SEMESTER II

Course Code: DSC 4

Course Title: Mathematical Physics II

Total Credits: 04 (Credits: Theory: 02, Practical: 02)

Total Hours: Theory: 30, Practical: 60

Course 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.

Course Learning Outcomes: After completing this course, student will be able to,

- Understand the concept of divergence and curl of vector fields.
- Perform line, surface and volume integration and apply Green's, Stokes' and Gauss's theorems to compute these integrals. The students will be also enabled to apply these to physics problems.
- Use curvilinear coordinates to problems with spherical and cylindrical symmetries.
- Represent a periodic function by a sum of harmonics using Fourier series

Pre-requisite: DSC course - Mathematical Physics I

THEORY (Credit: 02; 30 Hours)

Unit 1:

Vector Calculus: Divergence and curl of a vector field and their physical interpretation. Laplacian operator. Vector identities, Integrals of vector-valued functions of single scalar variable. Multiple integrals, Jacobian. Notion of infinitesimal line, surface and volume elements. Line, surface and volume integrals of vector fields. Flux of a vector field. Gauss divergence theorem, Green's and Stokes' Theorems (no proofs) and their applications.

(15 Hours)

Unit 2:

Orthogonal Curvilinear Coordinates: Orthogonal Curvilinear Coordinates. Scale factors, element of area and volume in spherical and cylindrical coordinate Systems. Derivation of

Gradient, Divergence, Curl and Laplacian in Spherical and Cylindrical Coordinate Systems

(6 Hours)

Some Special Integrals: Beta and Gamma Functions and relation between them, expression of integrals in terms of Gamma and Beta Functions.

(3 Hours)

Unit 3:

Fourier Series: Periodic functions. Orthogonality of sine and cosine functions, Convergence of Fourier series and Dirichlet Conditions (Statement only). Expansion of periodic functions in a series of sine and cosine functions and determination of Fourier coefficients. Even and odd functions and their Fourier expansions (Fourier Cosine Series and Fourier Sine Series). Parseval's Identity.

(6 Hours)

References:

Essential Readings:

1) Mathematical methods for Scientists and Engineers, D. A. McQuarrie, 2003, Viva Book.
2) Advanced Engineering Mathematics, D. G. Zill and W. S. Wright, 5 Ed., 2012, Jones and Bartlett Learning.
3) Advanced Engineering Mathematics, Erwin Kreyszig, 2008, Wiley India.
4) Essential Mathematical Methods, K. F. Riley and M. P. Hobson, 2011, Cambridge Univ. Press.
5) Vector Analysis and Cartesian Tensors, D. E. Bourne and P. C. Kendall, 3 Ed., 2017, CRC Press.
6) Vector Analysis, Murray Spiegel, 2nd Ed., 2017, Schaum's outlines series.
7) Fourier analysis: With Applications to Boundary Value Problems, Murray Spiegel, 2017, McGraw Hill Education.

Additional Readings:

1) Mathematical Methods for Physicists, G. B. Arfken, H. J. Weber, F. E. Harris, 7 Ed., 2013, Elsevier.
2) Introduction to Electrodynamics, Chapter 1, David J. Griffiths, 4 Ed., 2017, Cambridge University Presss.
3) The Feynman Lectures on Physics, Volume II, Feynman, Leighton and Sands, 2008, Narosa Publishing House.
4) Introduction to Vector Analysis, Davis and Snider, 6 Ed., 1990, McGraw Hill.
5) Mathematical Tools for Physics, James Nearing, 2010, Dover Publications.

PRACTICAL (Credit: 02; 60 Hours)

The aim of this laboratory 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.

At least 12 programs must be attempted covering each unit.
Although Python is recommended for implementation of the algorithms, however, any programming language may used.

Unit 1: Root Finding: Bisection, Newton Raphson and Secant methods for solving roots of equations. Convergence analysis.

Recommended List of Programs (At least two):

a) Determine the depth up to which a spherical homogeneous object of given radius and density will sink into a fluid of given density.
b) Solve transcendental equations like $\alpha = \tan(\alpha)$.
c) To approximate nth root of a number up to a given number of significant digits.

Unit 2: Interpolation: Concept of Interpolation, Lagrange form of Interpolating polynomial. Error estimation, optimal points for interpolation.

Recommended List of Programs (At least one):

a) Write program to determine the unique polynomial of a degree n that agrees with a given set of $(n+1)$ data points (x_i, y_i) and use this polynomial to find the value of y at a value of x not included in the data.
b) Generate a tabulated data containing a given number of values $(x_i, f(x_i))$ of a function f(x) and use it to interpolate at a value of x not used in table.

Unit 3: Numerical Integration:
Newton Cotes Integration methods (Trapezoidal and Simpson rules) for definite integrals. Derivation of composite formulae for these methods and discussion of error estimation.
Gauss quadrature methods of integration with example of Legendre Gauss quadrature.

Recommended List of Programs (At least three):

a) Given acceleration at equidistant time values, calculate position and velocity and plot them.
b) Use integral definition of ln(x) to compute and plot ln(x) in a given range. Use Trapezoidal, Simpson and Gauss quadrature methods and compare the results.
c) Verify the rate of convergence of the composite Trapezoidal, Simpson and Gauss quadrature methods by approximating the value of a given definite integral.
d) Evaluate the Fourier coefficients of a given periodic function (e.g. square wave, triangle wave, half wave and full wave rectifier etc.)
e) Verify the Orthogonality of Legendre Polynomials.
f) Verify the properties of Dirac Delta function using its representation as a sequence of functions.

Unit 4: Solution of Linear system of equations: Solve system of linear equations using Gauss elimination method, need for pivoting. Iterative methods like Gauss Seidel method for solving system of equations, discussion of convergence of the method.

Recommended List of Programs (At least one with each method):

a) Use Kirchoff's laws to write down the set of mesh equations for a given linear electric circuit and solve these equations using the Gauss elimination and Gauss Seidel method
b) Solution of coupled spring mass system using Gauss elimination and Gauss Seidel method

Unit 5: Numerical Solutions of Ordinary Differential Equations: Euler, modified Euler, and Runge-Kutta (RK) second and fourth order methods for solving first order initial value problems (IVP), System of first order differential equations and second order initial value problems. Discussion of errors involved in the approximate solutions obtained by these numerical methods.

Recommended List of Programs (At least four):

a) Solve given first order differential equation (Initial value problems) numerically using Euler RK2 and RK4 methods and apply to the following physics problems:
    a. Radioactive decay
    b. Current in RC and LR circuits with DC source
    c. Newton's law of cooling
b) Write a code to compare the errors in various numerical methods learnt by solving a first order IVP with known solution.
c) Solve a system of first order IVP numerically using Euler and Runge-Kutta methods.
d) Solve second order IVP numerically using Euler and Runge-Kutta methods. Study the solution of a free undamped, overdamped and critically damped harmonic oscillator with application to a mechanical oscillator or a LCR circuit.
e) Solve a forced oscillator problem and study the resonance.

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 Edn., Scientific International Pvt. Ltd (2015).
4) Elementary Numerical Analysis, K. E. Atkinson, 3rd Edn., 2007, Wiley India Edition.
5) An Introduction to Computational Physics, T. Pang, Cambridge University Press (2010).
6) Introduction to Numerical Analysis, S. S. Sastry, 5th Edn., 2012, PHI Learning Pvt. Ltd.
7) Applied numerical analysis, Cutis F. Gerald and P. O. Wheatley, Pearson Education, India (2007).
8) Numerical Recipes: The art of scientific computing, William H. Press, Saul A. Teukolsky and William Vetterling, Cambridge University Press; 3rd Edition (2007)
9) Computational Problems for Physics, R.H. Landau and M.J. Paez, 2018, CRC Press.

Course Code: DSC 5

Course Title: Electricity and Magnetism

Total Credits: 04 (Credits: Theory: 03, Practical: 01)

Total Hours: Theory: 45, Practical: 30

Course Objectives: This course reviews the concepts of electromagnetism learnt at school from a more advanced perspective and goes on to build new concepts. The course covers static and dynamic electric and magnetic fields due to continuous charge and current distributions respectively.

Course Learning Outcomes: After completing this course, student will be able to,

- Apply Coulomb's law to line, surface, and volume distributions of charges.
- Apply Gauss's law of electrostatics to distribution of charges
- Solve boundary value problems using method of images
- Comprehend the genesis of multipole effects in arbitrary distribution of charges
- Understand the effects of electric polarization and concepts of bound charges in dielectric materials
- Understand and calculate the vector potential and magnetic field of arbitrary current distribution
- Understand the concept of bound currents and ferromagnetism in magnetic materials

THEORY (Credit: 03; 45 Hours)

Unit 1: **Hours: 15**

Electric Field and Electric Potential for continuous charge distributions: Electric field due to a line charge, surface charge and volume charge. Divergence of electric field using Dirac Delta function, Curl of electric field, electric field vector as negative gradient of scalar potential, Ambiguities of Electric potential, Differential and integral forms of Gauss's Law, Applications of Gauss's Law to various charge distributions with spherical, cylindrical and planar symmetries.

Boundary Value Problems in Electrostatics: Formulation of Laplace's and Poisson equations. The first and second uniqueness theorems. Solutions of Laplace's and Poisson equations in one dimension using spherical and cylindrical coordinate systems and solutions in three-dimensional using Cartesian coordinates applying separable variable technique. Electrostatic boundary conditions for conductors and capacitors.

Unit 2: **Hours: 15**

Special techniques for the calculation of Potential and Field: The Method of Images is applied to a system of a point charge and finite continuous charge distribution (line charge and surface charge) in the presence of (i) a Plane infinite sheet maintained at constant potential, and (ii) a Sphere maintained at constant potential.

Multipole Expansion: Monopole, dipole and quadrupole potentials at large distances due to an arbitrary charge distribution expressed in terms of Legendre polynomials, negative Gradient of Dipole potential in spherical coordinates.

Electric Field in Matter: Polarization in matter, Bound charges and their physical interpretation. Field inside a dielectric, Displacement vector D, Gauss' Law in the presence of dielectrics, Boundary conditions for D, Linear dielectrics, Electric Susceptibility and Dielectric Constant, idea of complex dielectric constant due to varying electric field. Boundary value problems with linear dielectrics

Unit 3: **Hours: 15**

Magnetic Field: Divergence and curl of magnetic field B, Magnetic field due to arbitrary current distribution using Biot-Savart law, Ampere's law, Integral and differential forms of Ampere's Law, Vector potential and its ambiguities, Coulomb gauge and possibility of making vector potential divergenceless, Vector potential due to line, surface and volume currents using Poisson equations for components of vector potential.

Magnetic Properties of Matter: Magnetization vector. Bound currents, Magnetic intensity. Differential and integral form of Ampere's Law in the presence of magnetised materials. Magnetic susceptibility and permeability. Ferromagnetism (Hund's rule).

Electrodynamics: Faraday's Law, Lenz's Law, inductance, electromotive force, Ohm's law ($\vec{J} = \sigma\vec{E}$), energy stored in a magnetic Field.

References:

Essential Readings:

1) Introduction to Electrodynamics, D. J. Griffiths, 3rd Edn., 1998, Benjamin Cummings
2) Schaum's Outlines of Electromagnetics by J. A. Edminister and M. Nahvi
3) Fundamentals of Electricity and Magnetism, Arthur F. Kip, 2nd Edn.1981, McGraw-Hill.
4) Electricity and Magnetism, Edward M. Purcell, 1986 McGraw-Hill Education
5) Electricity and Magnetism, J. H. Fewkes and J. Yarwood, Vol. I, 1991, Oxford Univ. Press.

Additional Readings:

1) Feynman Lectures Vol.2, R. P. Feynman, R. B. Leighton, M. Sands, 2008, Pearson Education
2) Electricity, Magnetism and Electromagnetic Theory, S. Mahajan and Choudhury, 2012, Tata McGraw
3) Electricity and Magnetism, J. H. Fewkes and J. Yarwood, Vol. I, 1991, Oxford Univ. Press.

4) Problems and Solutions in Electromagnetics (2015), Ajoy Ghatak, K Thyagarajan and Ravi Varshney.

PRACTICAL (Credit: 01; 30 Hours)

Every student must perform at least 06 experiments.

1) Measurement of current and charge sensitivity of ballistic galvanometer
2) Measurement of critical damping resistance of ballistic galvanometer
3) Determination of a high resistance by leakage method using ballistic galvanometer
4) Measurement of field strength B and its variation in a solenoid (determine dB/dx)
5) Determination of an unknown low resistance by Carey Foster's Bridge
6) Measurement of self-inductance of a coil by Anderson's Bridge.
7) Measurement of self-inductance of a coil by Owen's Bridge.
8) To determine the mutual inductance of two coils by the Absolute method.
9) Explore magnetic properties of matter using Arduino: To verify Faraday's law and Lenz's law by measuring the induced voltage across a coil subjected to the varying magnetic field. Also, estimate the dipole moment of the magnet.

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, 11^{th} Ed., 2011, Kitab Mahal

3) Advanced Level Physics Practicals, Michael Nelson and Jon M. Ogborn, 4^{th} Edition, reprinted 1985, Heinemann Educational Publishers

4) Engineering Practical Physics, S. Panigrahi and B. Mallick, 2015, Cengage Learning

5) Practical Physics, G.L. Squires, 2015, 4^{th} Edition, Cambridge University Press

Course Code: DSC 6

Course Title: Electrical Circuit Analysis

Total Credits: 04 (Credits: Theory: 02, Practical: 02)

Total Hours: Theory: 30, Practical: 60

Course Objectives: This course covers the basic circuit concepts in a systematic manner which is suitable for analysis and design. It aims at study and analysis of electric circuits using network theorems and two-port parameters.

Course Learning Outcomes: At the end of the course the student will be able to,

- Understand the basic concepts, basic laws and methods of analysis of DC and AC networks and their difference
- Solve complex electric circuits using network theorems.
- Discuss resonance in series and parallel circuits and also the importance of initial conditions and their evaluation.
- Evaluate the performance of two port networks.

THEORY (Credit: 02; 30 Hours)

Unit 1: **Hours: 10**

Circuit Analysis: Ideal voltage source, real voltage source, current source, Kirchhoff's current law, Kirchhoff's voltage law, node analysis, mesh analysis, Star and Delta conversion. **DC Transient Analysis:** Charging and discharging with initial charge in RC circuit, RL circuit with initial current, time constant, RL and RC Circuits with source

Unit 2: **Hours: 10**

AC Circuit Analysis: Sinusoidal voltage and current, Definitions of instantaneous, peak to peak, root mean square and average values, form factor and peak factor (for half-rectified and full-rectified sinusoidal wave, rectangular wave and triangular wave), voltage-current relationship in resistor, inductor and capacitor, phasor, complex impedance, power in AC circuits, sinusoidal circuit analysis for RL, RC and RLC Circuits, resonance in series and parallel RLC Circuits (Frequency Response, Bandwidth, Quality Factor), selectivity, application of resonant circuits

Unit 3: **Hours: 10**

Network Theorems: Principal of duality, Superposition theorem, Thevenin theorem, Norton theorem. Their applications in DC and AC circuits with more than one source, Maximum

Power Transfer theorem for AC circuits, Reciprocity Theorem, Millman's Theorem, Tellegen's theorem

Two Port Networks: Impedance (Z) Parameters, Admittance (Y) Parameters, Transmission Parameters, Impedance matching

References:

Essential Readings:

1) Electric Circuits, S. A. Nasar, Schaum's outline series, Tata McGraw Hill (2004)

2) Essentials of Circuit Analysis, Robert L. Boylestad, Pearson Education (2004)

3) Electrical Circuits, M. Nahvi and J. Edminister, Schaum's Outline Series, Tata McGraw-Hill (2005)

4) Fundamentals of Electric Circuits, C. Alexander and M. Sadiku, McGraw Hill (2008)

Additional Reading:

1) Network analysis, M. E. Van Valkenburg, Third edition, Prentice Hall

PRACTICAL (Credit: 02; 60 Hours)

Every student must perform at least seven experiments

1) Verification of Kirchoff's Law.
2) Verification of Norton's theorem.
3) Verification of Thevenin's Theorem.
4) Verification of Superposition Theorem.
5) Verification of Maximum Power Transfer Theorem.
6) Determination of time constant of RC and RL circuit
7) Study of frequency response of RC circuit
8) Study of frequency response of a series and parallel LCR Circuit and determination of its resonant frequency, impedance at resonance, quality factor and bandwidth.
9) Explore electrical properties of matter using Arduino:
    a. To study the characteristics of a series RC Circuit.
    b. To study the response curve of a Series LCR circuit and determine its resonant frequency, impedance at resonance, quality factor and bandwidth

References (for Laboratory Work):

1) A Textbook of Electrical Technology, B. L. Thareja, A.K. Thareja, Volume II, S. Chand

2) Fundamentals of Electric Circuits, C. Alexander and M. Sadiku, McGraw Hill (2008)

3) Electric Circuits, S. A. Nasar, Schaum's outline series, Tata McGraw Hill (2004)

4) Electrical Circuits, K.A. Smith and R.E. Alley, 2014, Cambridge University Press

5) Electrical Circuit Analysis, K. Mahadevan and C. Chitran, 2nd Edition, 2018, PHI learning Pvt. Ltd.