# DEPARTMENT OF PHYSICS
# B. SC. (HONOURS) PHYSICS

## DISCIPLINE SPECIFIC CORE COURSE – DSC - 7: MATHEMATICAL PHYSICS III

| Course Title & Code | Credits | Credit distribution of the course | | | Eligibility Criteria | Pre-requisite of the course |
|---|---|---|---|---|---|---|
| | | Lecture | Tutorial | Practical | | |
| Mathematical Physics III<br><br>DSC – 7 | 4 | 3 | 0 | 1 | Class $12^{th}$ Pass | Should have studied DSC - 1 and DSC - 4 of this program or its equivalent |

### LEARNING OBJECTIVES

The emphasis of course is on applications in solving problems of interest to physicists. The course will also expose students to fundamental computational physics skills enabling them to solve a wide range of physics problems. The skills developed during course will prepare them not only for doing fundamental and applied research but also for a wide variety of careers.

### LEARNING OUTCOMES

After completing this course, student will be able to,

- Determine continuity, differentiability and analyticity of a complex function, find the derivative of a function and understand the properties of elementary complex functions.
- Work with multi-valued functions (logarithmic, complex power, inverse trigonometric function) and determine branches of these functions.
- Evaluate a contour integral using parameterization, fundamental theorem of calculus and Cauchy's integral formula.
- Find the Taylor series of a function and determine its radius of convergence.
- Determine the Laurent series expansion of a function in different regions, find the residues and use the residue theory to evaluate a contour integral and real integral.
- Understand the properties of Fourier transforms and use these to solve boundary value problems.
- Solve linear partial differential equations of second order with separation of variable method.
- In the laboratory course, the students will learn to,
    - create, visualize and use complex numbers
    - use Gauss quadrature methods to numerically integrate proper and improper definite integrals
    - Solve the boundary value problems numerically
    - Compute the fast Fourier transform of a given function

## SYLLABUS OF DSC – 7

## THEORY COMPONENT

**Unit - I** **(28 Hours)**

Complex Analysis: The field of complex numbers. Graphical, Cartesian and polar representation. Algebra in the complex plane. Triangle inequality. Roots of complex numbers. Regions in the complex plane – idea of open sets, closed sets, connected sets, bounded sets and domain.

(3 Hours)

The complex functions and mappings. Limits of complex functions. Extended complex plane and limits involving the point at infinity. Continuity and differentiability of a complex function, Cauchy-Riemann equations in Cartesian and polar coordinates, sufficient conditions for differentiability, harmonic functions. Analytic functions, singular points. Elementary functions. Multi-functions, branch cuts and branch points.

(10 Hours)

Integration in complex plane: contours and contour integrals, Cauchy-Goursat Theorem (No proof) for simply and multiply connected domains. Cauchy's inequality. Cauchy's integral formula. Taylor's and Laurent's theorems (statements only), types of singularities (removable poles and essential), meromorphic functions, residues and Cauchy's residue theorem, Jordan Lemma (statement only), evaluation of real integrals by contour integration (excluding integrands with branch points)

(15 Hours)

**Unit – II** **(9 Hours)**

Fourier Transform: Fourier Integral theorem (Statement only), Fourier Transform (FT) and Inverse FT, existence of FT, FT of single pulse, finite sine train, trigonometric, exponential, Gaussian functions, properties of FT, FT of Dirac delta function, sine and cosine function, convolution theorem. Fourier Sine Transform (FST) and Fourier Cosine Transform (FCT)

**Unit – III** **(8 Hours)**

Partial Differential Equations: Solutions to partial differential equations (2 or 3 independent variables) using separation of variables: Laplace's equation in problems of rectangular geometry. Solution of wave equation for vibrational modes of a stretched string. Solution of 1D heat flow equation (Wave/Heat equation not to be derived)

**References:**

**Essential Readings:**


1) Mathematical methods for Scientists and Engineers, D.A. McQuarrie, Viva Book, 2003
2) Essential Mathematical Methods, K. F. Riley and M. P. Hobson, Cambridge Univ. Press, 2011
3) Mathematical Methods for Physicists, G. B. Arfken, H.J. Weber, F. E. Harris, 7th Edition, Elsevier, 2013
4) Complex Variables and Applications, J. W. Brown and R. V. Churchill, 9th Edition, Tata McGraw-Hill, 2021
5) Complex Variables: Schaum's Outline, McGraw Hill Education, 2009
6) Fourier analysis: With Applications to Boundary Value Problems, Murray Spiegel, McGraw Hill Education, 2017
7) Fourier series and boundary value problems, J. W. Brown and R. V. Churchill, 5th

Edition, Tata McGraw-Hill, 1993.
8) Applied Mathematics for Engineers and Physicists, 3rd edition, L. A. Pipes and L. R. Harvill, Dover Publications.

**Additional Readings:**

1) Mathematical Physics with Applications, Problems and Solutions, V. Balakrishnan, Ane Books, 2017
2) Complex Variables, A. S. Fokas and M. J. Ablowitz, 8th Edition, Cambridge Univ. Press, 2011
3) Fourier Transform and its Applications, third edition, Ronald New Bold Bracewell, McGraw Hill, 2000
4) A Students Guide to Fourier Transforms: With Applications in Physics and Engineering, 3rd edition, Cambridge University Press, 2015
5) Partial Differential Equations for Scientists and Engineers, S. J. Farlow, Dover Publications, 1993
6) Differential Equations – Theory, technique and practice, George F. Simmons and Steven G. Krantz, Indian Edition McGraw Hill Education Pvt. Ltd, 2014

## PRACTICAL COMPONENT

**(15 Weeks with 2 hours of laboratory session per week)**

The aim of this lab is not just to teach computer programming and numerical analysis but to emphasize its role in solving problems in Physics.

- The course will consist of practical sessions and lectures on the related theoretical aspects of the laboratory.
- Assessment is to be done not only on the programming but also on the basis of formulating the problem.
- The list of recommended programs is suggestive only. More programs may be done in the class with physics applications. Emphasis should be given to formulate a physics problem as mathematical one and solve it by computational methods.
- At least 6 programs must be attempted (taking at least one from each unit). The implementation can be either in Python/ C++/ Scilab. Inbuilt libraries can be used wherever applicable.

**Unit 1**

Handling of Complex Numbers: Syntax for creating complex numbers in Python/C++/Scilab, accessing real and imaginary parts, calculating the modulus and conjugate of a complex number, complex number arithmetic, plotting of complex numbers as ordered pairs of real numbers in a plane, conversion from Cartesian to polar representation.

Recommended List of Programs:

a) Determine the nth roots of a complex number and represent it in Cartesian and polar form.
b) Transformation of complex numbers as 2-D vectors e.g. translation, scaling, rotation, reflection.
c) Visualisation of mappings of some elementary complex functions w = f(z) from z-plane to w-plane.

**Unit 2**

Gauss Quadrature Integration Methods: Gauss quadrature methods for integration: Gauss Legendre, Gauss Lagaurre and Gauss Hermite methods.

Recommended List of Programs:

a) Solving a definite integral by Gauss Legendre quadrature method. Application – representation of a function as a linear combination of Legendre polynomials.
b) Solving improper integrals over entire real axis or the positive real axis using Gauss Lagaurre and Gauss Hermite quadrature method. Comparison of results with the ones obtained by contour integration analytically.
c) Comparison of convergence of improper integral computed by Newton Cotes and Gauss Quadrature Methods.

**Unit 3**

Fast Fourier Transform: Discrete Fourier transform, Any algorithm for fast Fourier transform.

a) Computation of Discrete Fourier Transform (DFT) using complex numbers.
b) Fast Fourier Transform of given function in tabulated or mathematical form e.g function $\exp(-x^2)$.

**Unit 4**

Numerical Solutions of Boundary Value Problems: Two-point boundary value problems, types of boundary conditions – (Dirichlet, Neumann and Robin), importance of converting a physics problem to dimensionless form before solving numerically. Finite difference method, Shooting method with bisection/Secant/Newton method for solving non-linear equation and using RK methods for solving IVP (The programs developed in the last semester may be used here).

Algorithm for any one numerical method to solve Partial Differential Equations e.g. Finite Difference method, relaxation methods, Crank-Nicolson method

Recommended List of Programs:

(a) The equilibrium temperature of a bar of length L with insulated horizontal sides and the ends maintained at fixed temperatures.
(b) Solve for the steady state concentration profile y(x) in the reaction-diffusion problem given by $y''(x) - y(x) = 0$ with $y(0) = 1, y'(1) = 0$.
(c) Use any numerical method to solve Laplace equation/ Wave equation/ Heat equation.

**References (for Laboratory Work):**


1) Documentation at the Python home page (https://docs.python.org/3/ ) and the tutorials there (https://docs.python.org/3/tutorial/ ).
2) Documentation of NumPy and Matplotlib: https://numpy.org/doc/stable/user/ and https://matplotlib.org/stable/tutorials/
3) Schaum's Outline of Programming with C++, J. Hubbard, 2000, McGraw-Hill Education.
4) An Introduction to Computational Physics, T. Pang, Cambridge University Press, 2010
5) Introduction to Numerical Analysis, S. S. Sastry, 5th Edition, 2012, PHI Learning Pvt. Ltd.
6) Numerical Recipes: The art of scientific computing, William H. Press, Saul A. Teukolsky and William Vetterling, Cambridge University Press; 3rd Edition, 2007
7) Computational Problems for Physics, R. H. Landau and M. J. Páez, CRC Press, 2018

## DISCIPLINE SPECIFIC CORE COURSE – DSC - 8: THERMAL PHYSICS

| Course Title & Code | Credits | Credit distribution of the course | | | Eligibility Criteria | Pre-requisite of the course |
|---|---|---|---|---|---|---|
| | | Lecture | Tutorial | Practical | | |
| Thermal Physics<br><br>DSC – 8 | **4** | **3** | **0** | **1** | Class $12^{th}$ Pass | NIL |

### LEARNING OBJECTIVES

This course deals with the relationship between the macroscopic and microscopic properties of physical systems in equilibrium. It reviews the concepts of thermodynamics learnt at school from a more advanced perspective and how to develop them further to build new concepts. The course gives an understanding about the fundamental laws of thermodynamics and their applications to various systems and processes. It also includes a basic idea about the kinetic theory of gases, transport phenomena involved in ideal gases, phase transitions and behaviour of real gases. The students will be able to apply these concepts to several problems on heat. The lab course deals with providing the knowledge of the concepts of thermodynamics studied in the theory paper with the help of experiments and give the students a hands-on experience on the construction and use of specific measurement instruments and experimental apparatuses used in the Thermal Physics lab, including necessary precautions.

### LEARNING OUTCOMES

At the end of this course, students will be able to

- Comprehend the basic concepts of thermodynamics, the first and the second law of thermodynamics.
- Understand the concept of reversibility, irreversibility and entropy.
- Understand various thermodynamic potentials and their physical significance with respect to different thermodynamic systems and processes.
- Deduce Maxwell's thermodynamical relations and use them for solving various problems in Thermodynamics.
- Understand the concept and behaviour of ideal and real gases.
- Apply the basic concept of kinetic theory of gases in deriving Maxwell-Boltzmann distribution law and its applications.
- Understand mean free path and molecular collisions in viscosity, thermal conductivity, diffusion and Brownian motion.
- While doing the practical, the students will have an opportunity to understand and hence use the specific apparatus required to study various concepts of thermodynamics. Hence, the student will be able to comprehend the errors they can encounter while performing the experiment and how to estimate them.

## SYLLABUS OF DSC - 8

## THEORY COMPONENT

**Unit – I - Zeroth and First Law of Thermodynamics (6 Hours)**

Fundamental idea of thermodynamic equilibrium and Zeroth Law of Thermodynamics, concept of work and heat, First law of Thermodynamics and its differential form, internal energy, applications of First law: General relation between $C_P$ and $C_v$, work done during various processes (all four) and related problems, adiabatic lapse rate, Compressibility and Expansion Co-efficient for various processes.

**Unit – II - Second law of Thermodynamics (6 Hours)**

Reversible and Irreversible processes, Carnot engine and Carnot's cycle, Refrigerator, efficiency of Carnot engine and refrigerator, Second Law of Thermodynamics: Kelvin-Planck and Clausius statements and their equivalence, Carnot's theorem, Applications of Second Law of Thermodynamics in the light of Phase Change, Thermodynamic Scale of Temperature and its equivalence to Perfect Gas Scale.

**Unit – III – Entropy (6 Hours)**

Concept of Entropy, Entropy changes in Reversible and Irreversible processes with examples, Clausius Theorem, Clausius inequality, Second Law of Thermodynamics in terms of Entropy. Temperature-Entropy diagrams for Carnot's cycle and related problems, Entropy of perfect and real gases, conceptual problems related to Entropy during a Phase Change, Nernst Heat Theorem: Unattainability of Absolute Zero and Third Law of Thermodynamics.

**Unit – IV - Thermodynamic Potentials and Maxwell's Relations (12 Hours)**

Basic concept of Thermodynamic Potentials, Internal Energy, Enthalpy, Helmholtz Free Energy, Gibb's Free Energy, Magnetic work and basic idea about cooling due to adiabatic demagnetization, Phase Transitions : First order and Second order Phase Transitions with examples, Clausius Clapeyron Equation, Ehrenfest Equations, Derivation of Maxwell's Thermodynamic Relations and their applications in Clausius Clapeyron Equation, value of $C_P$ – $C_v$, TdS equations, Energy equations, evaluation of $C_P$ /$C_v$ and Ratio of Adiabatic to Isothermal elasticity.

**Unit – V - Kinetic Theory of Gases and Molecular Collisions (8 Hours)**

Constrained maximization using Lagrange multipliers, Maxwell-Boltzmann law of distribution of velocities in an ideal gas and its experimental verification with any one method. Mean, Root Mean Square and Most Probable Speeds, Maxwell-Boltzmann equation for distribution of Energy: Average Energy and Most Probable Energy, Mean Free Path, Collision Probability, estimation of Mean Free Path, transport phenomena in ideal gases: viscosity, thermal conductivity and diffusion with continuity equation

**Unit – VI - Real Gases (7 Hours)**

Behaviour of Real Gases: Deviations from the ideal gas equation, Andrew's experiments on $CO_2$ Gas, Virial equation, Continuity of liquid and gaseous states, Boyle temperature, Van der Waals equation of state for real gases (derivation not required), comparison with experimental curves: P-V diagrams, value of critical constants, law of corresponding states, free adiabatic expansion of a perfect gas, Joule Thomson Porous - Plug Experiment, Joule Thomson Coefficient for Ideal and Van der Waals Gases, Temperature of Inversion and Joule Thomson cooling.

**References:**

**Essential Readings:**

1) Heat and Thermodynamics: M. W. Zemansky and R. Dittman, Tata McGraw-Hill, 1981
2) Thermal Physics: S. C. Garg, R. M. Bansal and C. K. Ghosh, 2nd Edition, Tata McGraw-Hill.
3) Thermodynamics, Kinetic Theory and Statistical Thermodynamics: Sears and Salinger, Narosa, 1988
4) Concepts in Thermal Physics: Blundell and Blundell, 2nd Edition, Oxford University Press, 2009
5) Thermal Physics, A. Kumar and S. P. Taneja, R. Chand Publications, 2014
6) A Text Book of Heat and Thermodynamics for Degree Students, J. B. Rajam, S. Chand, 1981

**Additional Readings:**

1) An Introduction to Thermal Physics: D. Schroeder, Oxford University Press (earlier published by Pearsons), 2021
2) Thermal Physics: C. Kittel and H. Kroemer, 2nd Edition, W.H. Freeman, 1980
3) Heat, Thermodynamics and Statistical Physics, Brij Lal, N. Subrahmanyam and P. S. Hemne, S. Chand and Company
4) Thermal Physics: Concepts and practices, A. L. Wasserman, Cambridge University Press, 2012
5) Fundamentals of Thermal and Statistical Physics, Frederick Reif, McGraw-Hill, 1965

## PRACTICAL COMPONENT

**(15 Weeks with 2 hours of laboratory session per week)**

**At least six experiments to be done from the following:**

1) To determine Mechanical Equivalent of Heat, J, by Callender and Barne's constant flow method.
2) To determine the Coefficient of Thermal Conductivity of Cu by Searle's Apparatus.
3) To determine the Coefficient of Thermal Conductivity of a bad conductor by Lee and Charlton's disc method using steam or electrical heating.
4) To determine the Temperature Coefficient of Resistance by Platinum Resistance Thermometer (PRT) using Carey Foster's Bridge.
5) To determine the Temperature Coefficient of Resistance using Platinum Resistance Thermometer (PRT) by Callender-Griffith Bridge.
6) To study the variation of thermo-e.m.f. of a thermocouple with difference of temperature of its two junctions using a null method.
7) To calibrate a thermocouple to measure temperature in a specified range by direct method and/or by using Op Amp and to determine Neutral Temperature.
8) To determine the coefficient of thermal conductivity of Copper (Cu) by Angstrom's method.

**References (for Laboratory Work):**

1) Advanced Practical Physics for students: B. L. Flint and H. T. Worsnop, Asia Publishing House, 1971

2) A Text Book of Practical Physics : Indu Prakash and Ramakrishna, 11th Edition, Kitab Mahal
3) Advanced level Practical Physics: Nelkon and Ogborn, 4th Edition, reprinted 1985, Heinemann Educational Publishers
4) An Advanced Course in Practical Physics: D. Chattopadhyay and P. C. Rakshit, New Central Book Agency, 1990
5) Practical Physics: G. L. Squires, Cambridge University Press, 1985
6) B. Sc Practical Physics: Harnam Singh, P. S. Hemne, revised edition 2011, S. Chand and Co.
7) B. Sc Practical Physics: C. L. Arora, 2001, S. Chand and Co.
8) B.Sc. Practical Physics: Geeta Sanon, R. Chand and Co.

## DISCIPLINE SPECIFIC CORE COURSE – DSC - 9: LIGHT AND MATTER

| Course Title & Code | Credits | Credit distribution of the course | | | Eligibility Criteria | Pre-requisite of the course |
|---|---|---|---|---|---|---|
| | | Lecture | Tutorial | Practical | | |
| Light and Matter<br><br>DSC – 9 | **4** | **2** | **0** | **2** | Class $12^{th}$ Pass | NIL |

### LEARNING OBJECTIVES

The objective of this course reviews the concepts of light and matter, their properties and their dual nature. This course provides an in depth understanding of dual nature of light, interference and diffraction with emphasis on practical applications of both. It prepares the student for the modern physics and quantum mechanics courses.

### LEARNING OUTCOMES

On successfully completing the requirement of this course the student will have the skill and knowledge to,

- Appreciate the dual nature of light which is part of the electromagnetic spectrum and the dual nature of matter simultaneously.
- Understand the phenomena of interference and diffraction exhibited by light and matter, their nuances and details.
- Delve in to the depth of understanding wave optics with its various kinds of interference and diffraction exhibited by light.
- Demonstrate basic concepts of diffraction: Superposition of wavelets diffracted from aperture, understand Fraunhofer and Fresnel diffraction.
- Learn about the application of matter waves in latest technological developments of electron microscope e.g. SEM and TEM used widely for characterization in several fields of physics such as material science, nanotechnology etc.
- In the laboratory course, students will gain hands-on experience of using various optical instruments, measurement of resolving power and dispersive power, and making finer measurements of wavelength of light using Newton's rings experiment. They will also find wavelength of Laser sources by single and double slit experiment, wavelength and angular spread of He-Ne Laser using plane diffraction grating.

### SYLLABUS OF DSC - 9

### THEORY COMPONENT

**Unit – I - Duality of Light and matter (5 Hours)**

Light an EM wave - Hertz's experiments; Particle characteristics by photoelectric effect and Compton effect (concepts only) and wave characteristics by interference and diffraction.

Wave properties of particles: de Broglie hypothesis, wavelength of matter waves; particle wave complementarity: Velocity of de Broglie wave and need of a wave packet; Group and phase velocities and relation between them; equivalence of group and particle velocity, dispersion of wave groups.

**Unit – II – Interference (10 Hours)**
Division of amplitude and wave-front. Two-slit interference experiment with photons: Young's double slit experiment. Lloyd's mirror. Phase change on reflection: Stokes' treatment. Interference in Thin Films: parallel and wedge-shaped films. Fringes of equal inclination (Haidinger Fringes); Fringes of equal thickness (Fizeau Fringe). Newton's Rings: Measurement of wavelength and refractive index. Single photon interference. Two-slit interference experiment with electrons.

**Unit – III – Diffraction (15 Hours)**
Fraunhofer diffraction: Single slit, double slit, diffraction grating, resolving power of grating.
Fresnel diffraction: Fresnel's assumptions, Fresnel's half-period zones for plane wave, explanation of rectilinear propagation of light, theory of a zone plate: multiple foci of a zone plate, Fresnel diffraction at straight edge, a slit and a wire by Fresnel half period zones.
Diffraction of photons (e.g. X-rays, gamma rays etc.) and particles by matter, experimental study of matter waves: Davisson-Germer experiment; Electron microscope: applications SEM, TEM.

**References:**
**Essential Readings:**

1) Concepts of Modern Physics, Arthur Beiser, McGraw-Hill, 2002
2) Modern Physics by R. A. Serway, C. J. Moses and C. A. Moyer, Thomson Brooks Cole, 2012
3) Modern Physics for Scientists and Engineers by S. T. Thornton and A. Rex, $4^{th}$ Edition, Cengage Learning, 2013
4) Optics, Ajoy Ghatak, McGraw-Hill Education, New Delhi, $7^{th}$ Edition
5) Fundamentals of Optics, F. A. Jenkins and H. E. White, McGraw-Hill, 1981
6) Fundamental of Optics, A. Kumar, H. R. Gulati and D. R. Khanna, R. Chand Publications, 2011
7) A Textbook of Optics N. Subrahmanyam, Brij Lal, M. N. Avadhanulu, S. Chand & Co Ltd.
8) Introduction to Optics I - Interaction of Light with Matter, Ksenia Dolgaleva, Morgan and Claypool, 2021
9) Physics for scientists and Engineers with Modern Physics, Jewett and Serway, Cengage Learning, 2010
10) Modern Physics, G. Kaur and G. R. Pickrell, McGraw Hill, 2014
11) Schaum's Outline of Beginning Physics II: Waves, electromagnetism, Optics and Modern Physics, Alvin Halpern, Erich Erlbach, McGraw Hill.
12) Theory and Problems of Modern Physics, Schaum's outline, R. Gautreau and W. Savin, $2^{nd}$ Edition, Tata McGraw-Hill Publishing Co. Ltd.


**Additional Readings:**

1) Principles of Optics, Max Born and Emil Wolf, $7^{th}$ Edition, Pergamon Press, 1999
2) Introduction to Optics, Pedrotti Frank L. Cambridge University Press.
3) Optics, Eugene Hecht, $4^{th}$ Edition, Pearson Education, 2014
4) Six Ideas that Shaped Physics: Particle Behave like Waves, T. A. Moore, McGraw Hill, 2003

5) Thirty years that shook physics: the story of quantum theory, George Gamow, Garden City, NY: Doubleday, 1966.
6) Quantum Mechanics: Theory and Applications, (Extensively revised 6th Edition), Ajoy Ghatak and S. Lokanathan, Laxmi Publications, 2019
7) Optics, Karl Dieter Moller, Learning by computing with model examples, Springer, 2007
8) Modern Physics for Scientists and Engineers, J. R. Taylor, C. D. Zafiratos, M. A. Dubson, Viva Books Pvt Ltd, 2017
9) Physics of Atom, Wehr, Richards and Adair, Narosa, 2002

## PRACTICAL COMPONENT

**(15 Weeks with 4 hours of laboratory session per week)**

Mandatory activity:

- Sessions on the review of experimental data analysis, sources of error and their estimation in detail, writing of scientific laboratory reports including proper reporting of errors.
- Applications of the specific experiments done in the lab.
- Familiarization with Schuster's focusing; determination of angle of prism.

At least 6 experiments from the following list.

1) Determination of refractive index of material of prism using mercury (Hg) light.
2) To determine the dispersive power and Cauchy constants of the material of a prism using mercury source.
3) To determine wavelength of sodium light using Newton's Rings.
4) To determine the thickness of a thin paper by measuring the width of the interference fringes produced by a wedge-shaped Film.
5) To determine wavelength of (1) Na source and (2) spectral lines of Hg source using plane diffraction grating.
6) To determine dispersive power of a plane diffraction grating using mercury lamp.
7) To determine resolving power of a plane diffraction grating using sodium lamp.
8) To determine the wavelength of laser source using diffraction of single slit.
9) To determine the wavelength of laser source using diffraction of double slit.
10) To determine wavelength and angular spread of He-Ne laser using plane diffraction grating.

**References (for Laboratory Work):**

1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
2) A Text Book of Practical Physics, I. Prakash and Ramakrishna, 11th Edition, 2011, Kitab Mahal.
3) Advanced level Physics Practicals, Michael Nelson and Jon M. Ogborn, 4th Edition, reprinted 1985, Heinemann Educational Publishers.
4) A Laboratory Manual of Physics for undergraduate classes, D. P. Khandelwal, 1985, Vani Pub
5) B.Sc. Practical Physics, Geeta Sanon, R. Chand and Co.

# DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 1: BIOPHYSICS

| Course Title & Code | Credits | Credit distribution of the course | | | Eligibility Criteria | Pre-requisite of the course |
|---|---|---|---|---|---|---|
| | | Lecture | Tutorial | Practical | | |
| Biophysics<br><br>DSE – 1 | 4 | 3 | 0 | 1 | Class XII Pass | NIL |

## LEARNING OBJECTIVES

This course familiarizes the students with the basic facts and ideas of biology from a quantitative perspective. It shows them how ideas and methods of physics enrich our understanding of biological systems at diverse length and time scales. The course also gives them a flavour of the interface between biology, chemistry, physics and mathematics.

## LEARNING OUTCOMES

After completing this course, students will

- Know basic facts about biological systems, including single cells, multicellular organisms and ecosystems from a quantitative perspective.
- Gain familiarity with various biological processes at different length and time scales, including molecular processes, organism level processes and evolution.
- Be able to apply the principles of physics from areas such as mechanics, electricity and magnetism, thermodynamics, statistical mechanics, and dynamical systems to understand certain living processes.
- Get exposure to complexity of life at i) the level of cell, ii) level of multi cellular organism and iii) at macroscopic system – ecosystem and biosphere.
- Gain a systems level perspective on organisms and appreciate how networks of interactions of many components give rise to complex behaviour.
- Perform mathematical and computational modelling of certain aspects of living systems.
- Get exposure to models of evolution.
- Be able to perform experiments demonstrating certain physical processes that occur in living systems.

## SYLLABUS OF DSE – 1

## THEORY COMPONENT

**Unit – I** **(4 Hours)**

**Overview:** The boundary, interior and exterior environment of living cells. Processes: exchange of matter and energy with environment, metabolism, maintenance, reproduction, evolution. Self-replication as a distinct property of biological systems. Time scales and spatial scales.

**Unit - II** **(12 Hours)**

**Molecules of life:** Metabolites, proteins and nucleic acids. Their sizes, types and roles in structures and processes. Transport, energy storage, membrane formation, catalysis, replication, transcription, translation, signaling. Typical populations of molecules of various types present in cells, their rates of production and turnover. Energy required to make a bacterial cell. Simplified mathematical models of transcription and translation.

**Unit - III** **(12 Hours)**

**Molecular motion in cells:** Random walks and applications to biology: Diffusion; models of macromolecules. Mechanical, entropic and chemical forces: Osmosis, cell assembly, molecular motors, bacterial chemotaxis.

**Unit - IV** **(12 Hours)**

**The complexity of life:** At the level of a cell: Intracellular biochemical networks. Dynamics of metabolic networks; the stoichiometric matrix. The implausibility of life based on a simplified probability estimate, and the origin of life problem. At the level of a multicellular organism: Numbers and types of cells in multicellular organisms. Cellular differentiation and development. Brain structure: neurons and neural networks. At the level of an ecosystem and the biosphere: Foodwebs. Feedback cycles and self-sustaining ecosystems. Allometric scaling laws.

**Unit - V** **(5 Hours)**

**Evolution:** The mechanism of evolution: variation at the molecular level, selection at the level of the organism. Models of evolution.

## PRACTICAL COMPONENT

**(15 Weeks with 2 hours of laboratory session per week)**

List of experiments
1) Demonstration of diffusion, effect of medium, temperature, molecular weight and size on the rate of diffusion.
2) Demonstration of osmosis in a living system.
3) Demonstration of the relationship between viscosity and density.
4) Demonstration of how microscopic particles travel in air through aerosols.
5) Graphic visualization and demonstrations of 3D structure of biomolecules using in-silico visualization tools.
6) Estimation of serum protein using BSA as the standard. (Optional).

**References:**

**Essential Readings:**

1) Biological Physics: Energy, Information, Life; Philip Nelson (W. H. Freeman & Co, NY, 2004)
2) Cell Biology by the Numbers; Ron Milo and Rob Phillips (Garland Science, Taylor & Francis Group, NY USA and Abingdon UK, 2016)
3) Physical Biology of the Cell (2nd Edition); Rob Phillips et al (Garland Science, Taylor & Francis Group, NY USA and Abingdon UK, 2013)
4) Evolution; M. Ridley (Blackwell Publishers, 2009, 3rd Edition).

**Additional Readings:**

1) Physics in Molecular Biology; Kim Sneppen and Giovanni Zocchi (Cambridge University Press, Cambridge UK, 2005)
2) Biophysics: Searching for Principles; William Bialek (Princeton University Press, Princeton USA, 2012).

## DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 2: NUMERICAL ANALYSIS

| Course Title & Code | Credits | Credit distribution of the course | | | Eligibility Criteria | Pre-requisite of the course |
|---|---|---|---|---|---|---|
| | | Lecture | Tutorial | Practical | | |
| NUMERICAL ANALYSIS<br><br>DSE – 2 | **4** | **2** | **0** | **2** | Class $12^{th}$ Pass | NIL |

### LEARNING OBJECTIVES

The main objective of this course is to introduce the students to the field of numerical analysis enabling them to solve a wide range of physics problems. The skills developed during the course will prepare them not only for doing fundamental and applied research but also for a wide variety of careers.

### LEARNING OUTCOMES

After completing this course, student will be able to,

- Analyse a physics problem, establish the mathematical model and determine the appropriate numerical techniques to solve it.
- Derive numerical methods for various mathematical tasks such as solution of non-linear algebraic and transcendental equations, system of linear equations, interpolation, least square fitting, numerical differentiation, numerical integration, eigen value problems and solution of initial value and boundary value problems.
- Analyse and evaluate the accuracy of the numerical methods learned.
- In the laboratory course, the students will learn to implement these numerical methods in Python/C++/Scilab and develop codes to solve various physics problems and analyze the results.

### SYLLABUS OF DSE – 2

### THEORY COMPONENT

**Unit – I** **(3 Hours)**

Approximation and Errors in computing: Introduction to numerical computation, Taylor's expansion and mean value theorem. Floating Point Computation, overflow and underflow. Single and double precision arithmetic. Rounding and truncation error, absolute and relative error, error propagation.

**Unit – II** **(8 Hours)**

Linear Systems: Solution of linear systems by Gaussian elimination method, partial and complete pivoting, LU decomposition, norms and errors, condition numbers, Gauss-Seidel method, diagonally dominant matrix and convergence of iteration methods. Solution of Tridiagonal systems; Eigenvalue Problem: Power method, inverse power method.

**Unit – III** **(5 Hours)**

Interpolation: Lagrange and Newton's methods (divided difference) for polynomial interpolation, theoretical error of interpolation. Inverse Interpolation. Optimal points for interpolation and Chebyshev Polynomials. Minimax Theorem (Statement only)

**Unit – IV** **(7 Hours)**

Numerical Integration: Newton Cotes quadrature methods. Derivation of Trapezoidal and Simpson (1/3 and 3/8) rules from Lagrange interpolating polynomial. Error and degree of precision of a quadrature formula. Composite formulae for Trapezoidal and Simpson methods.

Gauss Quadrature methods. Legendre, Lagaurre and Hermite quadrature methods.

**Unit – V** **(7 Hours)**

Initial and Boundary Value Problems: Solution of initial value problems by Euler, modified Euler and Runge Kutta (RK) methods. Local and global errors, comparison of errors in the Euler and RK methods

Finite difference and shooting method for solving two-point linear boundary value problems.

**References:**

**Essential Readings:**


1) Applied numerical analysis, Cutis F. Gerald and P. O. Wheatley, Pearson Education, India, 2007
2) Advanced Engineering Mathematics, Erwin Kreyszig, Wiley India, 2008
3) Introduction to Numerical Analysis, S. S. Sastry, 5th Edition, PHI Learning Pvt. Ltd, 2012
4) Elementary Numerical Analysis, K. E. Atkinson, 3rd Edition, Wiley India Edition, 2007


**Additional Readings:**


1) Numerical Recipes: The art of scientific computing, William H. Press, Saul A. Teukolsky and William Vetterling, Cambridge University Press; 3rd Edition, 2007
2) Numerical methods for scientific and engineering computation, M. K. Jain, S. R. K. Iyenger, New Age Publishers, 2012

## PRACTICAL COMPONENT

**(15 Weeks with 4 hours of laboratory session per week)**

The aim of this lab is not just to teach computer programming and numerical analysis but to emphasize its role in solving problems in Physics. Assessment is to be done not only on the programming but also on the basis of formulating the problem. The list of recommended programs is suggestive only. Students should be encouraged to do more physics applications. Emphasis should be given to formulate a physics problem as mathematical one and solve by computational methods. The students should be encouraged to develop and present an independent project. At least 10 programs must be attempted (taking at least two from each unit).The implementation can be either in Python/ C++/Scilab.

**Unit 1 - Linear Systems**

a) Solve a system of linear equations using Gauss Elimination method with pivoting (application to electric networks).
b) Solve a system of linear equations using Gauss-Seidel method and study the convergence (application to spring mass system).
c) Determine the inverse of a square matrix using Gauss-Jordan method.
d) Solve a tri-diagonal system of linear equations.
e) Study an example of ill-conditioned systematic
f) Find the LU equivalent of a matrix.
g) Determine the largest and smallest eigenvalues using Power and inverse power methods. Consider a case where power method fails.

**Unit 2 - Interpolation**

a) Given a dataset (x, y) with equidistant x values, prepare the Newton's forward difference, backward difference and divided difference tables.
b) Given a dataset (x, y) corresponding to a physics problem, use Lagrange and Newton's forms of interpolating polynomials and compare. Determine the value of y at an intermediate value of x not included in the data set. This may be done with equally spaced and non-equally spaced x-values.
c) Given a tabulated data for an elementary function, approximate it by a polynomial and compare with the true function.
d) Compare the interpolating polynomial for a given dataset (following a known form e.g. exponential) with the approximation obtained by least square fitting.
e) Compare the interpolating polynomial approximating a given function in a given range obtained with uniformly spaced points and by Chebyshev points.
f) Compare the Chebyshev and Maclaurin series expansions of an exponential or sinusoidal function.

**Unit 3 - Integration**

a) Use integral definition of error function to compute and plot erf(x) in a given range. Use Trapezoidal, Simpson and Gauss Legendre methods and compare the results for small and large values of x.
b) Use the definition of erf(x) and numerically take the limit x going to infinity to get the value of Gaussian integral using Simpson method. Compare the result with the value obtained by Gauss Hermite and Gauss Lagaurre methods.
c) Verify the degree of precision of each quadrature rule.
d) Use Simpson methods to compute a double integral over a rectangular region.

e) Approximate the value of $\pi$ by evaluating the integral $\int_0^\infty \frac{1}{x^2+1} dx$using Simpson, Gauss Hermite and Gauss Lagaurre methods.

**Unit 4 - Initial Value Problems (IVP)**

a) Compare the errors in Euler, RK2 and RK4 by solving a first order IVP with known solution. Reduce the step size to a point where the round off errors takes over.
b) Solve a system of n first order differential equations by Euler and RK methods. Use it to solve an nth order IVP. Solve a damped free and forced harmonic oscillator problem using this.
c) Solve a physics problem like free fall with air drag or parachte problem using RK method.
d) Solve a compound spring system (3 springs) by solving a system of differential equations using Euler and RK for a given set of i1nitial conditions.
e) Obtain the current flowing in a series LCR circuit with constant voltage for a given set of initial conditions.

**Unit 5 - Boundary value problems (BVP)**

a) Solve a linear BVP using shooting and finite difference method and compare the results.
b) Solve a non-linear BVP using the finite difference and shooting method and compare the results.
c) Determine the temperature distribution along a rod made of two dissimilar materials (of different thermal conductivities) welded together when temperatures at two ends are maintained at given temperatures.
d) Design a physics problem that can be modelled by a BVP and solve it by any method.

**References for laboratory work:**


1) Documentation at the Python home page (https://docs.python.org/3/ ) and the tutorials there (https://docs.python.org/3/tutorial/ ).
2) Documentation of NumPy and Matplotlib: https://numpy.org/doc/stable/user/ and https://matplotlib.org/stable/tutorials/
3) Computational Physics, Darren Walker, 1st Edition, Scientific International Pvt. Ltd, 2015
4) An Introduction to Computational Physics, T. Pang, Cambridge University Press, 2010
5) Computational Problems for Physics, R. H. Landau and M. J. Páez, CRC Press, 2018