

**Dhanamanjuri University
Manipur
Department of Physics**

DHANAMANJURI UNIVERSITY

RR. No. : 8509

Date : 16/06/26

To,
The Registrar
Dhanamanjuri University Manipur.

[Through the Dean School of Mathematical and Physical Sciences]

Subject: Course structures and syllabus of The Two -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

ph no. 9612158092

Forwards
[Signature]
16/06/2026

Dean
School of Mathematical and Physical Sciences
Dhanamanjuri University, Manipur

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16-6-2026

Shomananda

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16/06/2026.

DEPARTMENT OF PHYSICS
DHANAMAJURI UNIVERSITY
 Imphal 795001

SYLLABUS FOR 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 four semesters. The course structure is given below.

Course structure of 2-year PG Programme in Physics
(4-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 501	Discipline Specific Core	Classical Mechanics	10	10		80	100	4
PHY 502	Discipline Specific Core	Mathematical Methods in Physics	10	10		80	100	4
PHY 503	Discipline Specific Core	Quantum Mechanics I	10	10		80	100	4
PHY 504	Discipline Specific Core	Electronics	10	10		80	100	4
PHY 505	Lab	Practical based on PHY 501 and PHY 502					100	4
PHY 506	Lab	Practical based on PHY 503 and PHY 504					100	4
Total							600	24

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

[illegible]

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 III

[illegible]

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 IV

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	Research Methodology/Theory	Research Methodology	10			40	50	2
PHY 620	Research (Thesis/Project/Field work/Patent)	Research					150	6
Total							550	20

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.

c) The list of experiments given above should be considered as suggestive of the standard and available equipment. The teachers are authorized to add or delete from this list whenever considered necessary.

Course Learning Objective - M.Sc. Physics

The M.Sc. Physics programme is designed to provide students with a strong foundation in the fundamental branches of Physics, including Classical Mechanics, Quantum Mechanics, Mathematical Physics, Statistical Physics, Electromagnetic Theory, Solid State Physics, Electronics, Nuclear and Particle Physics, as well as Atomic and Molecular Physics. Through tutorials, the programme also aims to nurture creative thinking and problem-solving skills.

Elective and open elective courses broaden the learning scope by offering specialized and interdisciplinary knowledge, while core and elective laboratories help students develop practical understanding of physical concepts and the functioning of scientific instruments and devices. The Computational Physics course equips students with computational skills necessary for scientific analysis and research.

Dissertations, whether theoretical or experimental, provide exposure to research methodologies and the process of generating new scientific insights. Overall, the programme seeks to prepare students for advanced research and lays a strong academic foundation for pursuing doctoral studies in Physics and related fields.

Course Learning Outcomes (CLOs) - M.Sc. Physics

On successful completion of the M.Sc. Physics programme, students will be able to:

- **Disciplinary Knowledge:**
Acquire a systematic and coherent understanding of Physics and its branches such as Astrophysics, Material Science, Nuclear and Particle Physics, Condensed Matter Physics, Atomic and Molecular Physics, Space Science, Mathematical Physics, and Analytical Dynamics along with its connections to allied disciplines like Chemistry, Mathematics, Environmental Science, Life Sciences, Atmospheric Physics, Computer Science, and Information Technology.
- **Procedural and Professional Knowledge:**
Apply theoretical and procedural knowledge to prepare for careers in research and development, teaching, public service, and emerging areas of technology and innovation in Physics.
- **Problem Solving Skills:**
Formulate, analyse, and solve Physics-related problems using appropriate principles, models, and methodologies, while appreciating the role of approximation and mathematical modelling in describing physical phenomena.
- **Experimental and Computational Skills:**
Plan and conduct experiments in both core and advanced areas of Physics (e.g., Nuclear Physics, Condensed Matter Physics, Nanoscience, Lasers, Electronics), analyse and interpret data, use modern software tools and programming languages, and present accurate reports linking results to theoretical frameworks.
- **Research and Investigative Skills:**
Demonstrate independent investigative abilities in Physics-related issues, including data analysis, simulation, and computational modelling, leading to research-level insights.
- **Generic and Transferable Skills:**
Develop competencies in communication (oral and written), critical thinking, analytical reasoning, ICT applications, teamwork, and leadership enabling effective engagement across academic, professional, and global contexts.
- **Ethics and Professional Conduct:**
Exhibit professional integrity by being objective, unbiased, and ethical; respect intellectual property; avoid misconduct such as plagiarism or data falsification; and uphold environmental and sustainability values while promoting safe practices.

- **Foundational Understanding of Physics:**

Demonstrate mastery of core Physics concepts, Classical Mechanics, Quantum Mechanics, Statistical Mechanics, and Electromagnetic Theory and appreciate how natural phenomena emerge from a unified set of fundamental laws.

- **Advanced Knowledge:**

Understand and engage with advanced topics such as High Energy Physics, Plasma Physics, Astrophysics, Relativity, Nonlinear Dynamics, and Quantum Field Theory.

- **Applied and Practical Competence:**

Gain hands-on training for applying Physics knowledge in technology, industry, and interdisciplinary fields, while also being equipped to teach Physics at school and undergraduate levels.

- **Critical and Logical Thinking:**

Cultivate Physics as a training ground for the mind developing logical reasoning, analytical thinking, and a critical attitude applicable not only to Physics but also to diverse fields.

Semester I

PHY 501: Classical Mechanics

100 Marks/4 Credits

Objective:

The objective of this course is to develop a deep understanding of analytical mechanics through Lagrangian and Hamiltonian formulations, variational principles, and canonical transformations, while equipping students with the ability to analyse dynamical systems, symmetries, conservation laws, small oscillations, and rigid body motion with applications to physical systems.

Course Learning Outcomes:

- *Understand generalized coordinates, d'Alembert principle, and Euler-Lagrange equations; Apply variational calculus and Hamilton's principle; Learn Hamilton's equations, cyclic coordinates, central and electromagnetic forces, coupled oscillators, and Poisson brackets.*
- *Learn canonical transformations and generators; Understand symmetry principles and conservation laws; Apply Hamilton-Jacobi theory, action-angle variables, and solve problems like Kepler's motion and precessing orbits.*
- *Understand normal coordinates and small oscillations with applications to molecules; Analyse rigid body dynamics using Euler angles; Study rotating frames, Coriolis force, Foucault's pendulum, and motion of a symmetrical top.*

Syllabus:

Unit 1

Types of constraints on dynamical systems, generalized coordinates, d'Alembert principle, Euler-Lagrange equations of motion, variational calculus and Hamilton's variational principle, Hamilton's canonical equations of motion, Cyclic coordinates, Lagrangian and Hamiltonian for central forces, electromagnetic forces, coupled oscillators and other simple systems, canonical variables, Poisson's bracket, Jacobi identity.

50 Marks

Unit 2

Canonical transformations, generators of infinitesimal canonical transformations, symmetry principles and conservation laws, Hamilton-Jacobi theory, action and angle variables, centre of mass and laboratory systems, Kepler problem, precessing orbits.

25 Marks

Unit 3:

Small oscillations, normal coordinates and its applications to chain molecules and other problems, degrees of freedom for a rigid body, Euler angles, rotating frame, Coriolis force, Foucault's pendulum, Eulerian coordinates and equations of motion for a rigid body, motion of a symmetrical top.

25 Marks

References

1. H. Goldstein, *Classical Mechanics* (Narosa, 2001)
2. L.D. Landau and E.M. Lifshitz, *Mechanics* (Pergamon, 1976)
3. K.C. Gupta, *Classical Mechanics of Particles and Rigid Bodies* (John Wiley, 1988)
4. N.C. Rana and P.S. Joag, *Classical Mechanics* (Tata Mc Graw Hill Education)
5. Harald J.W. Muller-Kirsten, *Classical Mechanics and Relativity* (World Scientific, 2008)
6. W. Dittrich, Reuter, *Advanced Classical and Quantum Dynamics* (Springer, 1992)
7. T.W.B. Kibble and Frank H. Berkshire, *Classical mechanics* (Imperial College Press, 2004)
8. V.I. Arnold, *Mathematical Methods of Classical Mechanics* (Springer, 1978)

Semester I

PHY 502: Mathematical Methods in Physics

100 Marks/4 Credits

Objective:

The objective of this course is to equip students with advanced tools of probability theory, group theory, and integral transforms, enabling them to model, analyse, and solve complex physical and mathematical problems.

Course Learning Outcomes:

- Understand probability theorems, Bayes' rule, random variables, expectation, variance, and special distributions including binomial, Poisson, and Gaussian.
- Learn fundamentals of group theory, symmetries, representations, permutation, rotation and unitary groups, and relation between $SO(3)$ and $SU(2)$.
- Apply Laplace and Fourier transforms, convolution, Parseval's theorem, and their use in solving differential equations.

Syllabus:

Unit 1:

Advanced Probability Theory: Fundamental Probability Theorems. Conditional Probability, Bayes' Theorem, Repeated Trials, Binomial and Multinomial expansions. Random Variables and probability distributions, Expectation and Variance, Special Probability distributions: The binomial distribution, The Poisson distribution, Continuous distribution: The Gaussian (or normal) distribution, The principle of least squares.

35 Marks

Unit 2:

Group Theory: Symmetries and groups, multiplication table and representations, permutation group, translation and rotation groups, $O(N)$ and $U(N)$ groups, generators of rotation and unitary groups, relation between $SO(3)$ and $SU(2)$.

35 Marks

Unit 3:

Integral Transforms: Properties of Laplace transform, Inverse Laplace transform, LT of derivative and integral of a function. Fourier and inverse Fourier transform, Properties of FT, Convolution theorem of LT and FT, Parseval's theorem, Application of LT and FT in solving differential equations.

30 Marks

References

1. G Arfken and Weber, *Mathematical Methods for Physics*.
2. A W Joshi, *Matrices and Tensors for Physicists*.
3. A K Ghatak, Chu, *Differential Equations in Physics*
4. K F Reily, M P Hobson and S J Bence, *Mathematical Method for Physicists and Engineers*.
5. P K Chattopadhyay, *Mathematical Physics*.
6. E.P. Wigner, *Group Theory*.
7. M. Hamermesh, *Group Theory and its Applications to Physical Problems*.
8. M.L. Boas, *Mathematical Methods in Physical Sciences*.

30 Marks

Semester I

PHY 503: Quantum Mechanics I

100 Marks/4 Credits

Objective:

The course aims to provide students with a deep understanding of the abstract formalism of quantum mechanics, including linear vector spaces, operator theory, and quantum dynamics, enabling them to analyse symmetries, angular momentum, and solve quantum systems using both wave and operator methods.

Outcomes:

- *Understand the postulates of quantum mechanics, linear vector spaces, eigenvalues and eigenvectors, Dirac notation, operator representations, commutation relations, and the generalized uncertainty principle.*
- *Learn quantum dynamics in the Schrödinger and Heisenberg pictures, solve harmonic oscillator problems using operator methods, and analyse symmetries including spatial, temporal, parity, and time-reversal transformations.*
- *Apply angular momentum theory, ladder operators, matrix representations, addition of angular momenta, and Clebsch–Gordan coefficients in quantum systems.*

Syllabus:

Unit 1:

Abstract formalism of Quantum Mechanics: Review of quantum postulates, Mathematical properties of linear vector spaces, Postulates of quantum mechanics, Eigenvalues and eigenvectors, Orthonormality, completeness, closure, Dirac's bra and ket notation, Matrix representation of operators, Position and momentum representations – connection with wave mechanics. Dirac delta (δ) function, Commuting operators, Generalised uncertainty principle, Change of basis and unitary transformation, Expectation values. Ehrenfest theorem **35 Marks**

Unit 2:

Quantum Dynamics: Schrodinger picture, Heisenberg picture, Heisenberg equation of motion, Classical limit, Solution of Harmonic oscillator problem by the operator method, Symmetries in Quantum Mechanics: General view of symmetries, spatial translation – continuous and discrete, Time translation, Parity, Time reversal. **35 Marks**

Unit 3:

Angular Momentum: Commutation relations of angular momentum operators, Eigenvalues, Eigen functions, Ladder operators and their matrix representations, Addition of angular momenta, Clebsch – Gordon coefficients **30 Marks**

References

1. B. H. Bransden & C. J. Joachain, *Quantum Mechanics* (Pearson Education, 2000)
2. R. Shankar, *Principles of Quantum Mechanics* (3rd Ed., Springer, 2008)
3. Claude Cohen- Tannoudji, Bernard and Frank Laloe, *Quantum Mechanics* (II Vol. Set, 2006)
4. J.J. Sakurai, *Modern Quantum Mechanics* (Addison – Wessley, 1993)
5. F. Schwabl, *Advanced Quantum Mechanics* (Springer, 2000)
6. A. S. Davydov, *Quantum Mechanics* (2nd Ed., Pergamon, 1991)
7. Eugen Merzbacher, *Quantum Mechanics* (3rd Ed., Wiley, 1997)
8. N. Zettili, *Quantum Mechanics*, (Wiley)

Semester I

PHY 504: Electronics

100 Marks/4 Credits

Objective:

The course aims to provide a comprehensive understanding of semiconductor devices and digital electronics, covering fundamental principles, operational characteristics, and applications in modern electronic systems.

Outcomes:

- Understand the physics and characteristics of p-n junctions, LEDs, solar cells, and semiconductor lasers.
- Learn the operation, biasing, and models of Bipolar Junction Transistors including HBTs.
- Analyse the behaviour of JFETs, MESFETs, MOS capacitors, and MOSFETs using electrical models.

- Apply digital electronics concepts including logic gates, Boolean algebra, sequential circuits, and A/D and D/A converters.

Syllabus:

Unit 1: p-n junction

Energy Band Diagram; Forward and Reverse Bias; Full depletion analysis; Transient Response of P-n junction; Linearly graded junction; Abrupt p-i-n junction; Hetero p-n junction, Solar cell, Semiconductor laser, Light emitting diode. **25 Marks**

Unit 2: Bipolar Transistors

Bipolar Junction Transistor: Principle of Operation; Current Components and Current Gain; Bias modes and operation of bipolar transistor; Ebers-Moll Model; BJT small signal equivalent circuit model; Heterojunction Bipolar Transistors. **25 Marks**

Unit 3: Field Effect Transistors

JFET and MESFET: I-V characteristics; arbitrary doping and enhancement mode, advanced device structures

MOS Capacitors: Surface Charge in Metal Oxide Semiconductor Capacitors; Capacitance-Voltage Characteristics of a MIS Structure; Capacitance-Voltage characteristics.

Metal Oxide Semiconductor Field Effect Transistors (MOSFETs): Gradual Channel Approximation and Constant Mobility Model, Charge Control Model, Threshold Voltage. **25 Marks**

Unit 4: Digital Electronics

Basic digital concepts; Binary logic gates, binary arithmetic, number system, Basics and combinational logic gates; gate types and truth tables, Boolean algebra and DeMorgan's theorems, logic minimization and Karnaugh Maps, Multiplexing. Flip-Flops and introductory sequential logic, Counters, registers and state machines: Synchronous and asynchronous counters, basic and shift registers, Analogue to digital (A/D) and digital to analogue (D/A) convertors. **25 Marks**

References:

1. A P Malvino and D Leech, *Digital Principles and applications* (McGraw-Hill Pubs.)
2. S M Sze, *Semiconductor Devices-Physics and Technology* (John Willey Publications)
3. Abhay Man Singh, *Measurement, Instrumentation and Experiment Design in Physics and Engineering* (Prentice Hall Pubs.)
4. J Millman and C.C. Halkias, *Integrated Electronics* (Mc Graw Hill Pubs.)
5. R.P. Jain, *Modern Digital Electronics* (Tata Mc Graw Hill Publishing Company Limited)

Semester I

PHY 505: Laboratory Course I

100 Marks/4 Credits

(Classical Mechanics and Mathematical Methods in Physics)

Classical Mechanics

Objective:

To develop experimental skills in applying theoretical concepts of statistical physics, acoustics, thermodynamics, electromagnetism, and spectroscopy through practical measurements, data analysis, and validation of physical laws.

Course Learning Outcomes:

- *Apply chi-square statistical methods to test the goodness of fit of Poisson distribution in cosmic ray data.*
- *Measure velocities of ultrasonic waves in liquids using quartz oscillator and ultrasonic interferometer techniques.*
- *Determine the velocity of sound with precision using a Cathode Ray Oscilloscope (CRO).*
- *Verify Stefan's law experimentally and determine Stefan's constant.*
- *Perform Fourier analysis of given waveforms to study frequency components.*
- *Measure the charge-to-mass ratio (e/m) of an electron using a magnetron valve.*
- *Analyse the spectral distribution of radiation energy at different temperatures in the visible range.*

Experiments:

1. Testing goodness of fit of Poisson distribution to cosmic ray burst by chi-square test.
2. To determine the velocities of ultrasonic waves in liquid medium using quartz oscillator.
3. To determine the velocity of sound using CRO
4. To determine the velocity of ultrasonic wave using ultrasonic interferometer
5. To verify Stefan's law and determination of Stefan's constant
6. To measure the value of e/m of an electron using a magnetron valve.
7. To study the spectral distribution of energy in radiation at different temperatures (in visible range)

References

1. General Physics Laboratory Manual, Department of Physics, DMU
2. Any Laboratory Manual or General Physics Practical Text Book available

Mathematical Methods in Physics

(Python/SciLab/Mathematica/C/C++/Spreadsheet)

1. Curve Fitting using the Principle of Least Squares
2. Solution of ODE
3. Generating square wave, sine wave, saw tooth wave
4. Fourier analysis of given waveforms
5. Find the two square roots of $-5+12j$.
6. Compute the n th roots of unity for $n = 2, 3$, and 4 .
7. Verification of the Binomial Distribution by Monte Carlo Simulation.
8. Simulation of the Poisson Distribution and Rare Events.
9. Gaussian Distribution and the Central Limit Theorem.
10. Least-Squares Fitting of Experimental Data.
11. Verification of Bayes' Theorem Using Simulated Data.
12. Study of Permutation Groups and Symmetry Operations

11. Verification of Bayes' Theorem Using Simulated Data.
12. Study of Permutation Groups and Symmetry Operations.
13. Matrix Representations of Rotation Groups.
14. Generators of SO(3) and SU(2)
15. Laplace Transform and Solution of Differential Equations.
16. Fourier Transform and Spectral Analysis.
17. Numerical Verification of the Convolution Theorem for Laplace and Fourier transforms.
18. Diffusion Equation Using Fourier Transform
19. Solve the one-dimensional diffusion equation.
20. Heat Equation via Fourier Series and FFT
21. Quantum Spin-1/2 Rotations Using SU(2)
22. Random Walk and Gaussian Emergence.
- 23.

PHY 505: Laboratory Course II
(Quantum Mechanics I and Electronics)

100 Marks/4 Credits

Quantum Mechanics I

(Python/SciLab/Mathematica/C/C++/Spreadsheet)

1. Solve the s-wave Schrodinger equation for the ground state and the first excited state of the hydrogen atom:

$$\frac{d^2 y}{dr^2} = A(r)u(r), \quad A(r) = \frac{2m}{\hbar^2}[V(r) - E] \quad \text{where } V(r) = -\frac{e^2}{r}.$$

Here, m is the reduced mass of the electron. Obtain the energy eigenvalues and plot the corresponding wavefunctions. Remember that the ground state energy of the hydrogen atom is approximately -13.6 eV. Take $e = 3.795 \text{ (eV}\text{\AA})^{1/2}$, $\hbar c = 1973 \text{ (eV}\text{\AA})$ and $m = 0.511 \times 10^6 \text{ eV}/c^2$.

2. Solve the s-wave radial Schrodinger equation for an atom:

$$\frac{d^2 y}{dr^2} = A(r)u(r), \quad A(r) = \frac{2m}{\hbar^2}[V(r) - E]$$

where m is the reduced mass of the system (which can be chosen to be the mass of an electron), for the screened coulomb potential

$$V(r) = -\frac{e^2}{r} \exp(-r/a)$$

Find the energy (in eV) of the ground state of the atom to an accuracy of three significant digits. Also, plot the corresponding wavefunction. Take $e = 3.795 \text{ (eV}\text{\AA})^{1/2}$, $m = 0.511 \times 10^6 \text{ eV}/c^2$, and $a = 3 \text{ \AA}, 5 \text{ \AA}, 7 \text{ \AA}$. In these units $\hbar c = 1973 \text{ (eV}\text{\AA})$. The ground state energy is expected to be above -12 eV in all three cases.

3. Solve the s-wave radial Schrodinger equation for a particle of mass m :

$$\frac{d^2 y}{dr^2} = A(r)u(r), \quad A(r) = \frac{2m}{\hbar^2}[V(r) - E]$$

For the anharmonic oscillator potential

$$V(r) = \frac{1}{2}kr^2 + \frac{1}{3}br^3$$

for the ground state energy (in MeV) of particle to an accuracy of three significant digits. Also, plot the corresponding wave function. Choose $m = 940 \text{ MeV}/c^2$, $k = 100 \text{ MeV fm}^{-2}$, $b = 0, 10, 30 \text{ MeV fm}^{-3}$. In these units, $\hbar c = 197.3 \text{ MeV fm}$. The ground state energy is expected to lie between 90 and 110 MeV for all three cases.

4. Solve the s-wave radial Schrodinger equation for the vibrations of hydrogen molecule:

$$\frac{d^2 y}{dr^2} = A(r)u(r), \quad A(r) = \frac{2\mu}{\hbar^2}[V(r) - E]$$

Where μ is the reduced mass of the two-atom system for the Morse potential

$$V(r) = D(e^{-2ar'} - e^{-ar'}), \quad r' = \frac{r - r_0}{r_0}$$

Find the lowest vibrational energy (in MeV) of the molecule to an accuracy of three significant digits. Also plot the corresponding wave function.

Take: $m = 940 \times 10^6 \text{ eV}/c^2$, $D = 0.755501 \text{ eV}$, $\alpha = 1.44$, $r_0 = 0.131349 \text{ \AA}$.

5. Diagonalization of matrices, Inverse of a matrix, Eigen vectors, eigen values problems.
 6. Construct position (x) and momentum (p) operators in a discrete matrix basis. Compute the commutator $[x, p]$. Verify the Generalized Uncertainty Principle by checking the below relation,
 If $\sigma_A \sigma_B \geq \frac{1}{2} |\langle [A, B] \rangle|$.

Electronics

Objective:

To provide hands-on training in designing, analysing, and testing fundamental electronic circuits including power supplies, amplifiers, oscillators, multivibrators, modulation systems, and semiconductor devices, with emphasis on practical verification of theoretical concepts and performance evaluation.

Course Learning Outcomes:

- Design and test regulated power supplies and analyse their performance.
- Construct and study astable and monostable multivibrators, comparing experimental outputs with theoretical predictions.
- Investigate the characteristics and applications of Silicon Controlled Rectifiers (SCRs), measuring parameters like forward break-over voltage, holding current, and firing angle.
- Analyse push-pull amplifiers in different classes of operation, determine efficiency, and study frequency response in class AB.
- Perform modulation and demodulation experiments, sketch waveforms, and analyse effects of modulation index and RC constants.
- Study RC-coupled feedback amplifiers, plot frequency response, determine bandwidth, and compare performance with and without feedback.
- Construct sinusoidal oscillators (phase-shift, Hartley, Colpitts), measure frequencies of oscillation, and validate results with theoretical values.

Experiments:

1. Design and study of a Regulated Power Supply
2. Multivibrators:
 - (i) Astable: To sketch the wave shape of a stable multivibrator output for at least 3 different combinations of R and C and to compare the experimental result with the theoretical value,
 - (ii) Monostable: Using a square wave as the input to the mono shot, sketch the input in relation to the output of the mono shot for at least three different input frequencies.
3. Characteristics and applications of Silicon Controlled Rectifier:
 - (i) To plot the SCR characteristics under different gate current conditions and to obtain the values of the following parameters, (a) Forward break over voltage (V_{BRF}) for specified gate current (b) Forward ON voltage (V_F), (ii) To measure holding current (I_H), (iii) To study the effect of varying dc gate current on the firing point of the SCR connected as an ac rectifier.

4. Push-Pull Amplifier:

(i) To study the output waveforms of push-pull amplifier in different classes of operation and to measure the efficiencies in each case, and(ii) To plot the frequency response of the amplifier operated at the class *AB*.

5. Modulation and Demodulation:

(i) To sketch the modulated waveform for at least two modulating signal frequencies and different indices of modulation, (ii) To sketch the demodulated signal for a particular modulating signal and modulation index for three values of the *RC* time constant.

6. RC Coupled feedback amplifier,

To plot the frequency response for RC coupled feedback amplifier and hence to determine the bandwidth (BW) - (i) without feedback,(ii) with negative feedback, and(iii) with positive feedback(iv) To determine the signal handling capacities of the amplifier for each of the above three cases.

7. Sinusoidal Oscillators,

To study and measure the frequencies of oscillation for different values of *R*, *L* and *C* for

1. Phase shift,

2. Hartley's and

3. Colpitts's oscillators and compare with the theoretical values.

4. Experiment on FET and MOSFET characterization and application as an amplifier:

- To measure V_p .
- To plot the output characteristics of the CS configuration.
- To plot the transfer characteristics and hence to obtain transconductance.
- To plot the frequency response of the CS FET amplifier with and without feedback.

5. Experiment on Uni-Junction Transistor and its applications:

- To plot the input characteristics of UJT and to obtain the values of η , I_p , V_v , I_v , $V_{e(sat)}$.
- To plot the output characteristics of UJT and to obtain the values of R_{BB} .
- To study the working of a UJT saw tooth generator.

6. Digital I (Basic Logic Gates, TTL, NAND and NOR):

Realization of Boolean expression using (a) Different logic gates (b) Only universal building blocks (NAND/NOR).

7. Digital II (Combinational Logic):

Design a circuit using half adder by using NAND or NOR gates. Give specifications, truth table and Boolean equation.

8. Design a circuit using full adder by using gates. Give specifications, truth table and Boolean equation.

9. Design a four-bit controlled inverter circuit using XOR/NAND gates.

10. Design a circuit that can be used for addition and subtraction of two given four bit binary numbers using full adders and XOR/NAND gates. Explain its working and verify the result.

11. Flip-Flops.

12. Operational Amplifiers (741):

- To measure the input bias, offset currents and voltages etc.
- To measure the gain in the inverting amplifiers and to compare with the theoretical values.

13. 555 Timer:
To study 555 IC as a
- monoshot and hence to measure the pulse width,
 - Long duration timer and hence measure the duration, and
 - Astable multivibrator and to measure the frequency of oscillation.
14. Electronic voltmeter:
- To determine the percentage error for the ordinary voltmeter and electronic voltmeter and to determine their internal resistances.
 - To plot the frequency response of the same.
- 15.

References

1. *Integrated Electronics*: Millman and Halkias.
2. *Physics of Semiconductors Devices*: Sze.
3. *Op-Amps and Linear Integrated Circuits*: Gayakwa
4. *Electronic Communication Systems*: Kennedy
5. *Linear Integrated Circuits*: Choudhary and Jain.
6. *Digital Electronics*: Jain
7. Any Laboratory Manual Provid

Semester II

PHY 507: Quantum Mechanics II

100 Marks/4 Credits

Objective:

The objective of this course is to equip students with advanced knowledge of quantum mechanics through approximation methods, scattering theory, relativistic formulations, and the treatment of identical particles, enabling them to analyze and apply quantum principles to physical systems.

Outcomes:

- Apply time-independent perturbation, variational, and WKB methods to quantum systems and phenomena like Zeeman, Stark, and isotopic effects.
- Understand time-dependent perturbation theory, Fermi's Golden Rule, and approximations for constant, harmonic, adiabatic, and sudden perturbations.
- Learn semi-classical treatment of radiation-matter interaction, Einstein coefficients, and processes of absorption and emission.
- Analyse scattering using wave packet description, Green's function, Born approximation, partial wave analysis, and optical theorem.
- Understand relativistic quantum mechanics through Klein-Gordon and Dirac equations, electron spin, spin-orbit coupling, and energy levels in a Coulomb field.
- Learn the role of identical particles, symmetric and antisymmetric wavefunctions, spin incorporation, and the Pauli exclusion principle.

Syllabus:

Unit 1

Approximation Methods for Stationary Systems: Time-independent perturbation theory:

(a) non-degenerate and (b) degenerate. Applications to Zeeman effect, isotopic shift and Stark effect. Variational method and its applications. WKB Approximation **25 Marks**

Unit 2

Approximation Methods for Time-dependent Problems: Interaction picture. Time-dependent perturbation theory. Transition to a continuum of final states – Fermi's Golden Rule. Application to constant and harmonic perturbations. Adiabatic and sudden approximations **25 Marks**

Unit 3

Semi-classical treatment of interaction of radiation with matter. Einstein's co-efficients, Spontaneous and stimulated emissions and absorption **10 Marks**

Unit 4

Scattering: Wave packet description of scattering. Formal treatment of scattering by Green function method. Born approximation and applications. Partial wave analysis. Optical theorem. **10 Marks**

Unit 5

Relativistic Quantum Mechanics: Klein-Gordon and Dirac equations. Properties of Dirac matrices. Plane wave solutions of Dirac equation. Spin and magnetic moment of the electron. Nonrelativistic reduction of the Dirac equation. Spin-orbit coupling. Energy levels in a Coulomb field. **20 Marks**

reduction of the Dirac equation. Spin-orbit coupling. Energy levels in a Coulomb field.
20 Marks

Unit 6

Identical particles: Indistinguishability, symmetric and anti-symmetric wave functions, incorporation of spin, Pauli exclusion principle.
10 Marks

References

24. C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics (Vol II)*, Wiley
25. B. H. Bransden and C. J. Joachain, *Quantum Mechanics*, Pearson Education
26. R. Shankar, *Principles of Quantum Mechanics*, Springer
27. J.J. Sakurai, *Modern Quantum Mechanics*, Addison-Wesley
28. Schwabl F., *Advanced Quantum Mechanics*, Springer
29. A.S. Davydov, *Quantum Mechanics*, Pergamon
30. E. Merzbacher, *Quantum Mechanics*, Wiley
31. H.J.W. Muller-Kirsten, *Introduction to Quantum Mechanics: Schrodinger equation and Path Integral*, World Scientific
32. L.H. Ryder, *Quantum Field Theory*, Cambridge Univ. Press
33. J.D. Bjorken and S.D. Drell, *Relativistic Quantum Fields Vol. I & II*, Mc-Graw-Hill

Semester II

PHY 508: Statistical Physics

100 Marks/4 Credits

Objective:

The objective of this course is to provide students with a deep understanding of classical and quantum statistics, radiation theories, and the statistical behaviour of systems of particles. It aims to develop the ability to connect microscopic states with macroscopic properties and to apply statistical methods to gases, radiation, and condensed matter systems.

Course Learning Outcomes:

- *Understand microstates, macrostates, ensembles, entropy, thermodynamic probability, partition function, and Maxwell–Boltzmann distribution with applications to specific heat, Gibbs paradox, Sackur–Tetrode equation, and negative temperature systems.*
- *Grasp properties of thermal radiation, Kirchhoff's law, Stefan–Boltzmann law, Wien's displacement law, Wien's and Rayleigh–Jean's distribution laws, Saha's ionization formula, and limitations of classical theory leading to ultraviolet catastrophe.*
- *Learn Planck's quantum postulates and law of blackbody radiation, along with its experimental verification and deductions of Wien's, Rayleigh–Jeans, Stefan–Boltzmann, and Wien's displacement laws.*
- *Apply Bose–Einstein distribution to degenerate Bose gases, study Bose–Einstein condensation, photon gas, thermodynamic functions of radiation, and properties of liquid helium.*
- *Understand Fermi–Dirac distribution, Fermi energy, electron gas in metals, specific heat of metals, degenerate and relativistic Fermi gases, and astrophysical applications such as white dwarf stars and Chandrasekhar mass limit.*

Syllabus:

Unit 1. Elementary Probability Theory

Binomial, Poisson and Gaussian distributions. Central limit theorem

25 Marks

Unit 2. Review of Thermodynamics

Extensive and intensive variables. Laws of Thermodynamics. Legendre transformations and thermodynamic potentials. Maxwell relations. Applications of Thermodynamics to (a) ideal gas, (b) magnetic material, and (c) dielectric material. **25 Marks**

Unit 3. Formalism of Equilibrium Statistical Mechanics

Phase space, Liouville's theorem. Basic postulates of Statistical Mechanics. Microcanonical, canonical and grand canonical ensembles. Relation to Thermodynamics. Fluctuations. Applications of various ensembles. Equation of state for a non-ideal gas, Van der Waal's equation of state. Meyer cluster expansion, virial coefficients. Ising model, mean field theory.

25 Marks

Unit 4. Quantum Statistics

Fermi-Dirac and Bose-Einstein statistics.

Ideal Boson gas, Debye theory of specific heat, properties of blackbody radiation. Bose-Einstein condensation, experiments on atomic BEC, BEC in a harmonic potential.

Ideal Fermi gas. Properties of simple metals. Pauli paramagnetism. Electronic specific heat. White dwarf stars.

25 Marks

References

1. **F. Reif**, *Fundamentals of Statistical and Thermal Physics*, Levant
2. **K. Huang**, *Statistical Mechanics*, Wiley
3. **R.K. Pathria**, *Statistical Mechanics*, Elsevier
4. **D.A. McQuarrie**, *Statistical Mechanics*, University Science Books
5. **S.K. Ma**, *Statistical Mechanics*, World Scientific
6. **R.P. Feynman**, *Statistical Mechanics*, Levant
7. **D. Choudhury and D. Stauffer**, *Principles of Equilibrium Statistical Mechanics*, Wiley-VCH

Semester II

PHY 509: Electrodynamics and Plasma Physics

100 Marks/4 Credits

Objective:

The course aims to provide students with a comprehensive understanding of classical and modern electrodynamics, covering electrostatics, magnetostatics, Maxwell's equations, electromagnetic waves and radiation, and the basics of plasma, enabling them to analyse and solve a wide range of electromagnetic phenomena.

Outcomes:

- *Understand electrostatics and magnetostatics, including Coulomb's law, Gauss's law, Poisson and Laplace equations, Green's functions, multipole expansion, dielectrics, Biot-Savart law, Ampere's theorem, vector potentials, and energy densities of fields.*
- *Learn Maxwell's equations, scalar and vector potentials, gauge invariance, displacement current, electromagnetic energy and momentum, field tensors, and covariant formulation of electrodynamics.*
- *Apply concepts of electromagnetic waves, plane waves in dielectrics, reflection and refraction, dispersion, waveguides, resonant modes, and boundary conditions in wave propagation.*
- *Analyse radiation from localized oscillating sources, dipole and quadrupole fields, Lienard-Wiechert potentials, radiation from accelerated charges, and antenna behaviour.*
- *Understand plasma as a state of matter, Debye length, plasma frequency, collisions, conductivity, and dispersion relations in plasmas.*

Syllabus:

Unit 1. Review of Electrostatics and Magnetostatics

Coulomb's law, Gauss's law, Poisson and Laplace equations, formal solution for potential with Green's functions, boundary value problems; multipole expansion; Dielectrics, polarisation of a medium; Biot-Savart law, Ampere's theorem, differential equation for static magnetic field, vector potential, magnetic field from localized current distributions; Faraday's law of induction; energy densities of electric and magnetic fields

20 Marks

Unit 2. Maxwell's equations

Maxwell's equations in vacuum, Scalar and Vector potentials in electrodynamics, gauge invariance and gauge fixing, Coulomb and Lorenz gauges. Displacement current. Electromagnetic energy and momentum. Conservation laws. Inhomogeneous wave equation and its solutions using Green's function method. Transformation properties of electric and magnetic fields. Electromagnetic field tensor. Covariant formulation of Maxwell's equations.

20 Marks

Unit 3. Electromagnetic waves

Electromagnetic waves in free space, plane waves in a dielectric medium, reflection and refraction at dielectric interfaces, Frequency dispersion in dielectrics and metals. Dielectric constant and anomalous dispersion, Wave propagation in one dimension, group velocity, metallic wave guides, boundary conditions at metallic surfaces, propagation modes in wave guides, resonant modes in cavities. Dielectric waveguides.

20 Marks

Unit 4. Radiation

EM field of a localized oscillating source. Fields and radiation in dipole and quadrupole approximations. Antenna: Radiation by moving charges, Lienard-Wiechert potentials, total power radiated by an accelerated charge, Lorentz formula.

20 Marks

Unit 5. Basics of plasma

Plasma as a state of matter, Debye length, plasma frequency, collisions, dc conductivity and ac conductivity, Dispersion relation in plasma.

20 Marks

References

1. J.D. Jackson, *Classical Electrodynamics*, Wiley
2. D.J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall
3. A. Das, *Lectures on Electromagnetism*, Hindustan Book Agency
4. J.R. Reitz, F.J. Milford and R.W. Christy, *Foundations of Electromagnetic Theory*, Addison-Wesley
5. W.K.H. Panofsky and M. Philips, *Classical Electricity and Magnetism*, Dover
6. R.P. Feynman, *Feynman Lectures on Physics (Vol. II)*, Addison-Wesley
7. A. Zangwill, *Modern Electrodynamics*, Cambridge Univ. Press

Semester II

PHY 510: Condensed Matter Physics

100 Marks/4 Credits

Objective:

The course aims to provide students with a deep understanding of crystal physics, defects in solids, and electronic properties of materials, enabling them to analyse crystal structures, diffraction phenomena, and the electronic, magnetic, and superconducting behaviour of solids.

Outcomes:

- *Understand* crystal structures, Bravais lattices, close-packed arrangements, and X-ray interaction with matter, including diffraction, structure factors, and powder methods.
- *Learn* point, line, and planar defects in crystals and analyse imperfections using X-ray and electron microscopy.
- *Apply* concepts of ordered phases, liquid crystals, conducting polymers, and quasicrystals to real materials.
- *Analyse* electronic properties of solids including Bloch theorem, band theory, effective mass, Fermi surfaces, Hall effect, magnetoresistance, superconductivity, and magnetic ordering such as ferromagnetic, ferri-, and antiferromagnetic phases.

Syllabus:

Unit 1. Crystal Physics and Defects in Crystals:

Crystalline solids, unit cells and direct lattice, two- and three-dimensional Bravais lattices, close packed structures.

Interaction of X-rays with matter, absorption of X-rays, elastic scattering from a perfect lattice, the reciprocal lattice and its applications to diffraction techniques, powder method, crystal structure factor and intensity of diffraction maxima, extinctions due to lattice centering

Point defects, line defects and planar (stacking) faults, Observation of imperfections in crystals, X-ray and electron microscopic techniques.

Ordered phases of matter, translational and orientational order, kinds of liquid crystalline order, conducting polymers, quasicrystals.

50 Marks

Unit 2. Electronic properties of solids:

Electrons in a periodic lattice, Bloch theorem, band theory, classification of solids, effective mass, tight binding, cellular and pseudopotential methods, Fermi surface, cyclotron resonance, magneto resistance, Hall effect, quantum Hall effect Superconductivity, critical temperature, persistent current, Meissner effect, Weiss theory of ferromagnetism, Heisenberg model and molecular field theory spin waves and magnons, Curie-Weiss law for susceptibility, Ferri- and antiferromagnetic order, Domains and Bloch- wall energy.

50 Marks

References

1. C. Kittel, *Introduction to Solid State Physics*.
2. N.W. Ashcroft and N.D. Mermin (BROOKS/COLE, 1976), *Solid State Physics*.

3. . A.R. Varma and O.N. Srivastava, *Crystallography for Solid State Physics*.
4. M.P. Marder, *Condensed Matter Physics*.
5. Azaroff, *Introduction to Solids*.

Semester II

PHY 511: Laboratory Course III (Quantum mechanics II and Condensed Matter Physics) 100 Marks/4 Credits

Quantum mechanics II

(Python/SciLab/C/C++/Mathematica/Spreadsheet)

1. Construct an unperturbed Hamiltonian matrix $\hat{H}_0$ and a perturbation matrix $\hat{H}$ (Stark/Zeeeman effect); calculate analytical first- and second-order energy corrections; compare these perturbative shifts against exact eigenvalues obtained via matrix diagonalization (numpy.linalg.eigh).
2. Define a non-solvable potential (e.g., $V(x) = x^4$) and a trial wave function $\psi(x, \alpha)$; write a function to evaluate the energy expectation value $\langle E(\alpha) \rangle$ using numerical integration; minimize $\langle E(\alpha) \rangle$ with respect to α using an optimization routine to estimate the ground-state energy.
3. Define a smooth potential barrier; numerically locate the classical turning points where $E = V(x)$ using a root-finding algorithm; compute the WKB action integral $\int \sqrt{2m(E - V(x))} dx$ via numerical integration; calculate and plot the transmission coefficient $T(E)$.
4. Set up a two-level system matrix equation; apply a time-dependent driving potential $V(t) = V_0 \cos(\omega t)$; solve the coupled differential equations for the state coefficients $c_1(t)$ and $c_2(t)$ using an ODE solver; plot probability populations over time to observe Rabi oscillations.
5. Model a discrete state coupled to a dense grid of unperturbed final states; apply a constant perturbation switched on at $t=0$; track the total transition probability to the continuum over time; calculate the transition rate $\frac{dP}{dt}$ to verify that it becomes constant, validating Fermi's Golden Rule.
6. Set up and solve the rate equations for a multi-level atomic system; incorporate parameters for spontaneous emission (A_{21}), stimulated emission $B_{21}\rho(\nu)$, and absorption $B_{12}\rho(\nu)$; simulate and plot the time-dependent state populations under varying radiation densities to model population inversion.
7. Numerically solve the radial Schrödinger equation for different partial waves $l = 0, 1, 2, \dots$ inside a spherical potential $V(r)$; extract the scattering phase shifts δ_l by matching internal and external wave functions at the boundary; calculate the total scattering cross-section σ and verify the Optical Theorem.
8. Construct the 4X4 Dirac α_i and β matrices using Kronecker products (numpy.kron); write routines to verify their fundamental anti-commutation relations $\{\alpha_i, \alpha_j\} = 2\delta_{ij}I$; write a code to calculate the spin-orbit coupling energy correction in a discrete basis.
9. Implement a function to generate the positive- and negative-energy four-component Dirac spinors for a given momentum $\mathbf{p}$; verify spinor orthogonality; plot the ratio of the "small component" to the "large component" across non-relativistic and ultra-relativistic momentum regimes.
10. Define two single-particle spatial orbitals; write a function to construct a Slater Determinant for fermions (anti-symmetric) and a permanent for bosons (symmetric); combine them with spin configurations (singlet/triplet); plot the joint probability density $|\Psi(x_1, x_2)|^2$ to visualize the spatial exchange hole.

Semester III

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)

Semester III

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)

Semester III

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 III

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 Briet 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 III

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)

Semester III

PHY 615: Laboratory Course 3 (Atomic and Molecular Physics & Nuclear Physics) **100 Marks/4 Credits.**

Condensed Matter Physics

Experiments:

1. Measurement of lattice parameters and indexing of powder 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 Fizeau fringes.
7. To obtain Multiple beams. 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 the film at different temperatures.
17. Measurement of complex refractive index and band gap of a thin film semiconductor.

Atomic and Molecular Physics

Experiments:

1. Constant deviation spectrometer-fine structure of Hg spectral lines.
2. e/m or hyperfine structure using Fabry Perot's interferometer.
3. Band spectrum in liquids.
4. Raman scattering using a laser source.
5. Luminescence.

Nuclear Physics

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

Nuclear Physics

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

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 IV

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*: Abhay Man 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 IV

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

100 Marks/4 Credits

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, Lienard 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 Schroedinger 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, nano-wires 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 IV

PHY 633: Elective IV (A) 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 (World Scientific, 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)

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

Objective:

To provide knowledge and practical understanding of advanced material characterization and imaging techniques for analysing structural, optical, electrical, and magnetic properties of materials at micro- and nano-scales.

Course Learning Outcomes:

- *Explain the principles of XRD, SEM, TEM, AFM, UV-Visible, IR, and Raman spectroscopy and analyse structural, morphological, and optical properties of materials.*
- *Demonstrate understanding of impedance spectroscopy using LCR meters, impedance and network analysers, and apply switching and I-V characterization techniques for evaluating electrical and magnetic properties of materials.*
- *Identify elements and phases in micro- and nano-materials using XRD, EDS, and various spectroscopic techniques including UV-Vis, Raman, IR, Mossbauer, and Laser Raman spectroscopy.*
- *Apply optical microscopy, SEM, TEM, and AFM for imaging, surface analysis, and microstructural characterization of materials.*

Syllabus:

1. Material characterization techniques: Powder X-ray Diffraction (XRD) technique, scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM), UV-Visible spectroscopy, IR -Spectroscopy and Raman spectroscopy techniques.

25 Marks

2. Impedance spectroscopy techniques: LCR meter, Impedance analyzers and Network analysers; Switching characterization techniques – Sawyer-tower circuit, capacitance-voltage (C-V) plotter, vibration sample magnetometer (VSM); Current-Voltage characterization systems.

25 Marks

3. Characterization of micro- and nano-materials: Element identification by Energy dispersive X-ray Spectroscopy, X-Ray Diffractometer, UV-Visible spectroscopy, Rotational and vibrational (Raman and Infrared) and Electronic Spectroscopy, Mossbauer spectroscopy, Laser Raman spectroscopy

25 Marks

4. Imaging techniques: Optical microscopy, Scanning electron microscopy, Atomic Force Microscopy and Transmission Electron Microscopy. Characterization and surface studies of materials

25 Marks

References:

1. *Elements of X-ray Diffraction* : Bernard Dennis Cullity, Addison-Wesley Publishing Company, Inc.(1956).
2. *Physical Principles of Electron microscopy*: An introduction to TEM, SEM and AEM by Ray F. Egerton, Springer.

3. *An Introduction to the Optical Spectroscopy of Inorganic Solids*: J. Garcia Sole, L. E. Bausa and D. Jaque, John Willey & Sons.
4. *Piezoelectric ceramics*: B. Jaffe, W.R. Cook, H. L. Jaffe, Academic Press 1971.
5. *176-1988-IEEE Standard on Piezoelectricity*.
6. *Introduction to Magnetism and Magnetic materials*: B. D. Cullity.
7. *Measurement and Characterization of Magnetic Materials*: Fausto Fiorillo, Elsevier series in Electromagnetism.

Semester IV

PHY 641: Elective V (A) Advanced Condensed Matter Physics II

100 Marks/4 Credits

Objective:

To introduce fundamental theoretical approaches for understanding interacting electron systems, density functional theory, optical properties of solids, and the physics of disordered materials, enabling students to analyse electronic, optical, and transport phenomena in advanced materials.

Course Learning Outcomes:

- *Explain the concepts of interacting electron gas, Hartree and Hartree-Fock methods, correlation energy, screening, plasmons, dielectric functions, and Friedel oscillations.*
- *Demonstrate understanding of density functional theory, Hohenberg-Kohn theorems, Kohn-Sham equations, and local density approximations.*
- *Analyse optical properties of solids including electron-photon and phonon-photon interactions, direct and indirect transitions, excitons, polaritons, and apply Kramer-Kronig relations.*
- *Discuss the physics of disordered solids such as amorphous materials, glasses, electron localization, density of states, mobility edge, Anderson and Mott's localization, and hopping conductivity.*

Syllabus:

Unit 1. Interacting Electron Gas: Hartree and Hartree-Fock Methods, Correlation Energy, Screening, Plasmons, Dielectric Functions and its Properties, Friedel Oscillations.

25 Marks

Unit 2. Density functional theory: Density functional, Hohenberg-Kohn theorems, Self consistent Kohn-Sham equations, local density approximations.

25 Marks

Unit 3. Optical properties : Interaction of electrons and phonons with photons, Direct and indirect transitions, Kramer-Kronig relations, Excitons, polaritons.

25 Marks

Unit 4. Disordered solids: amorphous materials, glasses, glass transition temperature, Electron localization, Density of states, mobility edge, Anderson model and Mott's localization, hopping conductivity.

25 Marks

References:

1. *Wave mechanics of electrons in metals* – Stanley Raimes
2. *ABC of ground-state Density Functional Theory* - Kieron Burke and Lucas Wagner
Departments of Physics and of Chemistry, University of California, Irvine, CA 92697, USA
January 5-9th, 2014
3. *Optical properties of solids* – J Singh
4. *Electronic processes in nanocrystalline materials*- Mott N. F. and Gurney

Semester IV

PHY 642: Elective V (B) Astrophysics

100 Marks/4 Credits

Objective:

To provide students with a comprehensive understanding of the fundamental concepts, methods, and modern developments in observational astronomy, stellar physics, solar studies, compact objects, interstellar medium, galaxies, and cosmology, enabling them to analyse celestial phenomena using both theoretical and observational approaches.

Course Learning Outcomes:

- *Explain astronomical coordinate systems, stellar magnitudes, methods for determining stellar parameters, stellar classification schemes, HR diagrams, and the principles of telescopes, photometers, CCDs, and atmospheric extinction.*
- *Describe the Sun as a star, its structure, magnetic fields, solar phenomena, and related solar system objects including meteorites, asteroids, comets, planets, satellites, and tides, along with theories of solar system origin.*
- *Analyse the structure and evolution of stars using virial theorem, hydrostatic equilibrium, polytropic models, energy generation mechanisms, radiative/convective energy transport, stellar structure equations, and the evolution of stars of different masses.*
- *Discuss the nature and fate of compact stellar objects including white dwarfs, neutron stars, pulsars, and black holes, with emphasis on degeneracy pressure, Chandrasekhar limit, and mass-radius relations.*
- *Evaluate the physical processes in the interstellar medium, star formation, structure of nebulae, galactic magnetic fields, properties of the Milky Way, galaxy classification, morphology, dynamics, dark matter, galaxy clusters, active galaxies, quasars, and large-scale structure of the Universe.*
- *Describe modern developments in astronomy including radio sources, 21-cm hydrogen line studies, gravitational waves, gravitational lensing, gamma-ray bursts, and cosmic expansion with Hubble's constant determination.*

Syllabus:

Unit 1. Observational Astronomy

Astronomical coordinates, Magnitude scales – apparent, instrumental and absolute magnitudes, distance modulus, Determination of mass, radius, luminosity, temperature and distance of a star, colour index, Stellar classification – Henry-Draper and M-K classification schemes, HR diagrams of stars and star clusters, Different types of astronomical telescopes and their mounts, Basic ideas of photometer and CCD, Atmospheric extinction.

25 Marks

Unit 2. The Sun

The sun as a star, Physical characteristics of the sun, basic data, solar magnetic field, solar observations, solar interior, photosphere, granulation, sunspots, Babcock model of sunspot formation, Solar atmosphere – chromosphere and corona, solar rotation, solar activity, flares, prominences, solar wind, meteorites, asteroids, comets, planets, satellites and rings, tides, origin of the solar system.

10 Marks

Unit 3. Stellar structure and evolution

Virial Theorem, Formation of stars, Hydrostatic equilibrium, Integral theorems on pressure, density and temperature, Homologous transformations, Polytropic gas spheres – Lane Emden 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. Carroll 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)

PHY 618: Laboratory Course VII (Computer Practical)

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:

$$\begin{aligned} &\rightarrow a = 2.500, b = 5.200, c = 6.200, p = 1.251, q = 2.605, r = 3.152 \\ &ax + b = c \\ &px + qy = r \end{aligned}$$

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 phasediagrams.
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

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

- a) 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

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

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 .

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.