VIDYASAGAR UNIVERSITY

Midnapore, West Bengal

PROPOSED CURRICULUM&SYLLABUS (DRAFT) OF

B.Sc. (HONOURS / HONOURS WITH RESEARCH)

MAJOR IN PHYSICS

4-YEAR UNDERGRADUATE PROGRAMME

(w.e.f. Academic Year 2023-2024)

Based on

Curriculum & Credit Framework for Undergraduate Programmes

(CCFUP), 2023& NEP, 2020

VIDYASAGAR UNIVERSITY
BACHELOR OF SCIENCE (HONOURS/ HONOURS WITH RESEARCH) MAJOR IN PHYSICS
(under CCFUP, 2023)

Level	YR.	SEM	Course Type	Course Code	Course Title	Credit	L-T-P	Marks		
								CA	ESE	TOTAL
B.Sc. (Hons./ Hons. with Research)	4th	VII	SEMESTER-VII							
			Major-14	PHSHMJ14	T: Advanced Mathematical Methods with Advanced Classical Mechanics	4	3-1-0	15	60	75
			Major-15	PHSHMJ15	T: Advanced Quantum Mechanics	4	3-1-0	15	60	75
			CRM	PHSHCRM	T: Research Methodology and Publication Ethics; P: Practical	4	3-0-1	15	60	75
			Major Elective-03	PHSHDSE 03	T: Classical Electrodynamics; P: Practical	4	3-0-1	15	60	75
			Minor-07 (Disc.-I)	PHSMIN07	T: Modern Physics; P: Practical *(To be taken by the other Discipline)*	4	3-0-1	15	60	75
					Semester-VII Total	20				375
		VIII	SEMESTER-VIII							
			Major-16	PHSHMJ16	T: Advanced Statistical Mechanics	4	3-1-0	15	60	75
			Major Elective-04	PHSHDSE04	T: Molecular Spectroscopy and Applied Optics	4	3-1-0	15	60	75
			Major Elective-05	PHSHDSE05	Advanced Electronics II OR Advanced Instrumentation OR Computational Physics OR Radiation Physics — FOR HONOURS STUDENTS	4	3-1-0 / 3-0-1	15	60	75
			Major Elective-06	PHSHDSE06	Physics of Nanomaterials OR Basics of Astrophysics and Cosmology OR Biological Physics OR Quantum Science & Technology — FOR HONOURS STUDENTS	4	3-1-0 / 3-0-1	15	60	75
			Research	PHSHRD	DISSERTATION: *FOR HONOURS WITH RESEARCH STUDENTS*	*8*	*0-0-8*	*-*	*150*	*150*
			Minor-8 (Disc.-II)	PHSMIN08	T: Nuclear Physics *(To be taken by the other Discipline)*	4	3-1-0	15	60	75
					Semester-VIII Total	20				375
					YEAR-4	40				750
					To be awarded *Bachelor of Science (Honours / Honours with Research) Major in Physics*	166	Marks (Year: I+II+III+IV)			3075

MJ = Major, MI = Minor Course, DSE = Discipline Specific Elective Course, CRM= Compulsory Research Methodology, CA= Continuous Assessment, ESE= End Semester Examination, T = Theory, P= Practical, L-T-P = Lecture-Tutorial-Practical

SEMESTER-VII

MAJOR (MJ)

Major – 14
Advanced Mathematical Methods with Advanced Classical Mechanics

[THEORY; CREDITS: 04; FM- 75; 60L]

Course contents:

UNIT-I (Advanced Mathematical Methods)

1. **Partial differential equations:** Elliptic, parabolic and hyperbolic type equations, Lagrange's formula for 2nd order partial differential equation, Dirichlet Neumann and Cauchy Boundary value problem. Greens function with applications. [5L]

2. **Tensor analysis:** Outer product, Inner product and Contraction. Symmetric and antisymmetric tensors. Quotient law. Metric tensor. Conjugate tensor. Length and angle between vectors. Associated tensors. Raising and lowering of indices. The Christoffel symbols and their transformation laws. Covariant derivative of tensors. [7L]

3. **Group theory:** Definition, nomenclature and examples. Rearrangement theorem. Cyclic groups. Subgroups and Cosets. Conjugate elements and class structure. Factor groups. Isomorphy and Homomorphy. Direct product groups. Symmetric groups, Cayley's theorem, Representation of finite groups- Definition, Unitary representation, Schur's Lemma, Orthogonality theorem, Reducible and irreducible representations, Characters, Regular representation, Product representation, Character table, Examples of S_3 and C_4v. Introduction to Lie groups and Lie algebra. Clebsch-Gordon coefficients.

[16L]

UNIT-II (Advanced Classical Mechanics)

4. **Recapitulation of Mechanics:** Lagrange & Hamiltonian for Non conservative system: Velocity dependent potential, dissipation function, charge particle is moving in an electromagnetic field.

[4L]

5. **Hamilton – Jacobi Theory:** Hamilton – Jacobi equation for Hamilton's principal function, Physical significance of Hamilton's principal function, Hamilton – Jacobi equation for Hamilton's characteristic function, Physical significance of Hamilton's characteristic function Hamilton-Jacobi equation from Schrodinger equation, Action-angle variables.

[10L]

6. **Dynamics of rigid bodies:** Euler angles, rigid body problems and the Euler equations of motion, torque free motion of rigid bodies, the symmetrical top. [5L]

7. **Introduction to Classical Chaos:** Periodic Motion, Attractors, Chaotic Trajectories and Lyapunov Exponents, Poincare Map, Logistic Equation, Classification of fixed points, limit cycles. [8L]

8. **Systems with infinite degrees of freedom:** Lagrangian and Hamiltonian formulations for continuous systems and fields, equations of motion. Symmetries and invariance principles, Noether's theorem. [5L]

Books Recommended:

1. Spiegel, M.R. (2000) Theory and Problems of Complex Variables (Schaum's outline series). McGraw-Hill Publishing Co.; Metric Ed., United States.
2. Arfken, G.B. and Weber, H.J. (2005) Mathematical Methods for Physicists, 16th ed., Elsevier Academic Press, USA.
3. Mathews, J. and Walker, R.I. (1971) Mathematical Methods of Physics, 2nd ed., Pearson Addison-Wesley, United States.
4. Dennery, P. and Krzywicki, A. (1996) Mathematics for Physicists, 1st ed., Dover Publications Inc., United States.
5. Grewal, B.S. (1965) Higher Engineering Mathematics, 1st ed., Khanna Publisher, India. 6. Joshi, A.W. (2018) Group Theory for Physicists, 5th ed., New Age International Publishers, India.
6. Hamermesh, M. (1989) Group Theory and Its Application to Physical Problems, 1st ed., Dover Publications Inc., United States.
7. Dass, T. and Sharma, S.K. (1998) Mathematical Methods in Classical and Quantum Physics, 1st ed., Universities Press Pvt. Ltd., India.
8. Joshi, A.W. (1995) Matrices and Tensors, 3rd ed., New Age International Publishers, India.
9. Goldstein, H. (2011) Classical Mechanics, 3rd ed., Narosa Publishing Home, India.
10. Jose J. V., Seletan E. J. (1998) , Classical Dynamics: A contemporary approach, 1st ed., Cambridge University Press
11. Thornton, S., and Marion, J. (2003) Classical Dynamics of Particles and Systems, 5th ed., Horoloma Book Jovanovich College Publisher. UK.
12. Rana, N. C., and Joag, P. S. (1991) Classical Mechanics, 1st ed., Tata McGraw-Hill Pub. Co., India.
13. Takawale, R. G., and Puranik, P. S. (1979) Introduction to Classical Mechanics, 1st ed., Tata Mc- Graw Hill Publishing Company Limited, India.
14. Upadhyaya, J. C. (2019) Classical Mechanics, 1st ed., Himalaya Publishing House, India.
15. Morlin, D. (2008) Introduction to Classical Mechanics, 1st ed., Cambridge University

1. Press, UK.

Major – 15
Advanced Quantum Mechanics

[THEORY; CREDITS: 04; FM- 75; 60L]

Course contents:

1. **Quantum Dynamics:** Schrodinger picture, Heisenberg picture, Heisenberg equation of motion. Solution of simple harmonic oscillator by the operator method. [5L]

2. **Angular Momentum:** Spin 1/2 system. Rotation matrices. General commutation relations of angular momentum operators. Eigenvalues, eigenvectors. Ladder operators and their matrix representations. Orbital angular momentum. Addition of angular momenta. Clebsch-Gordan coefficients. Tensor operators and Wigner-Eckart theorem. [8L]

3. **Symmetries in Quantum Mechanics:** Symmetries and conservation laws, Degeneracies, Discrete spatial translation, time translation. parity, time reversal. [5L]

4. **Approximation Methods for Stationary Systems:** Time-independent perturbation theory: nondegenerate and degenerate. Stark effect, Zeeman effect. Variational and WKB methods and applications. [12L]

5. **Approximation Methods for time-dependent perturbations:** Interaction picture. Time-dependent perturbation theory. Transition to a continuum of final states–Fermi's Golden Rule. Constant and harmonic perturbations. Sudden and adiabatic approximations. [8L]

6. **Identical particles:** Permutation Symmetry. Symmetrization postulate: symmetric and antisymmetric wave function, Pauli's exclusion Principle. Slater determinant. Two-Electron System- The Helium atom, ground state of Helium atom. [4L]

7. **Non-relativistic Scattering:** Lippmann-Schwinger Equations, Green's function method. Born approximation, S-Matrix, Optical theorem, Method of Partial Waves, Phase shifts. [7L]

8. **Relativistic quantum mechanics:** Historical survey. Klein-Gordon and Dirac equations. Properties of Dirac matrices. Plane wave solutions of Dirac equation. Spin and magnetic moment of the electron, non-relativistic limits. [11L]

Books Recommended:

1. Sakurai J. J. and Napolitano J. (2020) Modern Quantum Mechanics, 3rd ed., Addison-Wesley.
2. Schiff L. I., (1969) Quantum Mechanics, 3rd ed., McGraw-Hill Book, New York.
3. Schwabl F. (2007) Quantum Mechanics, 4th ed., Springer.
4. Griffiths D. J. & Schroeter D. F. (2019) Introduction to Quantum Mechanics, 3rd ed., Cambridge Univ. Press.
5. Ghatak A. K. & Lokanathan S. Quantum Mechanics: Theory and Applications, Macmillan India Ltd.
6. Cohen-Tannoudji C., Diu B. & Laloe F. (2019) Quantum Mechanics, Vol I & II, 2nd Ed., Wiley.
7. Zettili N. (2009) Quantum Mechanics: Concepts and Applications, 2nd ed., Wiley India.
8. Singh J., (1996) Quantum Mechanics: Fundamentals and Applications.

COMPULSORY RESEARCH METHODOLOGY (CRM)

[for both Hons. and Hons. with Research students]

CRM: Research Methodology and Publication Ethics
Credit: 4; Full Marks: 75

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Theory (3 Credit, 45 hrs.)

1. Basics of Research:

Definition, importance, and characteristics of research; distinction between method and methodology; types of research – basic, applied, qualitative, quantitative, descriptive, analytical, experimental.

2. **Research Problem and Literature**

Review Identification and formulation of research problems; research questions and objectives; survey of literature – importance, sources, and research gaps.

3. **Hypothesis and Research Process**

Hypothesis – meaning, role, and types (null, alternative, simple, complex, directional, causal); research process – steps from problem identification to report writing.

4. **Introduction to Ethics**

Definition, nature, and scope of ethics; different branches of ethics; importance of ethics in research and academic life.

5. **Research Ethics**

Meaning and significance; responsibilities of researchers towards fellow researchers, public, and academic community; concept of academic integrity. Suggested Text:

Practical (1 Credit, 30 hrs.)

Group A: Computer programming using C/Python

1. Finite and infinite series. Finding roots using Bisection, Secant and Newton-Raphson methods.

2. Solving first and second order differential equations using Euler and Runge Kutta methods. Integration using Trapezoidal, Simpson methods.

3. Matrices: Use of arrays, Matrix Operations, Eigenvalues & Eigenvectors, Matrix Inversion, Solving Systems of Linear Equations.

4. Partial differential equations. Finite Difference method; Forward and Backward difference methods, Finite Element method. Examples: (i) Quantum Mechanics: Solving Schrodinger's equations in a few potentials (box, triangle, one dimensional harmonic oscillator). (ii) Electromagnetism: Poisson and Laplace's equation. (iii) Heat equation and Wave equation.

5. Use of various software packages like, Gnuplot, Origin, Mathematica.

Group B: Electronics

1. To develop a LC filter (L type and π type) circuit having different cut-off frequencies and to find out frequency response characteristics.

2. To study the drain characteristics & transfer characteristics (ID sat vs Vgs with VDS as parameter) of a FET/MOSFET and to find out the drain resistance, mutual conductance and amplification factor.

3. To construct and design a regulated power supply using Op-Amp as comparator and power transistor as pass element and to find out its ripple factor and percentage of regulation.

4. To design various counter circuits.

5. To design a 4 bit shift register in SISO and SIPO mode. 6. To design adder/subtractor and BCD adder.

MAJOR ELECTIVE (DSE)

Major Elective – 03:
Classical Electrodynamics

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Theory (3 Credits):

1. **Revisions of electrodynamics:** Maxwell's field equations; Electromagnetic scalar and vector potentials; Wave equations; Wave guides – TE, TM and TEM modes; Rectangular and cylindrical waveguides; Resonant cavities. [4L]

2. **Field of moving charges and radiations:** Green function for relativistic wave equation. Retarded potentials; Lienard-Wichert potentials; Fields produced by arbitrarily and uniformly moving charged particles; Radiations from an accelerated charged particle at low velocity and at high velocity (Larmor's formula); Angular distribution of radiated power; Radiation due to an oscillating electric dipole; Electric quadrupole radiation; Radiation due to small current element; Radiation from linear (thin) and half-wave antennas; Antenna arrays.

[15L]

3. Radiation in material media: Cherenkov radiation; Scattering of electromagnetic wave– Thomson, Rayleigh and resonant scattering; Polarization of scattered light; Coherence and incoherence scattered light; Dispersion and absorption of radiations in media; Elementary theory of dispersion – dispersions in gas, liquid and solid. [10L]

4. **Relativistic electrodynamics:** Lorentz transformation of space and time in 4-vector from; Transformations for charge and current densities; Transformation equations for field vectors; Covariance of Lorentz condition; Invariance of Maxwell's field equations under relativistic transformation; Covariance of Maxwell's field equations in 4-vector form; Electromagnetic field tensor; Maxwell's stress tensor; Maxwell's field equations in covariance 4-tensor form; Transformation equations for magnetic field induction components; Invariance of electromagnetic fields; Covariance of Lorentz force equation; Transformation law of Lorentz force.

[16L]

Practical (1 Credit):

1. Measurement of the velocity of electromagnetic waves in a waveguide
1. 2.. Measurement of Brewster's angle and determination of refractive index
2. Determination of attenuation characteristics of microwave absorbers
3. Study of the Time Response of a Light Dependent Resistor (LDR) under ON/OFF Modulated Incident Light
4. Determination of Planck's Constant by Using a Solar Cell

5. Study of the radiation pattern of a half-wave dipole antenna using a smartphone as an RF field-strength meter.

Books Recommended:

1. Jackson, J.D. (2007). *Classical Electrodynamics*, 3rd ed., John Wiley & Sons, Inc., United States.
2. Griffiths, D.J. (1999). *Introduction to Electrodynamics*, 3rd ed., Prentice Hall, New Jersey, United States.
3. Reitz, J.R., Milford, F.J., & Christy, R.W. (2008). *Foundations of Electromagnetic Theory*, 4th ed., Pearson Education, New Delhi, India.
4. Panofsky, W.K.H., & Phillips, M. (2005). *Classical Electricity and Magnetism*, 2nd ed., Dover Publications, New York, United States.
5. Lorrain, P., Corson, D.R., & Lorrain, F. (1988). *Electromagnetic Fields and Waves*, 3rd ed., W.H. Freeman and Company, New York, United States.
6. Stratton, J.A. (2007). *Electromagnetic Theory*, Wiley-IEEE Press, New Jersey, United States.
7. Landau, L.D., & Lifshitz, E.M. (2013). *The Classical Theory of Fields*, 4th ed., Butterworth-Heinemann, Oxford, United Kingdom.
8. Landau, L.D., & Lifshitz, E.M. (1984). *Electrodynamics of Continuous Media*, 2nd ed., Butterworth-Heinemann, Oxford, United Kingdom.
9. Heald, M.A., & Marion, J.B. (2012). *Classical Electromagnetic Radiation*, 3rd ed., Dover Publications, New York, United States.
10. Zangwill, A. (2013). *Modern Electrodynamics*, Cambridge University Press, Cambridge, United Kingdom.
11. Cheng, D.K. (1989). *Field and Wave Electromagnetics*, 2nd ed., Addison-Wesley Publishing Company, Reading, Massachusetts, United States.
12. Edminister, J.A. (1993). *Schaum's Outline of Electromagnetics*, 2nd ed., McGraw-Hill, New York, United States.
13. Lim, Y.K. (1998). *Problems and Solutions on Electromagnetism*, World Scientific Publishing Co. Pte. Ltd., Singapore.

MINOR (MI)

Minor-07
Modern Physics
[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Theory (MI-C7T) **Credits 3 [45L]**

Course contents:

1. **Atoms in Electric and Magnetic Fields**: Electron Spin and Spin Angular Momentum. Space Quantization. Larmor's Theorem. Electron Magnetic Moment and Magnetic Energy, Spin Magnetic Moment. Gyromagnetic Ratio and Bohr Magneton. Stern-Gerlach Experiment. Normal Zeeman Effect, Anomalous Zeeman Effect (Qualitative idea only).
[10L]

2. **Quantum theory of radiation**: Failure of wave theory to explain Black body radiation, Planck's quantum hypothesis, Planck's radiation formula (statement only). Photo-electric effect. Compton effect. **[5L]**

3. **Basic Quantum Mechanics**: Wave nature of material particles, wave-particle duality, wavelength of de Broglie waves, Davisson Germer experiment, Heisenberg uncertainty principle, Schrödinger equations: Time-dependent and Time-independent, Wave function and its probabilistic interpretation. Observables, Introduction to linear operators (Hermitian and Unitary). Eigen function & Eigen value, Expectation value, Calculation of various commutation relations. Stationary state, Particle in a one-dimensional infinite well: energy eigenvalues and eigen functions. Schrödinger equation for one-dimensional harmonic oscillator and energy eigenvalues (no detailed derivation required). **[14L]**

4. **Crystal structure**: Crystalline nature of solid, Miller indices, lattice planes, Interplanar spacing, Bravais Lattices, simple cubic, FCC and BCC lattices. Diffraction of X-ray, Bragg's law, Reciprocal Lattice. Elementary idea on lattice vibration and phonon. **[6L]**

5. **Free Electron Model:** Free electron gas in metals, effective mass, drift current, mobility and conductivity, Hall effect in metals. **[5L]**
6. **Dielectric properties of materials**: Polarization. Local electric field at an atom. Depolarization field. Electric susceptibility. Polarizability. **[5L]**

Suggested Readings:

- Concepts of Modern Physics, Arthur Beiser, 2009, McGraw-Hill
- Theory and Problems of Modern Physics, Schaum's outline, R. Gautreau and W. Savin,2nd Edn, 2020, Tata McGraw-Hill.

- Elements of Solid State Physics, J. P. Srivastava, 2014, PHI Learning Pvt. Ltd.
- Modern Physics, R.Murugeshan & K.Sivaprasath, 2019, S. Chand Publishing
- Atomic and Nuclear Physics Volume 1, S.N. Ghoshal, 2010, S. Chand Publishing
- Quantum Mechanics, Jyotirmoy Guha,2019, Books and Allied (P) Ltd

Practical (MI-C7P) **[1 Credit]**

Course Outline:

1. Measurement of Planck's constant using three LEDs.
2. Determination of *e*/*m* of electrons by using a bar magnet.
3. To study the photoelectric effect: variation of photocurrent versus intensity and wavelength of light.
4. To show the tunnelling effect in tunnel diode using I -V characteristics.
5. Verification of Stefan's law by using a glowing tungsten filament of a torch bulb.

Suggested Readings:

- B.Sc. Practical Physics, C.L. Arora, 2010, S. Chand
- Practical Physics Vol 1 and Vol 2, B. Ghosh, K. G.Majumder, Sreedhar Publishers
- An Advanced Course in Practical Physics, D. Chattopadhyay, P. C. Rakshit, New Central Book Agency (P) Ltd.
- Laboratory Manual of Physics, Vol 1, M. Jana, 2020, Books and Allied (P) Ltd

SEMESTER-VIII

MAJOR (MJ)

Major – 16
Advanced Statistical Mechanics

[THEORY; CREDITS: 04; FM- 75; 60L]

Course contents:

1. **Scope and aim of statistical mechanics**. Transition from thermodynamics to statistical mechanics. Review of the ideas of phase space, phase points, Ensemble, Density of phase points. Liouville's equation and Liouville's theorem. [4L]

2. **Stationary ensembles**: Microcanonical, canonical and grand canonical ensembles. Partition function formulation. Fluctuation in energy and particle. Equilibrium properties of ideal systems: ideal gas, Harmonic oscillators, rigid rotators. Paramagnetism, concept of negative temperature. [8L]

3. **Density matrix**: Idea of quantum mechanical ensemble. Statistical and quantum mechanical approaches, Properties. Pure and Mixed states. Density matrix for stationary ensembles. Application to a free particle in a box, an electron in a magnetic field. Density matrix for a beam of spin ½ particles. Construction of the density matrix for different states (pure and mixture) and calculation of the polarization vector. [9L]

4. **Distribution functions**: Bose-Einstein and Fermi-Dirac statistics. General equations of state for ideal quantum systems. [4L]

5. **Ideal quantum systems**: [12L]

(i) Properties of ideal Bose gas: Bose-Einstein condensation: Transition in liquid He-4, Superfluidity in He-4. Photon gas: Planck's radiation law. Phonon gas: Debye's theory of specific heat of solids.

(ii) Properties of ideal Fermi gas: Review of the thermal and electrical properties of an ideal electron gas. Landau levels, Landau diamagnetism. White dwarf.

6. **Interacting systems**: [13L]

(i) Ising model. Idea of exchange interaction and Heisenberg Hamiltonian. Ising Hamiltonian as a truncated Heisenberg Hamiltonian.

(ii) Exact solution of one-dimensional Ising system. Bragg-William approximation (Mean field theory).

(iii) Introduction to 2D XY model and Kosterlitz-Thouless Transition

7. **Phase transition**: General remarks. Phase transition and critical phenomena. Critical indices. Landau's order parameter theory of phase transition. [6L]

8. **Fluctuations:** Thermodynamic fluctuations. Spatial correlations in a fluid. Brownian motion: Einstein-Smoluchowski's theory. [4L]

Books Recommended:

1. Pathria, R.K. (2001) Statistical Mechanics, 2nd ed., Butterworth-Heinemann, Oxford, England.
2. Huang, K. (1987) Introduction to Statistical Mechanics, 2nd ed., John Wiley & Sons, Inc., United States.
3. Blundell, S.J. and Blundell, K.M. (2006) Concepts in Thermal Physics, 2nd ed., Oxford University Press, Oxford University Press, England.
4. Reif, F. (2010) Fundamentals of Statistical and Thermal Physics, 56946th ed., Sarat Book Distributors, India.
5. Kadanoff, L.P. (2000) Statistical Mechanics: Statics, Dynamics and Renormalization, 1st ed., World Scientific Publishing Co. Pvt. Ltd., India.
6. Kubo, R. (1988) Statistical Mechanics: An Advanced Course with Problems and Solutions, 17th ed., Elsevier, Netherlands.
7. Ma, S.K. (1985) Statistical Mechanics, World Scientific Publishing Co. Pvt. Ltd., UK.
8. Ishihara, A. (1971) Statistical Physics, 1st ed., Elsevier, Netherlands.

MAJOR ELECTIVE (DSE)

Major Elective – 04
Molecular Spectroscopy and Applied Optics

[THEORY; CREDITS: 04; FM- 75; 60L]

Course contents:

1. **Basic Idea of Electromagnetic spectrum:** Conversation of different spectroscopic units, Basic idea about the generation of electromagnetic spectrum from radio frequency to γ-ray. [1L]

2. **Microwave spectroscopy:** Rotations of molecules, Diatomic molecular rotational spectroscopy of rigid and non-rigid diatomic molecules, Intensity of spectral lines, microwave spectroscopy of symmetric type of molecules, Stark effect. [7L]

3. **Infra-red spectroscopy:** Diatomic molecular vibrational spectroscopy with harmonic and anharmonic vibration, vibrational and rotational spectroscopy, anharmonic oscillation constant, rotational constant, Dissociation energy. [4L]

4. **Visible and ultraviolet spectroscopy:** Molecular electronic spectroscopy, Frank Condon principle, Molecular electronic vibrational-rotational spectroscopy, Born-Oppenheimer approximation, Fortrat diagram, Band head. [4L]

5. **Laser:** Spontaneous and stimulated emission, Laser resonator, population inversion, active and passive laser resonator, Threshold condition, saturation condition, Quality factor, Burger's law, classification of laser Three level laser and four level laser system, equation of population inversion and threshold power calculation for the laser systems. Q switching, Application of laser. [10L]

6. **Fiber optics:** Different types (single and multi-mode) of step index and graded index optical fiber, Ray path in graded index optical fiber, Multipath broadening, Modal analysis of Electromagnetic waves in planer waveguide. Application of fiber in digital communication. [10L]

7. **Holography:** Coherent light and application of coherent light in holography. Recording and reconstruction of wave front. [3L]

8. **Non-linear Optics:** Non-linearity of medium, second and higher harmonic generation, phase matching condition, sum-frequency generation and difference-frequency generation, self-focusing, Kerr type nonlinear materials, Examples of Organic and inorganic nonlinear materials. Photo dynamical therapy. [10L]

9. **Photonics Information Processing:** Optical logic operations, Optical arithmetic operation with binary, optoelectronic logic gates, all optical logic gates, tristate logic system and tristate AND & OR gate. [8L]

10. **Photosensors, different types of Photodetectors:** Photosensors, different types of Photodetectors, Graphene and graphene-based photodetectors, photo sensitivity, photoresponsivity. [3L]

Books Recommended:

1. Banwell, C. N., and McCah, E. M. (2017) Fundamentals of Molecular Spectroscopy, 4^{th} ed., Tata McGraw - Hill Publishing Company Limited, India.
2. Aruldas, G. (2007) Molecular Structure and Spectroscopy, 2nd ed., PHI Learning Private Limited, India.
3. Hertzberg, G. (1951) Molecular Structure and Molecular Spectra: vol. 1, Spectra of Diatomic Molecules, 2nd ed., Van Nostrand.
4. Herzberg, G. (1945) Molecular Structure and Molecular Spectra: vol. 2, Infrared and Raman Spectra of polyatomic Molecules, 16th printing ed., Van Nostrand.
5. Barrow, G. M. (1962) Molecular Spectroscopy, 1st ed. McGraw-Hill Inc., US.
6. Ghatak, A., and Thyagarajan, K. (2007) Optical Electronics, Special ed. for sale in South Asia, Cambridge University Press India Pvt. Ltd, India.
7. Bhattacharya, P. (1996) Semiconductor optoelectronic devices, 2nd ed., Prentice Hall publication, India.
8. Yariv, A. (1984) Optical Electronics, 3rd ed., Holt McDougal. 9. Tarasov, L. V. Laser Physics and Applications, Mir Publishers, USSR
9. Pipker, J. (2003) Semiconductor Optoelectronic Devices: Introduction to Physics and Simulation, 1st ed., Academic Press, USA
10. Bhattacharya, P. (2017) Semiconductor Optoelectronic Devices, end ed., Pearson, India.
11. Rosencher, E., and Vinter, B (2002) Optoelectronics, 1st ed., Cambridge, University Press.
12. Mukhopadhyay, S. (2000) Optical computation and parallel processing, 1st ed., Classique Books Publisher, India.

MAJOR ELECTIVE- 05

[to be studied by Honours students only]

Major Elective – 05
Option-I: Advanced Electronics II

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Theory (3 Credits):

1. **Operational Amplifiers:** Revision of Op-amp circuits, Differential amplifier, OP-AMP architecture, Constant current sources, Input stage of an Op-Amp, OP-AMP characteristics and parameters. [3L]

2. **Elements of Communication:** Principle of amplitude modulation (AM) and frequency modulation (FM), AM spectrum and FM spectrum, channel band width and signal band width, side band frequency, Generation of transmitted carrier and suppressed carrier type AM signals with necessary circuits, Principles of detection of different types of modulated signals (TC and SC types), Principle of generation of FM wave with necessary circuits, Detection of FM wave-Discriminators. Modulation techniques in some practical communication systems: Superheterodyne AM and FM radio receivers, FM stereo receiver principle, VSB AM technique. [12L]

3. **Radio wave propagation:** Ground wave, Ionospheric wave and space wave and their characteristics, reflection and refraction of radio waves in ionosphere, critical frequency, skip distance, Maximum usable frequency, fading, Secant law, duet propagation. [5L]

4. **Antenna:** Dipole antenna, half wave antenna, antenna with two half elements, N- elements array, induction field and radiation field, radiation resistance of an antenna. [5L]

5. **Radar:** Radar range equation, Basic pulsed radar system-Modulators, duplexers, indicators, radar antenna, CW radar, MTI radar, FM radar, Doppler radar. [5L]

6. **JFET and MESFET:** Introduction to Field Effect Transistors (FETs) and their advantages over BJTs. Junction Field Effect Transistor (JFET): construction, working principle, characteristics, and applications. Metal-Semiconductor Field Effect Transistor (MESFET): structure, operation, characteristics, and comparison with JFET. Basic device parameters: pinch-off voltage, transconductance, and drain characteristics. [5L]

7. **Sequential Circuit**: Revision of Flip-Flops, Conversion of Flip-Flops. [2L]

8. **Registers:** Shift Register, Serial in Serial out, Parallel in Serial out, Parallel in parallel out registers, Bi-directional and Universal registers. [4L]

9. **Counter:** Synchronous and Asynchronous counter, modulo-Counter, decade counter, ring counter and twisted ring counter, Up/Down Counter. [4L]

Practical (1 Credit):

1. To develop a LC filter (L type and π type) circuit having different cut-off frequencies and to find out frequency response characteristics.
2. To study the drain characteristics & transfer characteristics [$(I_D)_{sat}$ vs V_{GS} with V_{DS} as parameter] of a FET/MOSFET and to find out the drain resistance, mutual conductance and amplification factor.
3. To construct and design a regulated power supply using Op-Amp as comparator and power transistor as pass element and to find out its ripple factor and percentage of regulation.
4. To design various counter circuits.
5. To obtain the frequency response characteristic of an inverting and non-inverting operational amplifiers and to find out its band width.
6. To design adder/subtractor and BCD adder.

Books Recommended:

1. Ryder, J.D. (1975) Electronics fundamental and application, 5th ed., PHI, India.
2. Gayakwad, R.A. (2015) Op- Amps and Linear Integrated Circuits, 4th ed., Pearson Education, India.
3. Roddy, D. and Coolen, J. (2008) Electronic Communications, 4th ed., Pearson Education, India
4. Chattopadhyay, D. and Rakshit, P.C. (2020) Electronics Fundamentals and Applications, 16th ed., New Age International Publishers, India
5. Millman, J. and Grable, A. (2017) Microelectronics, 2nd ed., McGraw Hill Education, India.
6. Terman, F. E. (1955) Electronic and Radio Engineering, 4th ed., McGraw-Hill Book Company Inc., Europe.
7. Jain, R. P. (2010) Modern digital electronics, 4th ed., Tata McGraw Hill, India.
8. Anand Kumar, A. (2016) Fundamentals of Digital Circuits, 4th ed, PHI, India.
9. Millman J., Halkias C. C. and Parikh C. D. (2017) Integrated electronics, McGraw Hill, India.
10. Sivakumar M. S. (2014) 1st ed., Fundamental of Digital Design, S. Chand & Company, India.
11. Kothari D. P. and Dhillon (2015) J. S. Digital Circuits and Design 1st ed., Pearson Education India, India.
12. Mano M. (2016) Digital Logic and Computer Design, 1st ed., Pearson Education India, India.
13. Tocci, R. J. and Widmer, N. S. (2005) Digital Systems: Principles and Applications, 8th ed., Pearson New Int. Edition.

Major Elective – 05
Option-II: Advanced Instrumentation

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Theory (3 Credits):

Error analysis: Error determination in physical quantities, Propagation of error, Weighted average**,** Statistical analysis of data: arithmetic mean, average deviation, standard deviation, curve fitting and chi square test. [5L]

Vacuum system: Characteristics of vacuum: Gas law, Mean free path. Application of ultra-high vacuum system. Vacuum production: Rotary pumps, Diffusion pump & Turbo Modular pump, Pumping speed: Gaede's equation, Measurement of vacuum: Pirani, Penning, ionization gauges. [8L]

Cathode Ray Oscilloscope (CRO): Block diagram of basic CRO. Construction of CRT, electron gun, Time base operation, electrostatic focusing and deflection, Introduction of Digital Storage Oscilloscope (DSO) and its advantages over analogue storage. [4L]

Sensors and Transducers: Classification of transducers, Displacement transducers- resistive (strain gauge- mechanical, semiconductor strain gauge), Capacitive and Inductive transducers (LVDT, Hall effect sensors), Temperature transducers (RTD, Thermocouples), Pressure, and optical sensors (photodiodes, LDR). [8L]

Signal Generators: AF Sine and Square wave signal generators, function generators, and their specifications. Linear and Logic pulses, Function of pulse-processing units, Components common to many applications, pulse counting systems. [6L]

Spectroscopic Techniques: Application of Spectroscopic Techniques: UV/VIS and IR Absorption, Raman, Fluorescence and NMR for different physical systems. [6L]

Principle of imaging and Diffraction techniques: Basic principles of Magnetic Resonance Imaging (MRI), Computed tomography (CT) scan and Positron emission tomography (PET). Neutron diffraction and Electron diffraction, Working principle of SEM & TEM, Working principle of STM & AFM. [8L]

Practical (1 Credit):

(Attempt min. 5-6 experiments)

1. Statistical Analysis of Experimental Data Using a Simple Pendulum: Arithmetic Mean, Average Deviation, Standard Deviation, Gaussian Distribution, and Propagation of Error
2. Verification of Lissajous patterns using CRO

3. Calibration of Semiconductor type temperature sensor (AD590, LM35, or LM75) for temperature measurement
4. Calibration of RTD and Thermocouple for temperature measurement
5. Measurement of the change in temperature of ambient using Resistance Temperature Device (RTD)
6. Displacement measurement using LVDT and comparison with micrometer readings
7. Study of Photodiode characteristics under different illumination levels
8. Hall Effect Sensor: Measurement of magnetic field and calibration
9. SEM image analysis for particle size estimation (with supplied image)

References:

1. An Introduction to Error Analysis, J.R. Taylor (Oxford University Press)
2. Data Reduction and Error Analysis for the Physical Sciences, Philip R. Bevington, D. Keith Robinson (McGraw-Hill Science and Engineering)
3. Vacuum Technology, A. Roth (North Holland).
4. Vacuum Physics and Techniques, T. A. Delchar, Chapman and Hall
5. Electronic circuits: Handbook of design and applications, U. Tietze and C. Schenk, 2008, Springer.
6. Digital Electronics: Principles, Devices and Applications: Anil K Mani (Wiley International)
7. Fundamentals of Molecular Spectroscopy, C.N. Banwell and E.M. McCash (McGraw- Hill International Limited)
8. The Basics of Crystallography and Diffraction: Fourth Edition, Christopher Hammond (Oxford University Press)
9. Handbook of Physics in Diagnostic Imaging: R. S. Livingstone: B.I. Publication Pvt Ltd.

Major Elective – 05
Option-III: Computational Physics

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Prerequisites

Introductory Physics (Mechanics, Electromagnetism, Thermal Physics), Calculus, Linear Algebra, and Basic Programming Fundamentals (typically Python, MATLAB, or C++).

Course Objectives

After completing this course, students should be able to:

- Understand numerical methods used in physics.
- Write computer programs for solving physical problems.
- Analyze numerical errors, stability and understand the limitations of numerical accuracy.
- Visualize scientific data.
- Simulate physical systems.
- Apply computational techniques to modern physics problems.

Theory (3 Credit):

<u>Unit I</u>: Introduction to Computational Physics and Numerical Errors *(6L)*

Topics

- Role of computation in modern physics, Computational thinking, Algorithms and Flowcharts
- Programming basics: Variables and Data types, Conditional statements, Loops, Functions, Arrays, Scientific computing environment
- Errors: Round-off error, Truncation error, Absolute error, Relative error, Floating-point representation

Physics Applications

- ◦ Simulating the subtraction of nearly equal values in relativistic kinetic energy calculations ($\gamma mc^2 - mc^2$) at low velocities.
- ◦ Projectile Motion (no drag): Computing and plotting the trajectory of a projectile using loops and arrays; comparing numerical results with the analytical solution to observe the effect of time-step size on truncation error.

<u>Unit II</u>: Root Finding and Nonlinear Equations (6L)

Computational Methods

Bisection Method, Newton-Raphson Method, Secant Method, Fixed-Point Iteration

Physics Applications

- Celestial Mechanics: Solving Kepler's Equation to find the position of a planet in an elliptical orbit as a function of time.
- Thermodynamics: Determining the real volume or temperature of a gas using the Van der Waals equation of state.
- Quantum Mechanics: Finding the bound-state energy levels of a finite square potential well by locating the roots of the transcendental matching equations.

Unit III: Numerical Differentiation and Integration (8L)

Differentiation: Forward Difference, Backward Difference, Central Difference

Integration: Trapezoidal Rule, Simpson's Rule

Physics Applications

- Electricity & Magnetism: Computing the electric field $E = -dV/dx$ from a known electrostatic potential $V(x)$ using central differences; visualizing the field lines from the numerically obtained gradient.
- Classical Mechanics: Calculating the period of a large-amplitude anharmonic pendulum (which cannot be solved using the small-angle approximation $\sin\theta \approx \theta$).
- Electricity & Magnetism: Computing the total electric field or magnetic field along the axis of non-uniformly charged rings, disks, or wires.

Unit IV: Linear Algebra and Differential Equations (10L)

Linear Algebra

- Basic matrix operations: addition, multiplication, transpose, inverse
- Eigenvalues and eigenvectors: Jacobi method, Power method
- LU decomposition
- Gauss elimination

Physics Applications – Linear Algebra

- Oscillations: Solving for the normal modes and natural frequencies of a coupled multi-mass spring system (e.g., a linear triatomic molecule like CO_2) by finding eigenvalues of the dynamical matrix.
- Circuit Analysis: Solving simultaneous linear equations generated by Kirchhoff's Rules in complex mesh networks using Gauss elimination.
- Quantum Mechanics: Diagonalizing a Hamiltonian matrix to find the energy eigenvalues and eigenstates of a particle in a one-dimensional perturbed potential well.

Ordinary Differential Equations: Euler Method, Fourth Order Runge-Kutta Method

Physics Applications – ODEs

- Kinematics & Dynamics: Simulating projectile motion with realistic, velocity-dependent air resistance (quadratic drag).

- Astrophysics (Two-Body Problem): Simulating planetary orbits and verifying Kepler's Laws of Planetary Motion.
- Chaos Theory: Modeling the trajectories of the Lorenz Attractor or a double pendulum to study deterministic chaos.

Unit V: Partial Differential Equations (PDEs) (9L)

Computational Methods: Finite Difference Method (FDM), Boundary Value Problems, Relaxation methods (Jacobi/Gauss-Seidel iterations), Crank-Nicolson method

Physics Applications

- Electrostatics: Solving Laplace's equation ($\nabla^2 V = 0$) and Poisson's equation ($\nabla^2 V = -\rho/\varepsilon_0$) to find the electric potential distribution between complex, asymmetric conducting plates.
- Thermodynamics: Simulating time-dependent heat distribution along an insulated metal rod using the 1D Diffusion/Heat Equation.

Unit VI: Random Numbers and Stochastic Simulations (9L)

Computational Methods: Random numbers, Pseudo-random number generation, Monte Carlo method: principle and applications, Brownian motion and Random walk

Physics Applications

- Mathematical Physics: Estimating the value of π using the Monte Carlo dart-throwing method; observing convergence of the estimate as the number of random samples increases.
- Statistical Mechanics: Simulating Brownian motion using a random walk model; computing and analysing mean square displacement to verify the Einstein diffusion relation.

Delivery Mode

- Tutorial (03 hrs/week): Concept discussion, algorithm development, coding demonstrations, numerical problem solving, interpretation of results.
- Practical (01 hr/week): Hands-on implementation in Python/Jupyter Notebook.

Practical (1 Credit):

Each practical is mapped to its corresponding unit.

1. **[Unit I]** Simulate a Simple Harmonic Oscillator using the Euler method; compare the numerical solution with the exact analytical result (sin/cos) and plot the growth of energy error over many oscillation cycles.
1. **[Unit II]** Determine the bound-state energy levels of a finite square potential well by applying a root-finding algorithm to the transcendental matching equations.

2. **[Unit III]** Compute the electric field E = −dV/dx from a given electrostatic potential V(x) using the central difference method; visualize and compare with the analytical result.
3. **[Unit III]** Evaluate the total energy density of blackbody radiation by numerically integrating the Planck function using Simpson's Rule; verify the Stefan–Boltzmann law.
4. **[Unit IV]** Model a multi-loop DC circuit using Kirchhoff's Rules; set up the resulting system of linear equations and solve using Gauss elimination.
5. **[Unit IV]** Simulate a planetary orbit using the fourth-order Runge–Kutta method; verify Kepler's second law by computing the area swept in equal time intervals.
6. **[Unit V]** Solve the one-dimensional heat equation using the finite-difference method (Crank–Nicolson scheme); animate the time evolution of the temperature distribution.
7. **[Unit V]** Solve Laplace's equation for the electric potential in a 2D region with specified boundary conditions using the Jacobi relaxation method; plot the resulting potential and field lines.
8. **[Unit VI]** Simulate Brownian motion as a random walk in 2D; compute the mean square displacement as a function of time and verify the Einstein diffusion relation.

Suggested Readings

1. Giordano, N. J., & Nakanishi, H. Computational Physics, 2nd Edition. Pearson Education, 2006.
2. Newman, M. Computational Physics. CreateSpace Independent Publishing Platform, 2013.
3. Kar Gupta, A. Scientific Computing in Python. Techno World.
4. Jalan, A. K., & Sarkar, U. Numerical Methods. University Press, 2015.
5. Gould, H., Tobochnik, J., & Christian, W. An Introduction to Computer Simulation Methods: Applications to Physical Systems, 3rd Edition. Pearson/Addison-Wesley, 2006.
6. Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. Numerical Recipes: The Art of Scientific Computing, 3rd Edition. Cambridge University Press, 2007.
7. Sastry, S. S. Introductory Methods of Numerical Analysis, 5th Edition. PHI Learning, 2012.
8. Jain, M. K., Iyengar, S. R. K., & Jain, R. K. Numerical Methods for Scientific and Engineering Computation, 7th Edition. New Age International, 2012.
9. Bevington, P. R., & Robinson, D. K. Data Reduction and Error Analysis for the Physical Sciences, 3rd Edition. McGraw-Hill, 2003.
10. Landau, R. H., Páez, M. J., & Bordeianu, C. C. Computational Physics: Problem Solving with Python, 3rd Edition. Wiley-VCH, 2015.

Major Elective – 05
Option-IV: Radiation Physics

[THEORY; CREDITS: 04; FM- 75; 60L]

Course contents:

1.**Basic Radiation Physics:** Introduction, Classification of radiation – ionizing and non-ionizing, Nuclear structure, Nuclear reactions, Radioactivity, Modes of radioactive decay- alpha decay, beta decay, gamma decay, Activation of nuclides, Accelerators, Cyclotron, LINAC, reactors. Photon interactions, types of indirectly ionizing radiation, Photon beam attenuation, Half Value Thickness and Tenth Value Thickness. Types of photon interaction - Photoelectric effect, Coherent scattering, Compton effect (incoherent scattering), Pair production, Photonuclear reactions, attenuation coefficients, application in imaging. Effects following photon interactions- physical, chemical and biological. Electron interactions - Electron-orbital electron interactions, Electron-nucleus interactions, Stopping power, Mass scattering power. [14L]

2. **Production and properties of X-rays:** Physics of X ray production- Characteristic X-rays and Bremsstrahlung (continuous) X-rays, X-ray spectrum. X-ray technology – X-ray tubes, diagnostic and therapy tubes, Coolidge tube, stationary and rotating anode, line focus principles –dual focus tube – Hooded anode tube – Basic X-ray generators circuits – autotransformer – filament transformer-rectification of anode voltage – self-rectifier circuit, half wave rectifier circuit, full wave rectifier circuit. [10L]

3. Dosimetric principles & Quantities: Photon fluence and energy fluence, Kerma (kinetic energy released per unit mass), CEMA (converted energy per unit mass) absorbed dose, quantities used in describing a photon beam, photon fluence and rate, energy fluence and rate, inverse square law, penetration of photon beam into a phantom or patient, surface dose, build-up region, depth of dose maximum, exit dose, Percentage Depth Dose (PDD).Tissue Air Ratio (TAR), Tissue Maximum Ratio (TMR), Physics of radiation therapy (qualitative concept).

[10L]

4. **Radiation detection and measurement:** Gas filled detectors - regions of operation, ion chamber, proportional chambers and GM counters, film detectors, radiographic film, radiochromic film, luminescence dosimetry – scintillators, thermoluminescence, optically stimulated luminescence, semiconductor dosimetry, silicon diode dosimetry systems and MOSFET dosimetry systems. [10L]

5.**Radiobiology:** Introduction, classification of radiations in radiobiology, cell cycle and cell death, irradiation of cells, type of radiation damage, cell survival curves, measurement of radiation damage in a tissue, normal and tumour cells, therapeutic ratio, oxygen effect in radiotherapy, relative biological effectiveness, dose rate and fractionation in radiotherapy, radio protectors and radio sensitizers**.** [10L]

6.**Radiation Protection:** Principles of radiation protection – time, distance, shielding, quantities and units used in radiation protection, physical quantities, radiation protection quantities, organ dose, equivalent dose, effective dose, committed equivalent dose, collective dose, justification of medical exposure, optimization of exposure and protection, dose limits, ALARA, ICRP and AERB regulations. [6L]

Books Recommended

1. Thayalan, K. (2003). *Basic Radiological Physics*, Jaypee Brothers Medical Publishers, New Delhi, India.
2. Khan, F.M. (2003). *The Physics of Radiation Therapy*, 3rd ed., Lippincott Williams & Wilkins, Philadelphia, United States.
3. Hall, E.J. (1994). *Radiobiology for the Radiologist*, 4th ed., J.B. Lippincott Company, Philadelphia, United States.
4. Knoll, G.F. (2010). *Radiation Detection and Measurement*, 4th ed., John Wiley & Sons, Inc., Hoboken, New Jersey, United States.
5. Curry, T.S., Dowdey, J.E., & Murry, R.C. (1990). *Christensen's Physics of Diagnostic Radiology*, 4th ed., Lea & Febiger, Philadelphia, United States.
6. Podgorsak, E.B. (2010). *Radiation Physics for Medical Physicists*, Springer, Berlin, Germany.
7. S. K. Bhargava and S. Bhargava (2016). Textbook of Radiology for Residents & Technicians, 5^{th} ed., CBS Publishers & Distributors, New Delhi, India

MAJOR ELECTIVE- 06
[to be studied by Honours students only]

Major Elective – 06
Option-I: Physics of Nanomaterials

[THEORY; CREDITS: 04; FM- 75; 60L]

Course Content:

1. **Introduction to Nanoscience and Nanotechnology:** Introduction, Various length scales in physics, Classification of nanostructures (0-D, 1-D, 2-D, hierarchical (3-D) nanostructures). Properties, examples and applications of different nanostructures: nanorods, nanotubes, nanobelts, nanosheets, quantum dots, core-shell nanostructures. [8L]

2. **Electronic band structure of nanomaterials:** Origin of band structure, band structure of silicon and germanium, Density of states in different nanostructures-0-D, 1-D, 2-D, hierarchical (3-D), Van-Hove singularity. Band structure of graphene. [6L]

3. Phenomena at nanoscale: ***Surface effect***-fraction of atoms at the surface. Importance of surface effect with example. ***Quantum confinement:*** Quantum confinement in 1-D, 2-D nanostructures and quantum dots- Importance of quantum confinement-size dependent colour of metals, size dependent band gap of semiconductors-Brus equation-size effect on mechanical, thermal, electrical and magnetic properties. [6L]

4. Nanomaterials synthesis: Top-down and bottom-up; Lithography, Ball milling; Solution phase synthesis processes-sol-gel, spray pyrolysis, colloidal method, hydrothermal, spin coating etc. Vapour phase synthesis- Thermal evaporation, E-beam evaporation, Physical and chemical vapour deposition, sputtering, pulsed laser deposition, molecular beam epitaxy. [8L]

5. Characterization techniques: X-ray diffraction-powder Diffraction-Bragg's law, Intensity of diffraction, Diffraction under non-ideal condition-Scherrer formula, Williamson-Hall plot. *Electron microscopes*- de' Broglie wavelength; Scanning electron microscope and Transmission electron microscope (components, scanning process and image formation, magnification and resolution); *Scanning probe microscopes*- Atomic force microscope and scanning tunnelling microscope (components, principle, modes of operation). *Optical characterization:* UV-visible spectroscopy and photoluminescence spectroscopy (components, principle of working, applications). [8L]

6. Optical properties of nanomaterials: Metallic nanostructures and surface plasmon resonance (transverse and longitudinal), applications of plasmonic metal nanoparticles. Excitons (Wannier-Mott, Frankel, Biexcitons); direct and indirect band gap semiconductors, direct and indirect absorption. Excitonic recombination, Optical properties of semiconductor heterostructure. [10L]

7. Carrier transport in nanoscale: Length scale in transport- mean free path, phase relaxation length, de-Broglie wavelength, magnetic length, thermal length. Classification of transport mechanism- Classical diffusive transport, Coherent transport, Ballistic transport, Quantum size effect. Conduction quantization in 1-D nanostructures: Landauer formalism. Tunnelling Conduction-Coulomb blockade effect, Conditions to observe Coulomb blockade, Single-Electron Transistor (SET), Coulomb blockade diamond. Thermionic emission- Richardson's equation. Field emission. Basic concept of Fluctuation induced tunnelling conduction in nanostructures, hopping conduction of electron transport- Variable range hopping conduction: Mott's law and its validity, Arrhenius type thermally activated conduction, Polaron conduction.

[14L]

Reference books:

1. An introduction to nano science and technology, C. N. R. Rao, JNCASR, 2022.
2. M. A. Shah, Principles of Nanoscience and Nanotechnology, Alpha Science Publishers, 2020.
3. K. K. Chattopadhyay and A. N. Banerjee, *Introduction to Nanoscience and Nanotechnology*. New Delhi, India: PHI Learning Private Limited, 2009
4. C. Binns, Introduction to Nanoscience and Nanotechnology, John Wiley & Sons Inc, 2010.
5. T. Pradeep, Nano: The Essentials: Understanding Nanoscience and Nanotechnology, , Mc Graw-Hill Education, 2017.
6. Science and Technology of Nanomaterials, P. K. Samanta, Books & Allied Pvt. Ltd., 2025
7. C. P. Poole, F. J. Owens, Introduction to Nanoscience and Nanotechnology, an Indian Adaptation, Willey, 2020.
8. S. Datta, Quantum Transport: Atom to Transistor, Cambridge University Press, 2005.
9. Y. Leng, Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Johnwiley & Sons (Asia) Pte. Ltd., 2008
10. B.D. Cullity S.R. Stock, Elements of X-Ray Diffraction, 3e, Pearson, 2014.

Major Elective – 06
Option-II: Basics of Astrophysics and Cosmology

[THEORY; CREDITS: 04; FM- 75; 60L]

Part A: Astrophysics (30 L) + Part B: Cosmology (30 L)

PART A: ASTROPHYSICS

UNIT I – Radiation, Telescopes & the Solar System (15 Lectures)

Nature of Astronomical Radiation: Electromagnetic spectrum; flux, luminosity, and magnitude scales; colour index and H–R diagram. **(4 Lectures)**

Stellar Spectra and Classification: Blackbody radiation; Wien's law and Stefan–Boltzmann law; spectral classification; MK luminosity classes. **(5 Lectures)**

The Solar System: Solar nebula hypothesis; Kepler's laws; the Sun — interior, photosphere, corona, and solar wind; planetary types; asteroids and comets. **(6 Lectures)**

UNIT II – Stellar Physics & Compact Objects (15 Lectures)

Stellar Structure: Hydrostatic equilibrium; energy transport (radiative and convective); nuclear burning — pp-chain and CNO cycle. **(5 Lectures)**

Stellar Evolution: Pre-main-sequence evolution; main sequence and core hydrogen exhaustion; red giant branch; helium burning; AGB and planetary nebula formation. **(5 Lectures)**

Death of Stars and Compact Remnants: White dwarfs and the Chandrasekhar limit; core-collapse supernovae; neutron stars and pulsars; stellar-mass black holes. **(5 Lectures)**

PART B: COSMOLOGY

UNIT III – Foundations of General Relativity & Cosmological Framework (12 Lectures)

Introduction to General Relativity: Equivalence principle; failures of Newtonian gravity; curved spacetime; metric tensor; geodesic equation. **(5 Lectures)**

Einstein's Theory of Gravity: Christoffel symbols; Riemann and Ricci tensors; Einstein field equations; Schwarzschild solution; experimental tests — light deflection, perihelion precession, gravitational redshift. **(4 Lectures)**

The Expanding Universe and Cosmological Distances: Hubble's law; cosmological redshift; comoving, luminosity, and angular diameter distances; particle and event horizons. **(3 Lectures)**

UNIT IV – FLRW Metric & Big Bang Cosmology (18 Lectures)

FLRW Metric and Friedmann Equations: Homogeneity and isotropy; FLRW line element; scale factor; Christoffel symbols and Ricci tensor for FLRW spacetime; Friedmann equations; equation of state; flat, open, and closed universes; density parameter Ω. **(5 Lectures)**

Big Bang Cosmology: Hot Big Bang model; thermal history; Big Bang Nucleosynthesis — primordial abundances of H, He, D, and Li; Cosmic Microwave Background — recombination and decoupling; horizon and flatness problems; brief idea of inflation; Dark Matter and Dark Energy. **(7 Lectures)**

Black Holes: Schwarzschild geometry and event horizon; Hawking radiation and black hole thermodynamics; brief introduction to Kerr blackhole. **(6 Lectures)**

References

[1] B. W. Carroll and D. A. Ostlie, An Introduction to Modern Astrophysics, 2nd ed., Pearson, 2006.

[2] M. Zeilik and S. A. Gregory, Introductory Astronomy and Astrophysics, 4th ed., Saunders, 1998.

[3] R. Kippenhahn, A. Weigert, and A. Weiss, Stellar Structure and Evolution, 2nd ed., Springer, 2012.

[4] L. S. Sparke and J. S. Gallagher, Galaxies in the Universe, 2nd ed., Cambridge University Press, 2007.

[5] S. M. Carroll, Spacetime and Geometry: An Introduction to General Relativity, Addison-Wesley, 2004.

[6] J. A. Peacock, Cosmological Physics, Cambridge University Press, 1999.

[7] S. Dodelson and F. Schmidt, Modern Cosmology, 2nd ed., Academic Press, 2020.

[8] E. W. Kolb and M. S. Turner, The Early Universe, Addison-Wesley, 1990.

[9] T. Padmanabhan, Theoretical Astrophysics, Vol. I–III, Cambridge University Press, 2000–2002.

[10] V. Mukhanov, Physical Foundations of Cosmology, Cambridge University Press, 2005.

Major Elective – 06
Option-III: Biological Physics

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Course Content:

Overview: The boundary, interior and exterior environment of living cells. Concepts of physics for idealizing different biological stuffs and processes (qualitative ideas with some examples). The unifying ideas of biology. Time scales and spatial scales. [4L]

Molecules of life: Metabolites, proteins and nucleic acids. Their sizes, types and roles in structures and processes. Estimation of size of E. Coli cell and estimating the number of proteins, ribosomes, lipids, water molecules and ions per E. Coli cell. [4L]

Central Dogma: Concept of polymer languages of nucleic acids and proteins. The process of central dogma. Statistical mechanics of gene expression. Using Boltzmann distribution and partition function to estimate the probability of ligand receptor binding and the probability of RNA polymerase binding to the promoter. Simplified mathematical models of transcription and translation in terms of ODE employing Hill function. [13L]

Random walks and applications to biology: Macromolecules as random walks. Estimation of the probability distribution function of the end-to-end distance of polymer chains. Persistence length and Kuhn length. Size of viral and bacterial genome. [4]

Dynamical models for complex molecular processes: Biological networks, network motifs. Common network motifs such as positive feedback, negative feedback, incoherent feedforward, bi fan, etc. Modelling enzymatic reaction using law of mass action, Michaelis–Menten kinetics, enzymatic switch. Modelling signal transduction circuits such as positive and negative feedback. Simple statistical model of positive and negative regulation such as for *lac* Operon. Modelling bifurcation in terms of ODE. Multicellular organisms. Stem cells and cellular differentiation. [20L]

Practical [Total credit 1]

1. Solving some common problems such as i) spread of infectious disease ii) population growth using ODEs and solving them through numerical method such as Euler's method, RK method etc.
2. Solving the problem of bifurcation in fish tank through numerical solution of ODE.
3. Simulating Ligand binding problem through numerical solution of ODE.
4. Simulating a simple enzymatic reaction through numerical solution of ODE.
5. Simulating a positive feedback circuit through numerical solution of ODE.
6. Simulating a positive feedback circuit through numerical solution of ODE.

7. Plot of average occupancy as a function of ligand concentration in Ligand-Receptor binding and Plot of probability of promoter occupancy as a function of RNA polymerase.
8. Plot of end-to-end probability distribution for a 1D macromolecule with 100 segments for binomial and Gaussian distribution.

N.B: *The numerical solution may be performed through python programming or using software such as Jsim, Matlab etc.*

Suggested Readings:

1. Physics in Molecular Biology; Kim Sneppen & Giovanni Zocchi (CUP 2005)
2. Biological Physics: Energy, Information, Life; Philip Nelson (W H Freeman & Co, NY, 2004)
3. Physical Biology of the Cell (2nd Edition), Rob Phillips et al (Garland Science, Taylor & Francis Group, London & NY, 2013)
4. An Introduction to Systems Biology; Uri Alon (Chapman and Hall/CRC, Special Indian Edition, 2013)
5. https://nptel.ac.in/courses/102103056

Major Elective – 06
Option-IV: Quantum Science & Technology

[Credits: 3T FM – 40 (45L) + 1P FM-20 (30L)]

Course Content:

Atom-field interaction: Induced resonant transitions, The two-level atom approximation, Inclusions of decay phenomena, The time-dependent Schrodinger equation, Rotating wave approximation, The weak field case, The strong-field limit - Exact Rabi solution, Rabi flopping, Experimental observation of Rabi oscillations, Mollow triplet. [6L]

Density matrix: Pure case and mixed case, Rate equation for density matrix, Decay phenomena inclusion, Optical Bloch equations, Vector model of density matrix, The Bloch sphere, π-pulse. [6L]

Atomic coherence and interference: The Hanle effect, Coherent population trapping (CPT), Dark states, Electromagnetically induced transparency (EIT), Susceptibility under EIT condition on a lambda-type atomic system. Difference between CPT and EIT. [6L]

Coherent states and squeezed states of light: Phasor diagram and field quadratures, Coherent states and its significance, Coherent state in photon number representation, Distribution of coherent state: Poissonian distribution, Squeezed states. [6L]

Quantum theory of interaction of radiation field with matter: Quantization of electromagnetic field, Atom field interaction Hamiltonian, Dressed state, Wigner-Weisskopf theory of spontaneous emission. [6L]

Introduction to Quantum computation: Introduction to Quantum Computing: Classical vs. Quantum Computing, Qubits, Superposition, Entanglement, The Bloch sphere, Quantum Gates, Quantum Measurement, Basic Quantum Algorithms, Fundamentals of Machine Learning: Supervised & Unsupervised Learning, Neural Networks, Optimization. [15L]

Introduction to Quantum Cryptography: No-cloning theorem, Quantum correlations: Bell inequalities and entanglement, Schmidt decomposition, superdense coding, teleportation, quantum key distribution, BB84 protocol, Universal set of gates, quantum circuits, Solovay-Kitaev theorem, Deutsch-Jozsa algorithm, Simon's algorithm, Quantum Fourier transform, Shor' algorithm, Grover' algorithm. [15L]

Recommended Books:

[1] M. Fox, Quantum Optics: An Introduction. Oxford, U.K.: Oxford University Press, 2006.
[2] C. Gerry and P. Knight, Introductory Quantum Optics. Cambridge, U.K.: Cambridge University Press, 2005.

[3] P. Meystre and M. Sargent III, Elements of Quantum Optics, 4th ed. Berlin, Germany: Springer, 2007.
[4] M. O. Scully and M. S. Zubairy, Quantum Optics. Cambridge, U.K.: Cambridge University Press, 1997.
[5] P. Meystre, Atom Optics. New York, NY, USA: Springer-Verlag, 2001.
[6] M. Sargent III, M. O. Scully, and W. E. Lamb Jr., Laser Physics. Reading, MA, USA: Addison-Wesley Publishing Company, 1974.
[7] M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information, 10th Anniversary ed. Cambridge, U.K.: Cambridge University Press, 2010.
[8] N. D. Mermin, Quantum Computer Science: An Introduction. Cambridge, U.K.: Cambridge University Press, 2007.
[9] E. G. Rieffel and W. H. Polak, Quantum Computing: A Gentle Introduction. Cambridge, MA, USA: MIT Press, 2014.
[10] S. M. Barnett, Quantum Information. Oxford, U.K.: Oxford University Press, 2009.
[11] J. Preskill, Quantum Computation Lecture Notes. Pasadena, CA, USA: California Institute of Technology, 1998. [Online]. Available: https://theory.caltech.edu/~preskill/ph229/
[12] D. Bouwmeester, A. Ekert, and A. Zeilinger, Eds., The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation and Quantum Computation. Berlin, Germany: Springer-Verlag, 2000.
[13] N. S. Yanofsky and M. A. Mannucci, Quantum Computing for Computer Scientists. Cambridge, MA, USA: Cambridge University Press, 2008.
[14] D. F. Walls and G. J. Milburn, Quantum Optics, 2nd ed. Berlin, Germany: Springer, 2008.
[15] B. Schumacher and M. D. Westmoreland, Quantum Processes, Systems, and Information. Cambridge, U.K.: Cambridge University Press, 2010.
[16] J. Watrous, The Theory of Quantum Information. Cambridge, U.K.: Cambridge University Press, 2018.

PROJECT / DISSERTATION (RD)

[to be undertaken by students opting for and eligible for Hons. with Research]

PROJECT / DISSERTATION
Credit: 8;
Full Marks: 150

Structure of the project / dissertation

Preliminary Pages

- Title Page: Includes name of the student, university, degree, and submission date.
- Certificate/Declaration: Signed statement of originality and supervisor's approval
- Abstract: A 250-350 word summary covering research problem, methodology, and core findings.
- Acknowledgements: To supervisors and others, if any.
- Table of Contents: Clear hierarchical mapping of chapters with page number
- List of Abbreviations: Specialized terms, if any

Introduction

- Background & Context: Situates the topic in historical or theoretical context.
- Research Problem & Objectives: The specific question or gap the research is addressing.
- Thesis Statement/Hypothesis: The core argument the dissertation intends to prove.
- Scope and Significance: Why the study matters.
- Literature Review & Theoretical Framework

Literature Review: Analyzes existing scholarly works to show the gap the study fills.

- Theoretical Framework: Identifies the philosophers, critics, or schools of thought shaping the analysis in the dissertation.

Methodology

- Describes *how* the research was conducted - Anyone or a combination of textual analysis/ archival research/ conducting interviews/ ethnographic/semi-ethno-graphic research involving both textual analysis and field visit etc.
- Thematic or Analytical Chapters

The Core Body: Usually 3 to 4 chapters focusing on the core concerns of the study.

- Structure: Each chapter introduces its specific theme, analyzes primary and secondary sources, and contributes to the overarching thesis.

Conclusion

- Summary & Synthesis: Recaps your main points without simply repeating them.

Final Verdict: Answers the research questions posed in the introduction.

Future Scope: Suggests how future scholars can build upon your work.

- Works Cited/ Reference, and/or Bibliography: A comprehensive list of all primary and secondary sources cited as per the latest MLA style.

Appendices: Transcripts, interview logs, or raw archival data, if any.

Marks distribution-

Sl. No	Particulars	Marks
1	Research Project / Dissertation Report ▪ Proposal and Abstract (along with some keywords) ▪ Literature Review &Theoretical Framework ▪ Methodology and Research design ▪ Thematic Analysis (Chapter-wise) ▪ Report Quality	70 10 10 10 20 20
2	Seminar Presentation	30
3	Viva-Voce	50
	Total	**150**

MINOR (MI)

Minor-08
Nuclear Physics

[THEORY & PRACTICAL, TOTAL CREDITS: 04]

Theory (MI-C8T) **Credits 4 [60L]**

1. **Bulk properties of nuclei and nuclear structure:** Nuclear charge, mass, size, mass defect, binding energy, binding fraction; Impossibility of an electron being in the nucleus as a consequence of the uncertainty principle; Properties of nuclear force, Stability and binding, B/A versus A graph, N-Z plot. Nuclear models: Liquid Drop model, Nuclear shell model (qualitative discussions only) and magic numbers. [16L]

2. **Unstable nuclei:**

   (a). Radioactivity: Survival equation, Half-life, Mean-life, Transient and secular equilibrium, radioactive dating. [3L]

   (b). $\boldsymbol{\alpha}$ **−decay:** Alpha particle spectra – velocity and disintegration energy of α-particles, Range of α-particles, Geiger-Nuttal law. [4L]

   (c). $\boldsymbol{\beta}$ **−decay:** Detection of the β-energy, Nature of β-ray spectra, difficulties explaining the β-ray spectra, the neutrino hypothesis, energy levels & decay schemes, positron emission & electron capture. [6L]

   (d). $\boldsymbol{\gamma}$ **−decay:** Origin of γ-ray, γ-ray spectra & nuclear energy levels, γ-absorption in matter – photoelectric process, Compton scattering, $e^- - e^+$ pair production (qualitative discussions). [5L]

3. **Nuclear Reactions:**

   (a) Types of nuclear reactions, Q value and threshold energy, nuclear reaction cross-sections, examples of different types of reactions and their characteristics, Bohr's postulate of compound nuclear reaction. [6L]

   (b) Nuclear fission and fusion: mass deficit and generation of energy, Reaction characteristics, explanation in terms of liquid drop model, fission products and energy release, spontaneous and induced fission, transuranic elements. [8L]

4. **Cosmic ray:** Nature and origin of primary and secondary rays, latitude and altitude variations, hard & soft components, Cosmic Ray shower, Effect of Earth's magnetic fields. [5L]

5. **Elementary particles:** Fundamental interactions in nature and their relative strengths, Elementary particles and their families. [4L]

6. **Particle accelerators and detectors:** Linear Accelerator, Cyclotron, GM Counters. [3L]

Suggested Readings:

1. Basic ideas and concepts in nuclear physics: An introductory approach, K. Heyde, 3rd edition, 1999, IOP Publication.
2. Introductory Nuclear Physics, K. S. Krane, 2008, Wiley-India Publication.
3. Modern Atomic and Nuclear Physics, A. B. Gupta, Books & Allied Pvt. Ltd.
4. Nuclear Physics: Principles and applications, J. Lilley, 2006, Wiley Publication.
5. Concepts of Nuclear Physics, B. L. Cohen, 1974, Tata McGraw Hill Publication.
6. Radiation detection and measurement, G. F. Knoll, 2010, John Wiley and Sons.
7. Nuclear and Particle Physics, S. Bhattacharyya, 2020, Universities Press.
8. Nuclear Physics, An Introduction, S.B. Patel, 2018, New Age International
9. Problems and Solutions in Nuclear and Particle Physics, S. Petreta, 2019, Springer.
10. Schaum's Outline of Modern Physics, 1999, McGraw-Hill.

******