DISCIPLINE SPECIFIC CORE (DSC) COURSES

SEMESTER I

Course Code: DSC 1

Course Title: MATHEMATICAL PHYSICS I

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 teach the students to model a physics problem mathematically and then solve those numerically using computational methods. The course will expose the 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,
- Draw and interpret graphs of various elementary functions and their combinations.
- Understand the vector quantities as entities with Cartesian components which satisfy appropriate rules of transformation under rotation of the axes.
- Use index notation to write the product of vectors in compact form easily applicable in computational work.
- Solve first and second order differential equations and apply these to physics problems.
- Understand the functions of more than one variable and concept of partial derivatives.
- Understand the concept of scalar field, vector field and gradient of scalar fields.
- Understand the properties of discrete and continuous distribution functions.

In the laboratory course, the students will learn to,
- Prepare algorithms and flowcharts for solving a problem.
- Design, code and test programs in Python in the process of solving various problems.
- Perform various operations of 1-d and 2-d arrays.
- Visualize data and functions graphically by use of Matplotlib
- Perform least square fitting of a given data
- Solve physics problems involving differentiation

Unit 1

Functions: Plotting elementary functions and their combinations, Interpreting graphs of functions using the concepts of calculus, Taylor's series expansion for elementary functions.

(2 Hours)

Vector Algebra: Transformation of Cartesian components of vectors under rotation of the axes, Introduction to index notation and summation convention, Product of vectors – scalar and vector product of two, three and four vectors in index notation using δ_{ij} and ε_{ijk} (as symbols only – no rigorous proof of properties), Invariance of scalar product under rotation transformation

(5 Hours)

Unit 2

Ordinary Differential Equations: First order differential equations of degree one and those reducible to this form, Exact and Inexact equations, Integrating Factor, Applications to physics problems

(4 Hours)

Higher order linear homogeneous differential equations with constant coefficients, Wronskian and linearly independent functions. Non-homogeneous second order linear differential equations with constant coefficients, complimentary function, particular integral and general solution, Determination of particular integral using method of undetermined coefficients and method of variation of parameters, Cauchy-Euler equation, Initial value problems. Applications to physics problems

(12 Hours)

Unit 3

Multi-Variable Functions: Functions of more than one variable, Partial derivatives, chain rule for partial derivatives. Scalar and vector fields, concept of directional derivative, the vector differential operator $\vec{\nabla}$, gradient of a scalar field and its geometrical interpretation.

(3 Hours)

Probability Distributions: Discrete and continuous random variables, Probability distribution functions, Binomial, Poisson and Gaussian distributions, Mean and variance of these distributions.

(4 Hours)

References:
Essential Readings:
1) An introduction to ordinary differential equations, E.A. Coddington, 2009, PHI learning.
2) Differential Equations, George F. Simmons, 2007, McGraw Hill.
3) Mathematical methods for Scientists and Engineers, D.A. McQuarrie, 2003, Viva Book.
4) Advanced Engineering Mathematics, D.G. Zill and W.S. Wright, 5 Ed., 2012, Jones and Bartlett Learning.

5) Advanced Engineering Mathematics, Erwin Kreyszig, 2008, Wiley India.
6) Probability and Statistics, Murray R Spiegel, John J Schiller and R Alu Srinivasan, 2018, McGraw Hill Education Private Limited.
7) Essential Mathematical Methods, K.F.Riley and M.P.Hobson, 2011, Cambridge Univ. Press.
8) Vector Analysis and Cartesian Tensors, D.E. Bourne and P.C. Kendall, 3 Ed. , 2017, CRC Press.
9) Vector Analysis, Murray Spiegel, 2 Ed., 2017, Schaum's outlines series.
10) John E. Freund's Mathematical Statistics with Applications, I. Miller and M. Miller, 7th Ed., 2003, Pearson Education, Asia.

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 Press.
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) Differential Equations, R. Bronson and G.B. Costa, Schaum's outline series.
6) Mathematical Physics, A.K. Ghatak, I.C. Goyal and S.J. Chua, Laxmi Publications Private Limited (2017)
7) 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.

Basics of scientific computing (Mandatory):
(a) Binary and decimal arithmetic, Floating point numbers, single and double precision arithmetic, underflow and overflow, numerical errors of elementary floating point operations, round off and truncation errors with examples.
(b) Introduction to Algorithms and Flow charts. Branching with examples of conditional statements, for and while loops.

Unit 1

Basic Elements of Python: The Python interpreter, the print statement, comments, Python as simple calculator, objects and expressions, variables (numeric, character and sequence types) and assignments, mathematical operators. Strings, Lists, Tuples and Dictionaries, type conversions, input statement, list methods. List mutability Formatting in the print statement.

Control Structures: Conditional operations, if, if-else, if-elif-else, while and for Loops, indentation, break and continue, List comprehension.

Functions: Inbuilt functions, user-defined functions, local and global variables, passing functions, modules, importing modules, math module, making new modules.

Recommended List of Programs (At least two)

(a) Make a python function that takes a number N as input and returns the value of factorial of N and compare with the output of math.factorial() method. Use this function to print the number of ways a set of m red and n blue balls can be arranged.

(b) Generate random numbers (integers and floats) in a given range and calculate area and volume of regular shapes with random dimensions.

(c) Generate data for coordinates of a projectile and plot the trajectory. Determine the range, maximum height and time of flight for a projectile motion.

Unit 2

NumPy Fundamentals: Importing Numpy, Difference between List and NumPy array, Adding, removing and sorting elements, creating arrays using ones(), zeros(), random(), arange(), linspace(). Basic array operations (sum, max, min, mean, variance), 2-d and 3-d arrays, matrix operations, reshaping and transposing arrays, savetxt() and loadtxt(), create a Pandas dataframe from an array and then write the data frame to a csv file.

Plotting with Matplotlib: matplotlib.pyplot functions, Plotting of functions given in closed form as well as in the form of discrete data and making histograms.

Recommended List of Programs (At least two)

(a) Plot the displacement-time and velocity-time graph for the undamped, under damped critically damped and over damped oscillator using matplotlib

(b) Use recurrence relation for Legendre polynomials to generate and plot these polynomials for the first few orders using matplotlib.

(c) To generate array of N random numbers drawn from a given distribution (uniform, binomial, poisson and gaussian) and plot them using matplotlib for increasing N to verify the distribution. Verify the central limit theorem.

(d) To implement the transformation of physical observables under Galilean, Lorentz and Rotation transformation

Unit 3

Least Square fitting: Algorithm for least square fitting and its relation to maximum likelihood for normally distributed data.

Make Python function for least square fitting, use it for fitting given data (x,y) and estimate the parameters a, b as well as uncertainties in the parameters for the following cases :

(a) Linear ($y = ax + b$)

(b) Power law ($y = ax^b$) and

(c) exponential ($y = ae^{bx}$).

Unit 4

(a) To find value of π and to integrate a given function using acceptance-rejection method.

(b) Taylor's series expansion: To approximate the functions (e.g. exp(x), sin(x), cos(x), ln(1+x), etc.) by a finite number of terms of Taylor's series and discuss the truncation error. To plot the function as well the nth partial sum of its series for various values of n on the same graph and visualise the convergence of series using matplotlib.

Unit 5

Numerical Differentiation: Left, right and central approximations for derivative of a function

(a) Program to find the derivative of a function given in closed form. Plot both the function and derivative on the same graph. Plot the error as a function of step size on a log-log graph, study the behaviour of the plot as step size decreases and hence discuss the effect of round off error.

(b) Applications e.g. determination of slope of tangent to a curve, points of extrema of a given function, etc.

(c) Write program to calculate velocity and acceleration using given data of position at equidistant and small time intervals.

References:

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), ISBN-13 : 978-0521880688

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Course Code: DSC 2

Course Title: Mechanics

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

Total Hours: Theory: 45, Practical: 30

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Course Objectives: This course reviews the concepts of mechanics learnt at school from a more advanced perspective and goes on to build new concepts. It begins with Newton's Laws of Motion and ends with the Special Theory of Relativity. The students will learn the collisions in the centre of mass frame, rotational motion and central forces. They will be able to apply the concepts learnt to several real world problems. In the laboratory part of the course, the students will learn to use various instruments, estimate the error for every experiment performed and report the result of experiment along with the uncertainty in the result up to correct significant figures.

Course Learning Outcomes: Upon completion of this course, students will be able to,

- Learn the Galilean invariance of Newton's laws of motion.
- Understand translational and rotational dynamics of a system of particles.
- Apply Kepler's laws to describe the motion of planets and satellite in circular orbit.
- Understand Einstein's postulates of special relativity.
- Apply Lorentz transformations to describe simultaneity, time dilation and length contraction.
- Use various instruments for measurements and perform experiments related to rotational dynamics, elastic properties, fluid dynamics, acceleration due to gravity, collisions, etc.
- Use propagation of errors to estimate uncertainty in the outcome of an experiment and perform the statistical analysis of the random errors in the observations.

THEORY (Credit: 03; 45 Hours)

Unit 1:

Fundamentals of Dynamics: Inertial and Non-inertial frames, Newton's Laws of Motion and their invariance under Galilean transformations. Momentum of variable mass system: motion of rocket. Dynamics of a system of particles, principle of conservation of momentum. Impulse. Determination of centre of mass of discrete and continuous objects having cylindrical and spherical symmetry, Differential Analysis of a static vertically hanging massive rope.

(7 Hours)

Work and Energy: Work and Kinetic Energy Theorem. Conservative forces and examples (Gravitational and electrostatic), non-conservative forces and examples (velocity dependent forces e.g. frictional force, magnetic force). Potential Energy. Energy diagram. Stable, unstable and neutral equilibrium. Force as gradient of the potential energy. Work done by non-conservative forces.

(4 Hours)

Collisions: Elastic and inelastic collisions. Kinematics of $2 \to 2$ scattering in centre of mass and laboratory frames.

(3 Hours)

Unit 2:
Rotational Dynamics: Angular momentum of a particle and system of particles. Torque. Principle of conservation of angular momentum. Rotation about a fixed axis. Determination of moment of inertia of symmetric rigid bodies (rectangular, cylindrical and spherical) using parallel and perpendicular axes theorems. Kinetic energy of rotation. Motion involving both translation and rotation

(8 Hours)

Non-Inertial Systems: Non-inertial frames and fictitious forces. Uniformly rotating frame. Centrifugal force. Coriolis force and its applications.

(4 Hours)

Unit 3:
Central Force Motion: Central forces, Law of conservation of angular momentum for central forces, Two-body problem and its reduction to equivalent one-body problem and its solution. Concept of effective potential energy and stability of orbits for central potentials of the form kr^n for n = 2 and -1 using energy diagram, discussion on trajectories for $n = -2$. Solution of Kepler's problem, Kepler's laws for planetary motion, orbit for artificial satellites.

(7 Hours)

Unit 4:
Relativity: Postulates of special theory of relativity, Lorentz transformations, simultaneity, length contraction, time dilation, proper length and proper time, Life time of a relativistic particle (for example muon decay time and decay length). Space-like, time-like and light-like separated events. Relativistic transformation of velocity and acceleration. Variation of mass with velocity, Mass-energy Equivalence. Transformation of Energy and Momentum.

(12 Hours)

References:
Essential Readings:
1) An Introduction to Mechanics (2/e), Daniel Kleppner and Robert Kolenkow, 2014, Cambridge University Press.
2) Mechanics Berkeley Physics Course, Vol. 1, 2/e: Charles Kittel, et. al., 2017, McGraw Hill Education

3) Theory and Problems of Theoretical Mechanics, Murray R. Spiegel, 1977, McGraw Hill Education.
4) Classical Mechanics by Peter Dourmashkin, 2013, John Wiley and Sons.
5) https://phys.libretexts.org/Bookshelves/Classical_Mechanics/classical_Mechanics_(Dourmashkin)/
6) Introduction to Classical Mechanics With Problems and Solutions, David Morin, 2008, Cambridge University Press.
7) Fundamentals of Physics, Resnick, Halliday and Walker 10/e, 2013, Wiley.
8) Introduction to Special Relativity, Robert Resnick, 2007, Wiley.

Additional Readings:
1) Feynman Lectures, Vol. 1, R. P. Feynman, R. B. Leighton, M. Sands, 2008, Pearson Education.
2) University Physics, H. D. Young, R. A. Freedman, 14/e, 2015, Pearson Education.
3) Classical Mechanics, H. Goldstein, C. P. Poole, J. L. Safko, 3/e, 2002, Pearson Education.
4) Newtonian Mechanics, A.P. French, 2017, Viva Books.

PRACTICAL (Credit: 01; 30 Hours)

Introductory Concepts and related activities (Mandatory)
Use of Basic Instruments:
Determination of least count and use of instruments like meter scale, vernier callipers, screw gauge and travelling microscope for measuring lengths.
Errors:
(a) Types of errors in measurements (instrumental limitations, systematic errors and random errors), Accuracy and Precision of observations, significant figures.
(b) Introduction to error estimation, propagation of errors and reporting of results along with uncertainties with correct number of significant figures.
(c) Statistical analysis of random errors, need for making multiple observations, standard error in the mean as estimate of the error.
Graph Plotting:
Pictorial visualisation of relation between two physical quantities, Points to be kept in mind while plotting a graph manually.
Data Analysis:
Principle of least square fitting (LSF) and its application in plotting linear relations. Estimation of LSF values of slope, intercept and uncertainties in slope and intercept.

Mandatory Activities:
• Determine the least count of meter scale, vernier callipers, screw gauge and travelling microscope, use these instruments to measure the length of various objects multiple time, find the mean and report the result along with the uncertainty up to appropriate number of significant digits.

- Take multiple observations of the quantities like length, radius etc. for some spherical, cylindrical and cubic objects, find mean of these observations and use them to determine the surface area and volume of these objects. Estimate the uncertainties in the outcome using law of propagation of errors. Report the result to appropriate number of significant figures.
- Given a data (x, y) corresponding to quantities x and y related by a relation $y = f(x)$ that can be linearized. Plot the data points (manually) with appropriate choice of scale, perform least square fitting to determine the slope and intercept of the LSF line and use them to determine some unknown quantity in the relation. Determine the uncertainties in slope and intercept and use these to estimate the uncertainty in the value of unknown quantity.

Every student must perform at least 4 experiments from the following list.

1) To study the random errors in observations. It is advisable to keep observables of the order of least count of the instruments.
2) To determine the moment of inertia of a symmetric as well as asymmetric flywheel
3) To determine Coefficient of Viscosity of water by Capillary Flow Method (Poiseuille's method).
4) To determine g and velocity for a freely falling body using Digital Timing Technique.
5) To determine the Young's Modulus of a Wire by Optical Lever Method.
6) To determine the vertical distance between two given points using sextant.
7) To determine the coefficients of sliding and rolling friction experienced by a trolley on an inclined plane.
8) To verify the law of conservation of linear momentum in collisions on air track.

Suggested additional Activities:
1) Virtual lab collision experiments on two dimensional elastic and inelastic collisions (for example available on
   a) https://archive.cnx.org/specials/2c7acb3c-2fbd-11e5-b2d9-e7f92291703c/collision-lab/#sim-advanced-sim)
   b) https://phet.colorado.edu/en/simulations/collision-lab
2) Amrita Virtual Mechanics Lab : https://vlab.amrita.edu/?sub=1&brch=74

References (for Laboratory Work):
1) Advanced Practical Physics for students, B. L. Flint and H. T. Worshnop, 1971, Asia Publishing House.
2) Engineering Practical Physics, S. Panigrahi and B. Mallick, 2015, Cengage Learning India Pvt. Ltd.
3) Practical Physics, G. L. Squires, 2015, 4/e, Cambridge University Press.
4) A Text Book of Practical Physics, Vol I, Prakash and Ramakrishna, 11/e, 2011, Kitab Mahal.
5) An introduction to Error Analysis: The study of uncertainties in Physical Measurements, J. R. Taylor, 1997, University Science Books

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Course Code: DSC 3

Course Title: Waves and Oscillations

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

Total Hours: Theory: 30, Practical: 60

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Course Objectives: This course reviews the concepts of waves and oscillations learnt at school from a more advanced perspective and goes on to build new concepts. It begins with explaining ideas of free oscillations and superposition of harmonic motion leading to physics of damped and forced oscillations. The course will also introduce students to coupled oscillators, normal modes of oscillations and free vibrations of stretched strings. Concurrently, in the laboratory component of the course students will perform experiments that expose them to different aspects of real oscillatory systems.

Course Learning Outcomes: On successful completion of this course, the students will have the skill and knowledge to,

- Understand travelling and standing waves, stretched strings
- Understand simple harmonic motion
- Understand superposition of N collinear harmonic oscillations
- Understand superposition of two perpendicular harmonic oscillations
- Understand free, damped and forced oscillations
- Understand coupled oscillators and normal modes of oscillations

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THEORY (Credit: 02; 30 Hours)

Unit 1: Wave Motion   **Hours: 4**

One dimensional plane wave, classical wave equation, standing wave on a stretched string (both ends fixed), normal modes. Travelling wave solution

Unit 2: Simple Harmonic Motion   **Hours: 12**

Differential equation of simple harmonic oscillator, its solution and characteristics, energy in simple harmonic motion, linearity and superposition principle, rotating vector representation of simple harmonic oscillation, motion of simple and compound pendulum (Bar and Kater's pendulum), loaded spring.

Superposition of N collinear harmonic oscillations with (1) equal phase differences and (2) equal frequency differences, Beats

Superposition of two perpendicular harmonic oscillations: Graphical and Analytical Methods. Lissajous Figures with equal and unequal frequencies, effect of variation of phase

Unit 3: Damped and Forced Oscillations   Hours: 8

Damped Oscillations: Equation of motion, dead beat motion, critically damped system, lightly damped system: relaxation time, logarithmic decrement, quality factor

Forced Oscillations: Equation of motion, complete solution, steady state solution, resonance, sharpness of resonance, power dissipation, quality factor

Unit 4: Coupled Oscillations   Hours: 6

Coupled oscillators, normal coordinates and normal modes, energy relation and energy transfer, di-atomic molecules, representation of a general solution as a linear sum of normal modes, normal modes of N coupled oscillators.

References:
Essential Readings:
1) Vibrations and Waves by A. P. French. (CBS Pub. and Dist., 1987)
2) The Physics of Waves and Oscillations by N.K. Bajaj (Tata McGraw-Hill, 1988)
3) Fundamentals of Waves and Oscillations By K. Uno Ingard (Cambridge University Press, 1988)
4) An Introduction to Mechanics by Daniel Kleppner, Robert J. Kolenkow (McGraw-Hill, 1973)
5) Waves: BERKELEY PHYSICS COURSE by Franks Crawford (Tata McGrawHill, 2007).
6) Classical Mechanics by Peter Dourmashkin, John Wiley and Sons
7) https://phys.libretexts.org/Bookshelves/Classical_Mechanics/classical_Mechanics_(Dour mashkin)

Additional Readings:
1) Fundamentals of Physics, Resnick, Halliday and Walker 10/e, 2013, Wiley.
2) Feynman Lectures, Vol. 1, R. P. Feynman, R. B. Leighton, M. Sands, 2008, Pearson Education.
3) University Physics, H. D. Young, R. A. Freedman, 14/e, 2015, Pearson Education.

PRACTICAL (Credit: 02; 60 Hours)

Every student must perform at least 5 experiments

1) Experiments using bar pendulum:
   a) Estimate limits on angular displacement for SHM by measuring the time period at different angular displacements and compare it with the expected value of time period for SHM.
   b) Determine the value of g using bar pendulum.
   c) To study damped oscillations using bar pendulum
   d) Study the effect of area of the damper on damped oscillations. Plot amplitude as a function of time and determine the damping coefficient and Q factor for different dampers.

2) To determine the value of acceleration due to gravity using Kater's pendulum for both the cases (a) $T\_1 \approx T\_2$ and (b) $T\_1 \neq T\_2$ and discuss the relative merits of both cases by estimation of error in the two cases.

3) Understand the applications of CRO by measuring voltage and time period of a periodic waveform using CRO

4) Study the superposition of two simple harmonic oscillations using CRO: Study of Lissajous figures

5) Experiments with spring and mass system
   a) To calculate g, spring constant and mass of a spring using static and dynamic methods.
   b) To calculate spring constant of series and parallel combination of two springs.

6) To study normal modes and beats in coupled pendulums or coupled springs.

7) To determine the frequency of an electrically maintained tuning fork by Melde's experiment and to verify λ^2 – T Law.

References (For Laboratory Work):

1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
2) Engineering Practical Physics, S. Panigrahi and B. Mallick, 2015, Cengage Learning India Pvt. Ltd.
3) Practical Physics, G. L. Squires, 2015, 4/e, Cambridge University Press.
4) A Text Book of Practical Physics, Vol I and II, Prakash and Ramakrishna, 11/e, 2011, Kitab Mahal.
5) An introduction to error analysis: The study of uncertainties in Physical Measurements, J. R. Taylor, 1997, University Science Books List of experiments