einstein's field equations to physical systems, study particle orbits, Schwarzschild solution, and analyse experimental tests of General Relativity including gravitational waves.
- Understand cosmological models, Robertson–Walker metric, Hubble's law, Friedmann equations, early universe physics, and concepts of dark matter, dark energy, inflation, and CMBR.

Syllabus:

Unit 1.

Overview of Special Theory of Relativity, principle of relativity, space-time diagrams, electrodynamics in 4 dimensional language. **20 Marks**

Unit 2.

Introduction to General Relativity (GR), Equality of gravitational and inertial mass, principle of equivalence, gravitation as spacetime curvature. **10 Marks**

Unit 3.

Riemannian geometry, tensor analysis, covariant and contravariant tensors, Metric tensor, Parallel transport and covariant derivative, affine connection, physics in curved spacetime, Energy momentum tensor, Curvature tensor, Bianchi identities, Weyl tensor and conformal invariance. **25 Marks**

Unit 4.

Einstein's field equations, Newtonian approximation, test particle orbits for massive and massless particles, Solutions to Einstein's equations and their properties, Derivation of the Schwarzschild solution, Experimental tests for GR: Precession of perihelion of Mercury, binary pulsars, gravitational redshift and bending of light, gravitational waves. **25 Marks**

Unit 5.

Cosmology: Cosmological Principle, maximally symmetric spaces. Killing vectors, Robertson-Walker metric, Redshift of galaxies and Hubble's law, Magnitude-redshift relation, Hubble's constant and deceleration parameter, Friedmann equations and solutions, closed, open and flat Universes, Thermal history of early Universe, Big Bang, dark energy, Planck time, baryon asymmetry,

nucleosynthesis, decoupling of matter and radiation, Cosmic Microwave Background Radiation (CMBR), dark matter, inflation.

20 Marks

References:

1. James Foster and J. D. Nightingale, *A Short Course in General Relativity*, (Springer, 2006)
2. B. F. Schutz, *First Course in General Relativity* (Cambridge University Press, 2009)
3. Steven Weinberg, *Cosmology* (Oxford University Press, 2008)
4. Tai L. Chow, Gravity, Black Holes and the Very Early Universe: *An Introduction to General Relativity and Cosmology* (Springer, 2008)
5. L. D. Landau and E. M. Lifshitz, *Classical Theory of Fields* (Pergamon Press, 1975)
6. Robert M. Wald, *General Relativity* (University of Chicago Press, 1984)
7. Ray D'Inverno, *Introducing Einstein's Relativity* (Oxford University Press, 1998)
8. C. W. Misner, K. S. Thorne, J. A. Wheeler, *Gravitation* (W. H. Freeman and Company, 1973)

Semester I

PHY 631: Elective II (A) Advanced Nuclear Physics

100 Marks/4 Credits

Objective:

To develop a solid understanding of nuclear reactions, nuclear models, detection methods, and practical applications of nuclear techniques in research, industry, medicine, and daily life.

Outcomes:

- *Understand different types of nuclear reactions, resonance phenomena, direct and compound nuclear reactions, and Coulomb excitation with applications.*
- *Learn the collective model of the nucleus and interpret rotational and vibrational spectra, including beta and gamma vibrations.*
- *Gain knowledge of the interaction of radiation with matter and working principles of various nuclear detectors and experimental techniques.*
- *Apply nuclear techniques to real-world problems through understanding of the Mossbauer effect, activation method, biological effects of radiation, industrial uses, and nuclear medicine.*

Syllabus:

Unit 1. Nuclear Reaction

Types of reaction, One level Breit Wigner formula and resonance, Direct reaction – elastic and inelastic scattering, Compound nuclear reaction, Coulomb excitation and its applications.

25 Marks

Unit 2. Nuclear Model

Collective model of nucleus, Collective parameters, Rotational and Vibrational spectra, Beta and gamma vibration and bands.

25 Marks

Unit 3. Nuclear Detectors and Experimental Techniques

Interaction of nuclear radiations with matter, Gas detectors – Ionisation chamber, Proportional counter, multiwire proportional counter, GM counter, Scintillation detectors, Solid state detectors: Si(Li), Ge(Li), HPGe, Surface Barrier Detectors, Neutron Detectors, Gamma ray spectroscopy, High energy particle detectors, General principles, Nuclear emulsion, Cloud Chamber, Bubble chamber, Cerenkov Counter, Single and multichannel analysers.

30 Marks

Unit 4. Applications of Nuclear Technique

Mossbauer effect and its applications. Activation method. Biological effects of radiation. Industrial and Analytical application. Nuclear medicine.

20 Marks

References

1. *Nuclear Structure*, Vol. I & II: A. Bohr and B. R. Mottelson (World Scientific, 1998)
2. *Atomic and Nuclear Physics*, Vol. 2: S. N. Ghoshal (S Chand & Company, 1997)
3. *Theory of Nuclear Structure*: M. K. Pal (Aff. East – West Press, 2008)
4. *Concepts of Nuclear Physics*: Bernard L. Cohen (McGraw Hill, 2017)

5. *Nuclear Radiation Detectors*: S. S. Kapoor and V. S. Ramamurthy (John Wiley & Sons, 1986)
6. *Mossbauer Spectroscopy*: N. N. Greenwood and T. C. Gibb (Springer, 1971)
7. *Nuclear Radiation Detection*: W. J. Price (McGraw-Hill, 1964)
8. *Nuclear Structure*: M. A. Preston, and R. K. Bhaduri (CRC Press, 1993)

Semester I

PHY 632: Elective II (B) Quantum Field Theory

100 Marks/4 Credits

Objective:

To build a strong foundation in relativistic quantum mechanics, quantum field theory, and quantum electrodynamics, enabling students to analyze fundamental equations, quantization methods, field interactions, and renormalization techniques in modern physics.

Outcomes:

- *Understand four-vectors, covariant forms of relativistic wave equations, Klein-Gordon and Dirac equations, gamma matrices, bilinear terms, and Lorentz invariance.*
- *Learn the formulation of classical and quantum fields, canonical quantization, creation and annihilation operators, Fock space, conservation laws, and discrete symmetries including CPT theorem.*
- *Apply quantum electrodynamics to study interacting fields, S-matrix formalism, Feynman rules, scattering processes, and concepts of renormalization, Lamb shift, and anomalous magnetic moment.*

Syllabus:

Unit 1. Relativistic Quantum Mechanics (brief revision)

Concept of four vectors in special theory, covariant forms of equations in four dimensional Minkowski space, natural units and conversion factors, Klein-Gordon equation and Dirac equation in covariant forms, properties of Dirac gamma matrices and trace calculations, properties of Dirac bilinear terms, Lorentz invariance of Dirac equation.

35 Marks

Unit 2. Elements of Quantum Field Theory (QFT)

Concept of fields, classical fields as generalized coordinates, Schwinger's action principle, Lagrangian density of a field, Euler-Lagrangian equation of fields, canonical quantization of a one-Dimensional classical system, canonical quantization of free fields (Hermitian and non-Hermitian scalar fields, Dirac fields, electromagnetic fields), harmonic oscillator representation, creation and destruction operators, Fock space and their eigenvalues, Energy, momentum and charge of the field, vacuum state in quantum field theory, Noether's theorem, C, P and T transformations, CPT and spin statistics theorem.

40 Marks

Unit 3. Quantum Electrodynamics (QED)

Interacting Fields, Interaction representation, S – matrix, Time order products, Wick's theorem, Feynman Rules for various interacting Fields, calculation of second order processes, Mott Scattering, Klein-Nishina formula, Compton Scattering.

Renormalization of charge, mass and vertex in second order, Self-energy and Vacuum polarization, Lamb Shift, anomalous magnetic moment, Ward-Takahashi identities.

25 Marks

References

1. *Relativistic Quantum Mechanics* : James D. Bjorken and Sidney D. Drell (Primis, 2008)

2. *Relativistic Quantum Fields*: D. Bjorken and Sidney D. Drell (Dover, 2012)
 3. *Quantum Field Theory*: Lewis H. Ryder (Cambridge University Press, 1996)
 4. *Problem Book in Quantum Field Theory*: Voja Radovanovic (Springer, 2018)
 5. *Quantum Field Theory: An Introduction with Applications*: Mike Guidry (Wiley –VCH, 1999)
 6. *An Introduction to Quantum Field Theory*: Michael E. Peskin and Daniel V. Schroeder (Westview Press, 1995)
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Semester I

PHY 615: Laboratory Course 1 (Nuclear Physics & Atomic and Molecular Physics) **100 Marks/4 Credits.**

Objective:

To provide hands-on experience with nuclear radiation detectors, spectrometers, and related experimental techniques, enabling students to measure radiation properties, detector characteristics, and nuclear interactions with matter.

Course Learning Outcomes:

- *Determine the operating voltage, plateau slope, and dead time of a Geiger-Müller counter, and perform Feather's analysis.*
- *Understand the operation of a photomultiplier tube and evaluate the photopeak efficiency of NaI(Tl) detectors for gamma rays.*
- *Measure and analyze energy resolution of NaI(Tl) detectors, independent of amplifier gain, and calibrate gamma-ray spectrometers.*
- *Evaluate the energy of gamma-ray sources and determine the mass attenuation coefficient in different media.*
- *Study Compton scattering, multichannel analyzer modes, and analyze energy resolution and spectra of gamma rays.*
- *Measure beta-ray spectrum of Cs-137, calculate K-shell binding energy, and study Rutherford scattering with Am-241.*
- *Determine efficiency and resolution of HPGe detectors, perform alpha spectroscopy with surface barrier detectors, and analyze unknown sources.*
- *Measure range and energy of alpha particles using spark counters, and study X-ray measurements with proportional counters.*
- *Perform X-ray fluorescence experiments, neutron activation analysis, and gamma-gamma coincidence studies.*

Experiments:

1. To determine the operating voltage, slope of the plateau and dead time of a G. M. Counter.
2. Feather's analysis using G. M. Counter.
3. To determine the operating voltage of a photomultiplier tube and to find the photopeak efficiency of a NaI(Tl) crystal of given dimensions for gamma rays of different energies.
4. To determine the energy resolution of a NaI(Tl) detector and to show that it is independent of the gain of the amplifier.
5. To calibrate a gamma ray spectrometer and to determine the energy of a given gamma ray source.
6. To determine the mass attenuation coefficient of gamma rays in a given medium.
7. To study Compton scattering using gamma rays of suitable energy.
8. To study the various modes in a multichannel analyser and to calculate the energy resolution and energy of gamma ray.
9. To determine the beta ray spectrum of Cs-137 source and to calculate the binding energy of K-shell electron of Cs-137.
10. To study the Rutherford scattering using aluminium as scatterer and Am-241 as a source.
11. To measure the efficiency and energy resolution of a HPGe detector.
12. Alpha spectroscopy with surface barrier detector – Energy analysis of an unknown gamma source.
13. Determination of the range and energy of alpha particles using spark counter.
14. The proportional counter and low energy X-ray measurements.
15. X-ray fluorescence with a proportional counter.
16. Neutron activation analysis.
17. Gamma-gamma coincidence studies.

Semester I

PHY 616: Laboratory Course 3 (Condensed Matter Physics)

25 Marks/1 Credit.

Objective:

To provide experimental understanding of crystallography, lattice defects, material properties, and thin-film characterization through advanced solid-state physics laboratory techniques.

Course Learning Outcomes:

- Measure lattice parameters and perform indexing of powder photographs.
- Interpret transmission and back reflection Laue photographs to analyse crystal orientation.
- Record and interpret rotation/oscillation photographs for structural information.
- Study modulus of rigidity and internal friction in metals as a function of temperature.
- Measure cleavage step height of crystals using multiple Fizeau fringes.
- Perform multiple beam experiments to determine step height and study birefringence.
- Investigate magnetoresistance of bismuth crystals under varying magnetic fields.
- Analyse hysteresis in electrical polarization of TGS crystals and determine Curie temperature.
- Measure dislocation density of crystals through etching techniques.
- Determine Hall coefficient of a sample and calculate carrier concentration.
- Estimate activation energy from thermoluminescent peaks.
- Study F-centres in alkali halide crystals via optical absorption measurements.
- Determine dielectric constant of solids.
- Calculate Lande g-factor using DPPH samples.
- Deposit thin films using vacuum evaporation and measure their conductivity across temperatures.
- Measure complex refractive index and band gap of thin-film semiconductors.

Experiments:

1. Measurement of lattice parameters and indexing of power photographs.
2. Interpretation of transmission Laue photographs.
3. Determination of orientation of a crystal by back reflection Laue method.
4. Rotation/Oscillation photographs and their interpretation.
5. To study the modulus of rigidity and internal friction in metals as a function of temperature.
6. To measure the cleavage step height of a crystal by Multiple Fizeaue fringes.
7. To obtain Multiple beam. To determine crystal step height and study birefringence.
8. To determine magnetoresistance of a Bismuth crystal as a function of magnetic field.
9. To study hysteresis in the electrical polarization of a TGS crystal and measure the Curie temperature.
10. To measure the dislocation density of a crystal by etching.
11. Determination of the Hall coefficient of a given sample and calculate the carrier concentration.
12. Determination of the activation energy of a thermoluminescent peak
13. Study of F - centres in alkali halide single crystal by measuring optical absorption.
14. Determination of dielectric constant of a given solid.
15. Determination of Lande g factor for DPPH.
16. Deposit a thin film material in a vacuum evaporation coating unit and measure the electrical conductivities of of the film at different temperatures.
Measurement of complex refractive index and band gap of a thin film semiconductor.

PHY 617: Computational Physics

100 Marks/4 Credits

Objective:

To develop programming skills in Python and Unix/Linux, learn essential numerical methods for solving mathematical problems, and apply computational techniques to study physical systems, simulations, and chaotic dynamics.

Course Learning Outcomes:

- *Design algorithms and flowcharts, implement programs in Python, and use data types, operators, loops, functions, file handling, and data structures effectively.*
- *Demonstrate working knowledge of Unix/Linux operating systems for scientific computing.*
- *Apply numerical methods to find roots of equations using techniques such as bisection, regula falsi, secant, Newton-Raphson, and fixed-point iteration.*
- *Solve systems of linear equations using direct and iterative methods including Gauss elimination, Gauss-Jordan, matrix inversion, and Gauss-Seidel.*
- *Perform interpolation, numerical quadrature, and function approximation using trapezoidal, Simpson's, and Gauss-Legendre rules.*
- *Solve initial value problems with Taylor's, Euler's, and Runge-Kutta methods, and apply least squares techniques for curve fitting.*
- *Generate and analyse random numbers, apply Monte Carlo methods for numerical integration, and estimate values such as π .*
- *Model physical systems like free, damped, and driven harmonic oscillators computationally.*
- *Explore concepts of nonlinear dynamics and chaos through logistic maps, bifurcations, cobweb diagrams, and fractals.*

Syllabus:

Unit 1. Programming with Python

Flow charts and algorithms, Identifiers and Data types, Operators and Expressions, Managing Input and Output Operations, Decision making and Branching, Looping Functions, List, Dictionaries, Tuples and File handling.
Introduction to Operating Systems (Unix/Linux)

30 Marks

Unit 2. Numerical Methods

Roots of algebraic and transcendental equations, Fixed point iterations and Successive Approximation, Bisection, Regula falsi, secant and Newton-Raphson methods.

Simultaneous equations and solutions – Gauss elimination, Gauss Jordan matrix inversion, Gauss Siedel methods.

Interpolation and function approximation methods.

Numerical Quadratures – Trapezoidal rule, Simpson's rule (1/3) and Gauss-Legendre quadrature.

Initial value problems – Taylor's method, Euler's method and 4th order Runge – Kutta method.

The method of least squares and curve fitting.

40 Marks

Unit 3. Computational Physics

Random numbers, generators and properties, Introduction to Monte-Carlo (MC) simulation, numerical value of π by MC method, evaluation of definite integrals.

Free, damped and driven harmonic oscillators, Introduction to simple chaotic systems – the logistic map, fixed points, bifurcations, the cobweb diagram, Introduction to fractals.

30 Marks

References:

1. *Elementary Numerical Analysis, An Algorithmic Approach*: Samuel Daniel Conte and Carl de Boor (Society for Industrial & Applied Mathematics, U.S.A., 2018)
2. *Programming with Python and its applications to Physical Systems*: M. Subhakanta Singh (Manakin Press, New Delhi, 2017)
3. *Think Python*: Allen B. Downey (Green Tea Press, 2014)
4. *A Primer on Scientific Programming with Python*: Hans Peter Langtangen (Springer, 2012)
5. *Chaos and Nonlinear Dynamics, An Introduction for Scientists and Engineers*: Robert C. Hilborn (Oxford University Press, 1994)
6. *Introduction to Computational Physics*: Tao Pang (Cambridge University Press, 2006)
7. *Computational Physics, Problem Solving with Computers*: Rubin H. Landau (John Wiley and Sons, 1997)

Semester II

PHY 623: Elective III (A) Fabrication of Integrated Devices

100 Marks/4 Credits

Objective:

To provide a comprehensive understanding of crystal growth, thin film deposition, lithography, doping, and nanofabrication techniques for applications in semiconductor devices and nanotechnology.

Course Learning Outcomes:

- *Explain silicon and GaAs crystal growth processes, epitaxial techniques, and analyse structural defects in epitaxial layers.*
- *Describe thin film deposition methods including evaporation, sputtering, laser ablation, MBE, CVD, and sol-gel techniques.*
- *Apply lithography and etching methods, mask technologies, photoresists, and plasma-assisted processes in microfabrication.*
- *Demonstrate understanding of impurity doping techniques such as diffusion and ion implantation.*
- *Evaluate nanofabrication methods including e-beam, X-ray, ion-beam, imprint, and scanning probe lithography.*

Syllabus:

Unit 1. Crystal Growth and Epitaxy

Silicon crystal growth from melt, silicon float-zone process, GaAs Crystal growth techniques, epitaxial growth techniques, structure and defects in epitaxial layers.

10 Marks

Unit 2. Thin Film Deposition

Vacuum Pumps and Gauges, Techniques used for deposition of thin films-Thermal evaporation, sputtering, laser ablation, molecular beam epitaxy, chemical vapour deposition, sol-gel method.

20 Marks

Unit 3. Lithography and etching

Proximity, contact, projection, stepper. Mask technologies: photo-reduction, direct-write, phase-shift. Photoresists: positive, negative and image-reversal; edge profile modification, multilevel techniques. Wet-etching: chemistry and procedures; reaction rates, calibration, reproducibility; selective etching, etch-stop techniques. Dry-etching: plasma etching, RIE, RIBE; ion milling, sputter etching. Plasma-assisted processing.

30 Marks

Unit 4. Impurity Doping

Basic diffusion process, ion implantation and other implantation related processes.

10 Marks

Unit 5. Nanofabrication

E-beam lithography: basic principles, e-beam resists; exposure considerations, multilevel techniques. X-ray and ion-beam lithography: basic principles. Imprint lithography: Soft - elastomeric materials; techniques - near-field phase shift lithography; soft UV nanoimprint lithography; templates, masters and moulds. Scanning probe lithography: scanning probe tools; techniques - local oxidation nanolithography, local chemical nanolithography.

30 Marks

References:

1. *Semiconductor Devices-Physics and Technology*: S M Sze, John Willey Publications.
2. *Measurement, Instrumentation and Experiment Design in Physics and Engineering*: AbhayMan Singh, Prentice Hall Pubs.
3. *Fundamentals of Semiconductor Fabrication*: G S May and S M Sze, John Willey Pubs.
4. *Microelectronic Devices*: E S Yang, Mc Graw Hill Pubs. 27

Semester II

PHY 624: Elective III (B) Non-linear Dynamics
Credits

100 Marks/4

Objective:

To introduce the fundamental concepts of dynamical systems, nonlinear dynamics, chaos, and soliton theory, emphasizing analytical techniques and physical applications.

Course Learning Outcomes:

- *Explain the basic principles of dynamical systems including linearity, nonlinearity, and determinism.*
- *Analyse one-dimensional flows, fixed points, stability, bifurcations, and oscillators on the line and circle.*
- *Classify and interpret two-dimensional flows using phase portraits, limit cycles, and Poincaré–Bendixson theorem.*
- *Describe the concepts of chaos through logistic maps, attractors, Lorenz equations, Lyapunov exponents, and universality.*
- *Solve nonlinear wave equations and study soliton solutions of KdV, nonlinear Schrödinger, and sine-Gordon equations.*

Syllabus:

1. Introduction:

Dynamics, Dynamical systems, linear, nonlinear, determinism
20 Marks

2. One-dimensional flows:

Flows on the line, fixed points and stability, linear stability analysis, bifurcations, flows on the circle, uniform and nonuniform oscillator

20 Marks

3. Two-dimensional flows:

Linear systems, classification of linear systems, phase portraits, existence and uniqueness, fixed points and linearization, examples, limit cycle, Poincaré – Bendixson theorem, Liénard system, relaxation oscillation.

20 Marks

4. Chaos:

Logistic map, attractor, period doubling, chaos, Lorenz equations, strange attractor, Liapunov exponent, universality.

20 Marks

5. Soliton theory:

periodic, cnoidal and solitary wave solutions of Korteweg-de Vries equations, nonlinear Schrödinger and sine-Gordon equations

20 Marks

References:

1. *Nonlinear Dynamics and Chaos*: S.H. Strogatz (Westview Press, 2001)

2. *CHAOS: An Introduction to Dynamical Systems*: K. Alligood, T. Sauer, and J.A. Yorke (Springer, 2008)
3. *Perspectives of Nonlinear Dynamics, Vols. I & II*: E.A. Jackson (Cambridge University Press, 1991)
4. *Chaos in Dynamical Systems*: E. Ott (Cambridge University Press, 1993)
5. *Chaos and Nonlinear Dynamics*: R.C. Hilborn (Oxford University Press, 2000)

PHY 625: Elective III(C) Nanoscience

100 Marks/4 Credits

Objective:

To develop a comprehensive understanding of the synthesis, characterization, fundamental properties, and applications of nanomaterials, emphasizing quantum size effects and advanced characterization techniques relevant to modern nanoscience and technology.

Course Learning Outcomes:

- Classify different types of nanomaterials and explain how density of states and band gaps vary with crystal size.
- Describe physical and chemical synthesis methods for nanoparticles, nanowires, and carbon nanotubes.
- Explain quantum confinement effects in low-dimensional systems such as quantum wells, wires, and dots.
- Apply characterization techniques including XRD, AFM, SEM, and TEM to study structure, surface morphology, and particle size.
- Analyse optical, electrical, and magnetic properties of nanomaterials and understand quantum transport regimes, quantum channels, conductance oscillations, and applications in nanotechnology.

Syllabus:

Unit 1. Nanomaterials

Classification of Nanomaterials, Density of states in low dimensions, variation of density of states and band gap with size of crystal. Physical and Chemical Methods of Preparing nanoparticles, nanowires and carbon nanotubes.

30 Marks

Unit 2. Quantum Size Effect

Quantum confinement and its consequences, quantum well structure, Quantum wires, Quantum dots.

20 Marks

Unit 3. Characterisation of Nanomaterials

Structural studies by using XRD, Surface morphology and size determination using AFM, SEM and TEM.

25

Marks

Unit 4. Properties of Nanomaterials

Optical, electrical and magnetic properties of nanomaterials, Applications of nanomaterials, quantum transport regimes, quantum channels, Landauer formula, Conductance oscillation.

25 Marks

References:

1. *Introduction to Nanotechnology*: CP Poole Jr. & F.J. Owens, Wiley Interscience, 2003.
2. *Physics of low dimensional semiconductors*: John H. Davies, Cambridge Univ. Press 1997.
3. *Physics of Semiconductor nano structures*: K.P. Jain, Narose 1997.
4. *Characterization of Nanophase Materials*: ZL Wang (Ed.) Wiley, VCH, 2000.
5. *Nano particles and nano structured films; Preparation characterization and applications*: Ed. J.H. Fendler, John Wiley & Sons 1998.
6. *Physics of Semiconductor nano structures*: K.P. Jain, Narosa 1997.

Semester II

PHY 633: Elective III (D) Particle Physics

100 Marks/4Credits

Objective:

To provide a comprehensive understanding of elementary particles, their classification, underlying symmetries, gauge theories, the Standard Model, and developments beyond it.

Course Learning Outcomes:

- *Explain the classification of elementary particles, associated quantum numbers, conservation laws, and CP violation in weak interactions.*
- *Apply group theory and the quark model to classify hadrons, analyse quark properties, and understand QCD and quark-gluon plasma.*
- *Demonstrate the principles of gauge invariance in Abelian and non-Abelian groups and their implications for gauge bosons.*
- *Analyse spontaneous symmetry breaking, Goldstone's theorem, and the Higgs mechanism in generating particle masses.*
- *Describe the electroweak unification and experimental validation of the Standard Model including Higgs discovery.*
- *Discuss the motivations for physics beyond the Standard Model including GUTs, neutrino oscillations, supersymmetry, string theory, and dark matter/energy.*

Syllabus:

Unit 1. Classification of elementary particles

A brief history on the discovery of elementary particles, associated production of strange particles, Gell – Mann – Nishijima relation and concept of hypercharge (Y) and strangeness (S) quantum numbers, conservation laws and their violations in strong, weak and electromagnetic interactions, their characteristics and invariance laws – isospin, P, T, G, CP, CPT symmetry, non-conservation on parity, CP violation in weak interactions. V – A theory of weak interaction, Current X Current interaction form, Cabibbo angle, CKM matrix and its parametrization, theory of CP violation in terms of CKM matrix.

20 Marks

Unit 2. Quark model

Introduction to Lie groups: SU(2) – isospin, SU(3) – flavor groups, fundamental and conjugate representations, construction of higher representation using Young's Tableau method, classification of hadrons under SU(3) group, Gell – Mann – Nee'man eightfold way classification of hadrons, Gell – Mann – Okubbo mass formula for hadrons, Gell – Mann – Zweig quark model of hadrons, interpretation of SU(3) fundamental representation in terms of three flavor of quarks u, d, s. Eight-fold way classification of hadrons in terms of quark model, a brief history on the discovery of all the six quarks. Problem of quark model from spin – statistics theorem and introduction of colour quantum number, baryon and meson wave functions in terms of quarks and their applications in some decay processes, current and constituent quark masses, extension of quark model in SU(4) group, parton model and deep-inelastic scattering (DIS) of proton, quantum chromodynamics (QCD), quark confinement, quark-gluon plasma (QGP).

20 Marks

Unit 3. Gauge theory

Gauge invariance of global and local gauge transformations, continuous global gauge invariance,

Noether's theorem and conservation of charge, Abelian U(1) and non-Abelian (Yang Mills) symmetry groups SU(2), SU(3). Local gauge invariance for Abelian and non-Abelian groups and their implications for the existence of massless gauge bosons. **20 Marks**

Unit 4. Spontaneous Symmetry Breaking (SSB)

Mathematical definition of SSB of continuous symmetry groups, SSB of continuous global symmetry breaking and Goldstone's theorem, Goldstone bosons, examples with U(1) and SU(2), Higgs' mechanism for SSB of local gauge symmetry for generating masses of gauge bosons, examples U(1), SU(2). **10 Marks**

Unit 5. Standard Model (SM)

Electroweak theory – unification of electromagnetism and weak interactions, Glashow – Weinberg – Salam (GWS) theory of Standard Model (SM), theoretical prediction of W^+ , W^- and Z^0 boson masses, Higgs boson masses, experimental discovery of neutral current at CERN, detection of W and Z bosons in proton – antiproton collider at CERN, discovery of Higgs boson at LHC in CERN. **20 Marks**

Unit 6. Beyond Standard Model (BSM)

Brief introduction to Grand Unified Theories (GUTs) and proton decay prediction, solar and atmospheric neutrino problems and neutrino oscillations, neutrino masses and mixings, supersymmetry and minimal supersymmetric standard model (MSSM), superstring theory and extra dimensions, dark matter and dark energy. **10 Marks**

References

1. *Gauge Theory of Elementary Particle Physics*: Ta – Pei Cheng and Ling – Fong Li(Oxford, 2000)
2. *Quarks and Leptons – An Introductory Course in Modern Particle Physics*: Francis Halzen and Alan D. Martin (Wiley-India, 2008)
3. *Introduction to Elementary Particles*: David Griffiths (Wiley – VCH, 1987)
4. *A Modern Introduction to Particle Physics*: Fayyazuddin and Riazuddin (WorldScientific, 1992)
5. *Introduction to Particle Physics*: M. P. Khanna (Prentice Hall of India, 2004)
6. *Quark Model and Beyond – An Eternal Quest*: N. Nimai Singh (Regency Publications, 2003)
7. *Gauge Field Theories – An Introduction with applications*: Mike Guidry (Wiley –VCH, 1991)
8. *Principles of Non-relativistic and Relativistic Quantum Mechanics*: K. D. Krori(Prentice Hall of India, 2010)

Semester II

PHY 634: Elective III (E) Experimental Techniques for Material Characterization
100 Marks/4Credits

Objective:

To provide knowledge and practical understanding of advanced material characterization and

Equation and its solution, Energy generation in stars, P-P and C-N cycles, triple alpha reaction, Radiative and convective transport of energy, Radiative transfer equation and optical depth, Saha's ionisation formula, Equation of stellar structure, Evolution of stars of different masses, pre- and post main-sequence evolution, Supernovae and their types.

20 Marks

Unit 4. Compact objects

Fate of massive stars, Degenerate electron and neutron gases, White dwarfs – Chandrasekhar mass limit, mass-radius relation, Neutron stars and pulsars, black holes.

15 Marks

Unit 5. Interstellar medium and Galaxies

Physical processes in the interstellar medium, gaseous nebulae, H II regions, star formation, diffuse supernova remnants, galactic magnetic field,

The Milky way galaxy, General characteristics and classification of galaxies, galaxy morphology, surface brightness, masses, stellar content, galaxy rotation curves, mass distribution, dark matter, cluster of galaxies, formation of galaxies and large scale structure, Distribution of stars, Active galaxies, Radio galaxies and Quasars.

25 Marks

Unit 6. Overview of Modern Astronomy

Cosmic radio sources, 21-cm hydrogen line, Gravitational waves, Gravitational lensing, Expansion of the Universe and determination of Hubble's constant, gamma ray bursters.

5 Marks

References

1. S. Chandrasekhar, *An Introduction to the Study of Stellar Structure* (Dover, 1968)
2. Frank H. Shu, *The Physical Universe* (University Science Books, 1982)
3. B. W. Carrol and D. A. Ostlie, *Modern Astrophysics* (Cambridge University Press, 2017)
4. Erika Bohm-Vitense, *Introduction to stellar Astrophysics* Vol. 1 & 2 (Cambridge University Press, 1997)
5. B. Basu, T. Chattopadhyay and S. N. Biswas, *An Introduction to Astrophysics*, (PHI Learning Pvt. Ltd. , 2016)
6. M. L. Kutner, *Astronomy* (Cambridge University Press, 2003)

Semester II

PHY 618: Laboratory Course VII (Computer Practical)

100 Marks/4Credits

Objective:

To develop computational skills for solving scientific and engineering problems using Python, with emphasis on basic programming constructs, numerical methods, and computational physics applications involving dynamical systems, chaos, and nonlinear maps.

Course Learning Outcomes:

- Apply Python programming concepts to implement recursion, sorting, number theory, and classical algorithmic problems including Fibonacci series, Armstrong numbers, Pascal's triangle, and Tower of Hanoi.
- Implement numerical methods such as root finding, Gauss elimination, interpolation, numerical integration, and solution of differential equations using Python and C, and analyze accuracy and stability of the methods.
- Utilize computational physics techniques to simulate physical systems including harmonic oscillators, logistic and tent maps, Henon and Baker maps, Lorenz equations, and fractal structures, and interpret the resulting dynamical behaviours.

Practical/Experiments:

Unit 1 Basic Concepts

1. Write Python programs for the following with and without recursive functions:
 - A) To convert decimal numbers to binary numbers.
 - B) Write a Python program to reverse the digits of an integer.
 - C) To find the Greatest Common Divisor of two numbers.
2. Write a Python program to verify whether a given number is prime or not.
3. Write a Python program to generate prime numbers between any two given numbers.
4. Write a Python program to organize a given set of numbers in ascending order using:
 - A) Insertion sort
 - B) Bubble sort
 - C) Selection sort
5. Write a Python program to find out the Prime numbers from a sequence of Fibonacci series.
6. Write a Python program to check whether a given number is an Armstrong number or not.
7. Write a Python program to print Pascal Triangle.
8. Write a Python program to solve the Tower of Hanoi.

Unit 2 – Numerical Methods

1. Write a Python program to solve the simultaneous equations with the following values a, b, c, p, q, r :
→ $a = 2.500, b = 5.200, c = 6.200, p = 1.251, q = 2.605, r = 3.152$
 $ax + b = c$
 $px + qy = r$
Give the answer correct to 4 decimal places. Change the value of q to 2.606 and compare the two results.
2. Write a Python program to find the real roots of a given equation using

- A) Bisection Method
 - B) False Position Method
 - C) Newton Raphson Method
 - D) Secant Method
3. Write a Python program to solve a system of simultaneous equations using Gauss Elimination Method.
The program has to invoke separate subroutines for implementing pivotization, triangulation and back substitution parts. Check your program by interchanging the equations.
4. Write a Python program using second order Lagrange Interpolation Polynomial:
- A) To determine the square root of x at a given point from a set of values
 - B) To determine the value of f(4) and f(2) from the following table:

X	1.5	3	6	10	14
f(x)	-0.25	2	20	45	55

5. Write a Python program to approximate a definite integral using Simpson's $1/3^{\text{rd}}$ and $3/8^{\text{th}}$ rule of integration.

6. A rocket is launched from the ground. Its acceleration measured every 5 seconds is tabulated below. Write a Python program to find the velocity and position of the rocket at $t = 40$ seconds. Use Trapezoidal Rule and Simpson's rule and compare the results.

5. Consider the integral

$$S = \int_0^5 e^{-x^2} dx$$

Write a Python program to evaluate the integral by using

- A) Trapezoidal Rule with 10 and 20 points.
 - B) Simpson's $1/3^{\text{rd}}$ Rule with even and odd intervals
 - C) Simpson's $3/8^{\text{th}}$ Rule with even and odd intervals.
6. Write a C program to obtain the numerical solution of a given initial value problem by using (A) Euler's method (B) Runge-Kutta fourth order method. Compare the results.
 7. Write a Python program to solve the following differential equation:

$$\frac{dy}{dx} = 2xy$$

for $0 \leq x \leq 1$, $y(0) = 0.5$
by using

- A) Euler's method
- B) Runge-Kutta second order method
- C) Runge-Kutta fourth order method

Unit 3 – Computational Physics

1. Write a Python program to plot the probability densities of different states of quantum mechanical harmonic oscillator.
2. Write a Python program to estimate the value of π using Monte Carlo simulation.
3. Write a Python program to study the logistic map and plot the bifurcation diagram and calculate the Lyapunov exponents at the specified parameters.
4. Write a Python program to fit a least square polynomial to an x-y scatter and calculate the correlation coefficient R^2 .
5. Write a Python program to study the Henon Map and plot the basin of attraction and study its fractal properties.
6. Write a Python program to integrate the Lorentz equations and plot the three phase diagrams.
7. Write a Python program to integrate the equation of motion and plot the phase diagrams

for a damped driven harmonic oscillator.

8. Write a Python program to produce a Sierpinski gasket.

9. Write a Python program to produce Barnsley's Fern.

10. The logistic map is a simple non-linear (see quadratic term) iterative mapping, often to study how complex, chaotic behaviour can arise in a deterministic system. The equation of the system is given as

$$x_{n+1} = rx_n(1-x_n) \text{ for } 0 \leq r \leq 4 \text{ and } 0 \leq x \leq 1$$

a) Plot x_n vs n for different values of r : $r=1$, $r=2.8$, $r=3.4$ and $r=4$ (make subplot (2,2) with appropriate labels). For given value of r and $x_0 \in [0,1]$, find the sequences $x_1, x_2, x_3, \dots$

b) Plot the return map (x_n vs x_{n+1}) for the above values of r .

c) Plot the **cobweb diagram** for the above values of r .

Note: Procedure of making cobweb diagram:

Given a map $x_{n+1} = f(x_n)$ and an initial condition x_0 , draw a vertical line until it intersects the graph of f ; that height is the output x_1 . From x_1 , draw a horizontal line until it intersects the diagonal line ($x_{n+1} = x_n$). Repeat the procedure to get x_2 from x_1 . Continue the process n times to generate the first n points in the orbit.

d) Plot the bifurcation diagram of the logistic map by varying r from 0 to 4.

Note: Procedure of making bifurcation diagram:

For each value of r , iterate the map 30 steps. Remove transients (discard first 20 points) and take 10 points to plot x_n vs r .

e) Plot the variation of Lyapunov exponents (λ) vs r . Lyapunov exponent is a quantity that characterizes the rate of separation of infinitesimally close trajectories. For discrete time systems ($x_{n+1} = f(x_n)$), for an orbit starting with x_0 , the Lyapunov exponent is given by

$$\lambda = \lim_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n \ln |f'(x_i)|$$

11. Consider the following map

$$x_{n+1} = \begin{cases} rx_n & \text{for } 0 \leq x_n \leq \frac{1}{2} \\ r - rx_n & \text{for } \frac{1}{2} \leq x_n \leq 1 \end{cases} \text{ for } 0 \leq r \leq 2 \text{ and } 0 \leq x \leq 1.$$

a) Plot the return map (x_{n+1} vs x_n) for different values of r , and see why this map is called the "tent map".

- b) Plot the corresponding cobweb diagrams and identify the nature of the orbits. Is it a steady state, periodic or chaotic?
- c) Plot the return map and cobweb diagram for $r=2$.
- d) Plot the bifurcation diagram of tent map by varying r from 0 to 2.
- e) Plot the variation of Lyapunov exponents vs r for tent map.

12. The baker's map of the square $0 \leq x \leq 1, 0 \leq y \leq 1$ to itself is given by

$$(x_{n+1}, y_{n+1}) = \begin{cases} (2x_n, ay) & \text{for } 0 \leq x_n < \frac{1}{2} \\ \left(2x_n - 1, ay_n + \frac{1}{2}\right) & \text{for } \frac{1}{2} \leq x_n < 1 \end{cases}$$

Where a is a parameter in the range $0 < a \leq \frac{1}{2}$. The transformation is a product of two simpler transformations. A square is flattened into a $2 \times a$ rectangle. The rectangle is cut into half, yielding two $1 \times a$ rectangles, and the right half is stacked on the top of the left such that its base is at the level $y=1/2$.

- a) Plot n vs x_n and n vs y_n for $a = 0.25$.
- b) Plot the attractors (x_n, y_n) of the baker's map for $a=0.1, a=0.25$ respectively.

13. Henon map is the first two-dimensional dissipative quadratic map given by the coupled equations

$$\begin{aligned} x_{n+1} &= 1 - \alpha x_n^2 + y_n \\ y_{n+1} &= \beta x_n \end{aligned}$$

- a) Plot the attractors $(y_n$ vs $x_n)$ at $(\alpha=1.4, \beta=0.3)$ and $(\alpha=0.2, \beta=1.01)$
- b) Plot the bifurcation diagram of the system. Fix $\beta=0.3$ and vary α from zero to 1.5.

14. **Lorenz equations:** Ed Lorenz (1963) derived the following set of equations for 3-dimensional system from a drastically simplified model of convection rolls in the atmosphere,

$$\begin{aligned} \frac{dx}{dt} &= \sigma(y - x) \\ \frac{dy}{dt} &= rx - y - xz \\ \frac{dz}{dt} &= xy - bz \end{aligned}$$

Simulate and visualize this system for $\sigma=10, b=8/3$ and $r=28$.

- a) Plot the 2D attractors $x(t)$ vs $z(t)$ and $y(t)$ vs $z(t)$
- b) Plot the 3D attractors $x(t), y(t), z(t)$.
- c) Plot the time series $x(t), y(t), z(t)$ vs t .
- d) Lorenz map: To compare the results to those obtained with those obtained with 1D maps, Lorenz used a trick to obtain a map from a flow. Let us construct Lorenz map: Take $z(t)$ and find the successive local maxima z_n of $z(t)$. Plot the return map z_{n+1} vs z_n .

Semester II

PHY 619: Academic Project/Dissertation

150 Marks/6Credits

Objective:

The objective of the Academic Project/Dissertation is to provide students with an opportunity to apply the knowledge and skills acquired during their coursework to a real-world or research-oriented problem. It aims to develop independent research ability, critical thinking, problem-solving, technical writing, and presentation skills, thereby preparing students for higher studies, research careers, or professional practice.

Course Learning Outcomes:

- *Formulate a clear research problem or project objective by conducting a thorough literature survey and identifying research gaps or practical challenges.*
- *Apply appropriate theoretical knowledge, computational methods, experimental techniques, or analytical tools to design and implement solutions for the chosen project.*
- *Collect, analyse, and interpret data systematically, ensuring accuracy, reproducibility, and ethical research practices.*
- *Demonstrate critical thinking by evaluating results, comparing them with existing studies, and identifying possible limitations and future directions.*
- *Prepare a comprehensive project/dissertation report following academic and scientific writing standards, with proper referencing and documentation.*
- *Present and defend the project work effectively through oral presentations, posters, or viva voce, demonstrating clarity of thought and communication skills.*
- *Work independently and/or in collaboration, exhibiting time management, accountability, and professional responsibility throughout the project duration.*

PHY 620: Academic Project/Dissertation

50 Marks/2Credits

