DISCIPLINE SPECIFIC CORE COURSE – 7: MATHEMATICAL PHYSICS III

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Mathematical Physics III DSC – 7	4	3	0	1	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 **(25 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.

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.

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, meromorphic functions, residues and Cauchy's residue theorem, application of contour integration in solving real integrals.

Unit – II **(10 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), Solution of one dimensional Wave Equation using FT.

Unit – III **(10 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, 2003, Viva Book.
2) Essential Mathematical Methods, K. F. Riley and M. P. Hobson, 2011, Cambridge Univ. Press.
3) Mathematical Methods for Physicists, G.B. Arfken, H.J. Weber, F.E. Harris, 7 Ed., 2013, Elsevier.
4) Complex Variables and Applications, J. W. Brown and R. V. Churchill, 9th Ed. 2021, Tata McGraw-Hill.
5) Complex Variables: Schaum's Outline, McGraw Hill Education (2009).
6) Fourier Analysis: With Applications to Boundary Value Problems, Murray Spiegel, 2017, McGraw Hill Education.
7) A Student's Guide to Laplace Transforms, Daniel Fleisch, Cambridge University Press; New edition (2022).
8) Laplace Transform: Schaum's Outline, M.R. Spiegel, McGraw Hill Education

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 Ed., 2011, Cambridge Univ. Press.
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 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.

- 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 Edn., 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, 2018, CRC Press.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 8: THERMAL PHYSICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Thermal Physics DSC – 8	**4**	**3**	**0**	**1**	--

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 behavior 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-Boltzman 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, 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: their properties and applications, Surface Film and variation of Surface Tension with temperature, Magnetic work, 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.

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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-Boltzman equation for distribution of Energy: Average Energy and Most Probable Energy, Mean Free Path, Collision Probability, estimation of Mean Free Path, Continuity Equation for Transport Phenomena in ideal gases: Viscosity, Thermal Conductivity and Diffusion

Unit – VI - Real Gases (7 Hours)

Behavior 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, 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, 1981, Tata McGraw-Hill.
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, 1988, Narosa.
4) Concepts in Thermal Physics: Blundell and Blundell, 2nd Edition, 2009, Oxford University Press.
5) Thermal Physics, A. Kumar and S. P. Taneja, 2014, R. Chand Publications.
6) A Text Book of Heat and Thermodynamics for Degree Students, J.B Rajam, 1981, S. Chand.

Additional Readings:
1) An Introduction to Thermal Physics: D. Schroeder, 2021, Oxford University Press (earlier published by Pearsons).
2) Thermal Physics: C. Kittel and H. Kroemer , 1980, 2nd Edition, W.H. Freeman
3) Heat, Thermodynamics and Statistical Physics, Brij Lal, N. Subrahmanyam and P. S. Hemne, S. Chand and Company

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-emf 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, 1971, Asia Publishing House.
2) A Text Book of Practical Physics : Indu Prakash and Ramakrishna, 11th Edition, Kitab Mahal
3) Advanced level Practical Physics: Nelkon and Ogborn, 4th Ed, reprinted 1985, Heinemann Educational Publishers.
4) An Advanced Course in Practical Physics: D. Chattopadhyay and P. C. Rakshit, 1990, New Central Book Agency.
5) Practical Physics: G. L. Squires , 1985, Cambridge University Press.
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.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 9:
LIGHT AND MATTER

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Light and Matter DSC – 9	**4**	**2**	**0**	**2**	--

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.

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 EM 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 Fraunhoffer 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, student will gain hands-on experience of using various optical instruments and making finer measurements of wavelength of light using Newton Rings experiment. Wavelength of light sources, resolving power and dispersive power of optical equipment can be learnt first-hand.

SYLLABUS OF DSC - 9

THEORY COMPONENT

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

Light an EM wave - Hertz's experiments; Particle characteristic by Photoelectric effect and Compton Effect (only concept) and wave characteristic 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)**

By Light waves: 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 andrefractive index.

By matter waves: Two-slit interference experiment with electrons. Single photon interference, Quantum interference experiment

Unit – III – Diffraction **(15 Hours)**

By Light waves: 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 of Straight edge, a slit and a wire by Fresnel Half Period Zones.

By matter waves: Experimental study of matter waves: Davisson-Germer experiment; Electron microscope: applications SEM, TEM.

References:

Essential Readings:

1) Concepts of Modern Physics, Arthur Beiser, 2002, McGraw-Hill.
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, 4th Edn. , Cengage Learning, 2013.
4) Optics, (2017), 7th Edition, Ajoy Ghatak, McGraw-Hill Education, New Delhi.
5) Fundamentals of Optics, F.A. Jenkins and H.E. White, 1981, McGraw-Hill.
6) Principles of Optics, Max Born and Emil Wolf, 7th Edn., 1999, Pergamon Press.
7) Fundamental of Optics, A. Kumar, H.R. Gulati and D.R. Khanna, 2011, R. Chand Publications.
8) Optics, Eugene Hecht, 4th Edn., 2014, Pearson Education.

PRACTICAL COMPONENT

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

Mandatory activity: Familiarization with Schuster`s focusing; determination of angle of prism.

At least 5 experiments from the following:

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 Ed., 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.

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