DEPARTMENT OF PHYSICS AND ASTROPHYSICS

Undergraduate Curriculum Framework 2022

B.Sc. (Hons) Physics

Semester VII and VIII

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC CORE COURSE – DSC 19: CLASSICAL MECHANICS

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Classical Mechanics DSC 19	4	3	1	0	DSC – 2 (Mechanics)

COURSE OBJECTIVES

- To introduce variational principles and their application to derive equations of motion for complex systems with constraints.
- To deepen the understanding of foundational principles of Classical Mechanics including Lagrangian and Hamiltonian formalisms
- To Develop an understanding of symmetries and conservation laws through Noether's Theorem
- To develop analytical skills to solve problems in dynamics, including those involving rigid bodies.
- To analyze the motion of particles in central force fields, and understand orbital mechanics, including scattering phenomena.
- To introduce theory of small oscillations, enabling students to analyze stability and coupled oscillatory systems.

LEARNING OUTCOMES

By the end of this course, students will be able to:

- Apply the calculus of variations to derive the Euler-Lagrange equations and use them to analyze constrained mechanical systems.
- Formulate and analyze mechanical systems using Lagrangian and Hamiltonian formalisms.
- Apply the principles of symmetry and conservation laws through Noether's theorem.
- Analyze motion in phase space and construct phase portraits
- Understand the dynamics of rigid bodies.
- Analyze the motion of particles under central forces and solve scattering problems.
- Understand and compute normal modes and normal frequencies in small oscillation problems.
- Develop critical thinking and problem-solving skills

SYLLABUS OF DSC 19
THEORY COMPONENT
(Hours: 45)

Unit I **(10 Hours)**

Variational Principle and Lagrangian Formulation
Calculus of Variation with applications. Generalized coordinates. Lagrangian, Hamilton's Principle, Euler-Lagrange equations of motion. Constrained systems. Cyclic coordinates and conserved quantities. Applications to physical systems.

Unit II **(10 Hours)**

Hamiltonian Formulation and Phase Space
Legendre transformation, Hamilton's equations of motion. Phase space, phase trajectories, Phase portraits. Canonical transformations, Poisson brackets, Liouville's theorem and conservation of phase space volume. Applications to Physical Systems.

Unit III **(11 Hours)**

Rigid Body Dynamics
Rotation Matrices, Euler Angles. Angular momentum and kinetic energy of rigid bodies, The Inertia Tensor, Principal Axis Transformation. Euler's equations of motion for rigid body. Torque-free motion. The symmetrical top with one point fixed.

Unit IV **(14 Hours)**

Central Force and Orbital Mechanics
Equation of motion under central force, Classification and Stability of orbits**.** Virial Theorem. Bertrand's Theorem. The Kepler Problem. Scattering in central force field, Rutherford scattering.
Theory of small oscillations: Linearization of equations of motion. Principal Axis Transformation, Normal mode analysis of forced and coupled oscillators.

REFERENCES

Essential Readings

1. Classical Mechanics, H. Goldstein, C. P. Poole, J. L. Safko, 3/e, Pearson Education (2014).
2. Classical Mechanics, John R. Taylor, University Science Books (2005).
3. Classical Mechanics, R. Douglas Gregory, Cambridge University Press (2015).
4. Mechanics, L. D. Landau and E. M. Lifshitz, Pergamon (2010).
5. Classical Mechanics, P. S. Joag, N. C. Rana, McGraw Hall Education (2017).
6. Classical Dynamics of particles and system, S. T. Thornton, J. B. Marion, Cengage Learning (2012).

7. Theory and Problems of Theoretical Mechanics, Murray R. Spiegel, McGraw Hill Education (1997).

Additional Readings

1. Classical Mechanics, Tai L. Chow, CRC Press (2013).
2. Analytical Mechanics: Solutions to Problems in Classical Physics, I. Merches, D. Radu, CRC Press (2015).
3. Solved Problems in Classical Mechanics, O. L. Delange and J. Pierrus, Oxford University Press (2010).
4. Mathematical Methods of Classical Mechanics**,** V.I. Arnold, Springer Nature (1989).
5. Classical Mechanics: A course of lectures, A K Raychoudhuri, Oxford University Press (1984).

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 9: ADVANCED MATHEMATICAL PHYSICS II

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Advanced Mathematical Physics II DSE 9	4	3	1	0	Mathematical Physics-I and Mathematical Physics-II of this course or Equivalent courses

COURSE OBJECTIVES

The emphasis of the course is to acquire advanced mathematical inputs while solving problems of interest to physicists. The course aims to introduce the students to the principles of tensor analysis and equip them to use the concept in modelling of continuous media, electrodynamics, elasticity theory and the general theory of relativity. The mathematical 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,

- Have a knowledge and understanding of tensor analysis and tensor calculus
- Be able to do computation with tensors, both in coordinates and in coordinate-free form.
- Understand the transformation properties of covariant, contravariant and mixed tensors under general coordinate transformation.
- Be able to apply the concepts of tensors in anisotropic media with examples of moment of inertia tensor, elasticity tensor and polarizability tensor.
- Understand physical examples of tensors such as Moment of Inertia and Elasticity of asymmetrical physical systems.
- Be able to write down the Lorentz Transformation in four vector notation.
- Understand inner product and outer product of general tensors.
- Understand the concept of covariant derivatives.

SYLLABUS OF DSE 9
THEORY COMPONENT
(Hours:45)

Unit I **(12 Hours)**

Cartesian Tensors: Transformation of co-ordinates under rotation of axes. Einstein's Summation Convention. Relation between direction cosines. Transformation Law for a tensor of rank *n*. Sum, inner product and outer product of tensors, contraction of tensors, Quotient Law of tensors, symmetric and anti-symmetric tensors. Invariant tensors (Kronecker and Alternating Tensor). Association of anti-symmetric tensor of rank two with vectors. Vector algebra and calculus in tensor notation. Differentiation, gradient, divergence and curl of Tensor Fields. Vector Identities in tensor notation

Unit II **(12 Hours)**

Applications of Cartesian Tensors: Equation of a Line, Angle between Lines, Projection of a Line on another Line, Condition for Two Lines to be Coplanar and Length and Foot of the Perpendicular from a Point on a Line. Rotation Tensor and its properties.
Moment of Inertia Tensor, Stress and Strain Tensors, Elasticity Tensor, Generalized Hooke's Law, Electric Polarizability.

Unit III **(9 Hours)**

General Tensors: Transformation of co-ordinates and contravariant and covariant vectors. Transformation law for contravariant, covariant and mixed tensors. Kronecker Delta and permutation tensors. Algebra of general tensors. Quotient Law general tensors. Symmetric and anti-symmetric tensors. Metric Tensor. Reciprocal Tensors. Associated Tensors.

Unit IV **(12 Hours)**

Christoffel Symbols of first and second kind and their transformation laws. Covariant derivative, gradient, divergence and curl of tensor fields. Minkowski Space, Four Vectors (four-displacement, four-velocity, four-momentum, four- vector potential, four- current density,). Tensorial form of Lorentz Transformation.

REFERENCES

Essential Readings

1) Vector Analysis and Cartesian Tensors, 3^{rd} edition, D. E. Bourne, P. C. Kendall, 1992
2) Cartesian Tensors, H. Jeffreys, 1931, Cambridge University Press.
3) Mathematical Methods for Physicists, H. J. Weber and G. B. Arfken, 2010, Elsevier.
4) A Brief on Tensor Analysis, J. G. Simmonds, 1997, Springer.
5) Schaum's outlines series on Vector Analysis, M. Spiegel, 2^{nd} edition, 2017.

6) Schaum's Outline Series on Tensor Calculus, D. Kay, Revised 1st edition, 2011.
7) An Introduction to Tensor Calculus and Relativity, D. F. Lawden, 2013, Literary Licensing
8) Matrices and tensors in physics by A. W. Joshi, 1995, New Age International Publications.

Additional Readings

1) A Student's Guide to Vectors and Tensors, D. A. Fleisch, 2011, Cambridge Univ. Press.
2) The Feynman Lectures on Physics, Volume II, Feynman, Leighton and Sands, 2008, Narosa Publishing House.
3) Classical Electrodynamics, J. D. Jackson, 3rd edition, 2009, Wiley Publication.
4) A Primer in Tensor Analysis and Relativity, I. L. Shapiro, 1st edition, 2019, Springer.
5) Gravity-An introduction to Einstein's General Relativity, J. B. Hartle, 2009, Pearson Education.
6) A first course in general relativity, B. F. Schutz, 2004, Cambridge University Press

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DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 12: ADVANCED MATHEMATICAL PHYSICS - III

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Advanced Mathematical Physics – III DSE 12	4	3	1	0	Knowledge of Linear Algebra will be helpful.

COURSE OBJECTIVES

- To understand and apply Laplace transforms to solve ordinary differential equations, particularly in physical systems like electric circuits.
- To learn the formulation and application of Green's functions in solving linear differential equations, including partial differential equations in two and three dimensions.
- To grasp the foundational principles of group theory, including finite and continuous groups, and understand how these abstract structures underlie symmetries in physics.

LEARNING OUTCOMES

After completing the course the students will be able to

- Compute Laplace transforms and inverse transforms of a variety of functions.
- Use Laplace transforms to solve second-order ordinary differential equations with physical relevance (e.g. electric circuits).
- Work with finite permutation groups and construct matrix representations.
- Understand the structure and representations of continuous groups and apply group theoretical methods to angular momentum algebra and quantum mechanical symmetries.
- Construct Green's functions for linear differential operators and use them to solve inhomogeneous ODEs and PDEs.
- Understand the physical interpretation of Green's functions in electrostatics, vibrations, and wave propagation.

SYLLABUS OF DSE 12
THEORY COMPONENT
(Hours: 45)

Unit I **(15 Hours)**

Laplace Transforms
Integral transform and kernels. Definition and Condition for Existence of Laplace Transform (LT), LT of Elementary Functions, Properties of LT. LTs of Derivatives and Integrals of Functions and Derivatives and Integrals of LTs. LT of Unit Step function, Dirac Delta function and Periodic Functions. Convolution Theorem. Inverse LT: Properties of inverse LT, Methods of finding inverse Laplace transforms. Solution of nonhomogeneous linear constant coefficient differential equations using LT.

Unit II **(14 Hours)**

Green's Function
Green's functions for one-dimensional problems (ODEs), construction of Green's function, Application of Green's function in initial and boundary value problems, Green's function for two and three dimensional problems (PDEs). Green's function for the Laplacian operator, Solution of Poisson's Equation in three dimensions using Green's function. Green's function for wave operator, solution of wave equation in (1+1) and (2+1) dimensions using Green's function. Solution of Diffusion Equation in (3+1) dimensions using Green's function.

Unit III **(8 Hours)**

Basics of Group Theory
Groups and properties of groups, Cayley table, Subgroups, cyclic group, centre of a group, Cosets of a subgroup. Lagrange Theorem (No derivation). Homomorphism and Isomorphism of groups, Normal and conjugate subgroups. Permutation group, Cayley Theorem (no proof). Matrix representation of groups.

Unit IV **(8 Hours)**

Continuous groups
Rotation group SO(2) and its representations. Unitary groups U(1), SU(2) and their Representations, Pauli matrices as SU(2) generators and their algebra. Application to angular momentum operators, spin systems and symmetry transformations in quantum mechanics.

REFERENCES

Essential Readings

1. Mathematical Methods for Physicists, H. J. Weber and G. B. Arfken, Elsevier (2010).
2. Mathematical Methods for Physics and Engineering, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge University Press (2006).
3. Mathematical Physics with Applications, Problems and Solutions, V. Balakrishan, Ane Books (2017).

4. Schaum's Outline of Theory and Problems of Laplace Transforms, Murray R. Spiegel, McGrawHill (2005).
5. An Introduction to Laplace Transform and Fourier Series, Phil Dyke, Springer Nature (2014).
6. https://math.libretexts.org/Bookshelves/Differential_Equations/Introduction_to_Partial_Differential_Equations_(Herman)/07%3A_Green's_Functions.
7. Green's Functions, G. F. Roach, Cambridge University Press (1992).
8. Green's Functions in Classical Physics, Tom Rother, Springer International Publishing (2017).
9. Group Theory and its Applications to Physical Problems, by Morton Hamermesh, Dover Publications (1989).
10. Elements of Group Theory for Physicists, by A. W. Joshi, John Wiley (1997).

Additional Readings

1. Mathematical Methods for Physicists: A Concise Introduction, Tai L. Chow, Cambridge University Press (2000).
2. Introduction to Mathematical Physics: Methods and Concepts, Chun Wa Wong, Oxford University Press (2012).
3. Green's Functions with Applications, Dean G. Duffy, Chapman & Hall/CRC (2001).
4. Advanced Engineering Mathematics with MATLAB, D.G. Duffy, CRC Press (2017).
5. Group Theory and Physics, S. Sternberg, Cambridge University Press (1994).
6. Group Theory and Quantum Mechanics, Michael Tinkham, Dover Publications (2003).
7. Lie Algebras in Particle Physics, H. Georgi, CRC Press (1999)

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DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 13
ADVANCED QUANTUM MECHANICS - I

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Advanced Quantum Mechanics-I DSE 13	4	3	1	0	Quantum Mechanics-I (DSC 14), Mathematical Physics III (DSC 7) or equivalent courses. Knowledge of Linear Algebra will be helpful.

COURSE OBJECTIVES

- Equips students with the mathematical tools enabling them for transition from concrete wavefunction-based methods to the general abstract formalism of non-relativistic quantum mechanics.
- Presents the full dynamical structure of quantum theory, including both Schrödinger and Heisenberg pictures of time evolution, and introduce the density matrix formalism for describing mixed and entangled states.
- Formally analyzes angular momentum in quantum mechanics, with an emphasis on operator methods, spin, and the addition of angular momentum using Clebsch–Gordan coefficients.

LEARNING OUTCOMES

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

- Appreciate the necessity of abstract state vector formalism and articulate the meaning of each postulate of quantum mechanics.
- Solve time-dependent problems using both Schrödinger and Heisenberg pictures.
- Understand and compute time evolution in both ket and operator formalisms.
- Construct and interpret density matrices for pure and mixed states.
- Use ladder operator techniques and commutation relations to solve angular momentum problems and analyse spin systems.
- Apply the Pauli exclusion principle in the context of multi-fermion systems.
- Determine the angular momentum of a composite state using the concept of addition of angular momentum and C.G. coefficients.

<u>SYLLABUS OF DSE 13</u>
<u>THEORY COMPONENT</u>
(Hours: 45)

Unit I **(13 Hours)**

Abstract formulation of Quantum Mechanics
Motivation for developing a linear vector space formulation to describe quantum phenomena. Brief review of linear vector spaces with Dirac's ket notation, Inner product and norm, Schwarz Inequality. Dual space and Bra vectors. Orthonormal basis. Infinite dimensional (discrete) vector space. Hilbert Space of state vectors. Completeness. Dynamical observables as linear operators, Adjoint of a linear operator, Hermitian or self-adjoint operators, eigenvalues and eigenvectors. Projection operator and complete set of basis. Matrix representation of state vectors and operators. Unitary operators and change of basis.

Unit II **(13 Hours)**

Postulates, Measurement and Observables
Postulates of quantum mechanics. Continuous basis, position and momentum representations. Degenerate eigenvalues and complete set of commuting observables. Generalized uncertainty principle.
Quantum Dynamics
Unitary time-evolution, Schr**ö**dinger equation in ket notation and correspondence with wave mechanics. Momentum as generator of translation in space and Hamiltonian as generator of translation in time. Schrödinger vs Heisenberg picture. Evolution of a system in Heisenberg picture with example of simple harmonic oscillator. Classical Limit.

Unit III **(12 Hours)**

Angular Momentum: Abstract operator approach to angular momentum, Commutation Relations. Ladder operators, Matrix representation of angular momentum operators and ladder operators, Eigenvalues and eigenvectors.
Pauli matrices and their properties. Matrix representation of Spin angular momentum operators. Eigenvalues, eigenvectors of $\boldsymbol{S^2}$ and $\boldsymbol{S_z}$ for spin1/2 and spin 1 systems and General spin state for these systems.
Addition of angular momentum: Clebsch-Gordan coefficients, C. G. coefficients of addition for j = (i) 1/2, 1/2; (ii)1/2, 1 and (iii) 1, 1 systems.

Unit IV **(7 Hours)**

Density matrix Formalism
Density operator and matrix, pure and mixed states, expectation value of an observable, time evolution of density matrix, Reduced density matrix for subsystems of a composite system with example of entangled spin-1/2 pair.
Identical particles: Many-particle systems, Exchange degeneracy, concept of parity, symmetric and anti-symmetric wavefunctions. Pauli exclusion principle.

REFERENCES

Essential Readings

1. Introduction to Quantum Mechanics, D.J. Griffith, Pearson Education (2005).
2. Principles of Quantum Mechanics by R. Shankar (Springer, 3rd Edition, 2008)
3. Quantum Mechanics, B. H. Bransden and C. J. Joachain, Prentice Hall (2000).
4. Modern Quantum Mechanics, J. J. Sakurai and Jim Napolitano, Cambridge University Press (2021).
5. Quantum Mechanics: Theory and Applications, Ajoy Ghatak and S. Lokanathan, Laxmi Publications (2019).

Additional Readings

1. Introduction to Quantum Mechanics, Volume-I and II, C. Cohen-Tannoudji
2. The Principles of Quantum Mechanics, P.A.M. Dirac, Clarendon Press, Oxford (1981).
3. A Text book of Quantum Mechanics, P.M. Mathews and K. Venkatesan, 2nd Ed., 2010, McGraw Hill.
4. Introduction to Quantum Mechanics, R. H. Dicke and J. P. Wittke, Addison-Wesley Publications, 1966.
5. Quantum Mechanics, Leonard I. Schiff, 3rd Edn. 2010, Tata McGraw Hill.
6. Quantum Mechanics, Eugene Merzbacher, 2004, John Wiley and Sons, Inc.
7. Quantum Mechanics, Walter Greiner, 4th Edn., 2001, Springer.
8. Introductory Quantum Mechanics, R. L. Liboff; 4th Ed., Addison Wesley, 2003.
9. Angular Momentum in Quantum Mechanics, A. R. Edmonds, Princeton University Press (1996).
10. Elementary Theory of Angular Momentum, M. E. Rose, Dover Publications Inc. (2003)

ADVISORY

The course, Advanced Quantum Mechanics-I, is essential for several courses offered in the one-year M.Sc. program and is also included in the syllabi of various competitive examinations, including CSIR-NET, JEST, and GATE.
Colleges are advised to offer this as a Discipline Specific Elective (DSE). Students who intend to pursue postgraduate studies or appear for competitive exams are strongly encouraged to choose this course as a DSE.

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DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 14
ATMOSPHERIC PHYSICS AND CLIMATE CHANGE

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Atmospheric Physics and Climate Change DSE 14	4	3	0	1	

COURSE OBJECTIVES

This course familiarizes the students with the atmospheric processes, and vertical thermal and dynamical features in the lower and middle atmosphere. It enables to learn remote sensing techniques to explore atmospheric processes and helps to understand long term oscillations and fluid system dynamics which control climate change. Also, it delineates characteristics of pollutants and aerosols variability in the lower and middle atmosphere. Another important aspect would be how the different atmospheric and meteorological parameters are changing over a period of time from Climate change perspective.

LEARNING OUTCOMES

By successfully completing this course students will be able to,

- Have an overview of thermal structure of the Earth's atmosphere as well as various dynamical processes occurring in different layers of the atmosphere.
- Develop an understanding of remote sensing techniques such as radar, satellite, and lidar systems.
- Understand the origin of different atmospheric oscillations, which are prominent at different altitudes. In addition, understating will be improved on several features of low- and high-pressure systems and wind circulation.
- Atmospheric and Ocean interaction can be learnt how they influence each other on long term time scales connected with such as El Niño Southern Oscillations (ENSO)
- Climate Change can be understood by using long term atmospheric data (both observations and model) and further exploring and utilization of different numerical techniques for the fine and long-term temporal and regional to global scales.
- Develop the problem-solving skills using observations and conducting simulations. This would clarify the fundamental processes and modifications under different conditions.

SYLLABUS OF DSE 14
THEORY COMPONENT
(Hours: 45)

Unit I **(10 Hours)**

General features of Earth's atmosphere
Thermal structure of the Earth's Atmosphere, Composition of atmosphere, Hydrostatic equation, Potential temperature, Atmospheric Thermodynamics, Greenhouse effect, Local winds, monsoons, fogs, clouds, precipitation, Atmospheric boundary layer, Sea breeze and land breeze. Instruments for meteorological observations including RS/RW, meteorological processes and convective systems, fronts, Cyclones and anticyclones, thunderstorms. Dynamics of Particulate Matter (PM), pollutants and meteorological parameters diurnal, seasonal and annual variability. PM and their effect on human health.

Unit II **(13 Hours)**

Atmospheric Dynamics
Scale analysis, Fundamental forces, Basic conservation laws, The Vectorial form of the momentum equation in rotating coordinate system, scale analysis of equation of motion, Applications of the basic equations, Circulations and vorticity, Atmospheric oscillations, Quasi biennial oscillation, annual and semi-annual oscillations, Mesoscale and general circulations.
Atmospheric Waves
Surface water waves, wave dispersion, acoustic waves, buoyancy waves, propagation of atmospheric gravity waves (AGWs) in a nonhomogeneous medium, Lamb wave, Rossby waves and its propagation in three dimensions and in sheared flow, wave absorption, non-linear consideration.

Unit III **(7 Hours)**

Remote Sensing Techniques (Atmospheric Radar)
Radar equation and return signal, Signal processing and detection, Various type of atmospheric radars, Applications of radars to study atmospheric phenomena, Classification and properties of aerosols, Aerosol studies using Lidars.

Unit IV **(15 Hours)**

Climate Change
Historical trends of CO_2 and temperature, understanding on sea level rise. Thermodynamics in climatology, long term energy balance and cycles, and rudimentary introduction to climate change models. Physical processes of greenhouse gases warming the planet, Impact of climate change in extreme weather, regional case studies focus on India subcontinent, Climate policies and international agreement - UNFCCC, Kyoto Protocol, Paris Agreement, Role of COP meetings, Concept of Net-Zero Emission, and Climate Change and public health.

PRACTICAL COMPONENT: ATMOPHERIC PHYSICS AND CLIMATE CHANGE (Hours: 30)

Atmospheric Physics: Scilab/Python/Matlab based simulations experiments based on Atmospheric Physics problems listed below.
At least 03 Experiments from the following should be conducted.

1. Numerical Simulation for atmospheric waves using dispersion relations for
   a. Atmospheric gravity waves (AGW)
   b. Kelvin waves
   c. Rossby waves, and
   d. mountain waves.
2. Processing of radar data a. VHF radar, b. X-band radar, and c. UHF radar,
3. Offline and online processing of LIDAR data.
4. Radiosonde data and its interpretation in terms of atmospheric parameters using vertical profiles in different regions of the globe. Suggested parameters calculations are (i) Brunt Vaisala frequency, (ii) potential temperature, (iii) pressure-height conversion, and (iv) thermal wind equation.
5. Handling of satellite data and plotting of atmospheric parameters using radio occultation technique

Climate Change

i. Time series analysis of temperature using long term data over metropolitan cities in India – an approach to understand the climate change.
ii. PM 2.5 measurement using compact instruments and experience with data from CPCB and DPCC to investigate the Climate Change.

Field visits to National centre for medium range weather forecasting, India meteorological departments, and ARIES Nainital to visualise onsite radiosonde balloon launch, simulation on computers and radar operations on real time basis.

REFERENCES

Essential Readings for the Theory Component

1. Fundamental of Atmospheric Physics, M.L Salby; Academic Press, Vol 61, 1996
2. The Physics of Atmosphere – John T. Houghton; Cambridge University press; 3 rd edn. 2002.
3. An Introduction to dynamic meteorology – James R Holton; Academic Press, 2004
4. Radar for meteorological and atmospheric observations – S Fukao and K Hamazu, Springer Japan, 2014

Additional Readings for the Theory Component

1. Stratosphere Troposphere Interactions - K Mohanakumar, Springer Netherlands, 2008.
2. Climate change in the Himalayas, Springer publication, by GB Pant, P Pradeep Kumar, J V Revadekar, Narendra Singh, 2018.
3. PM2.5 diminution and haze events over Delhi during the COVID-19 lockdown period: an interplay between the baseline pollution and meteorology, Nature- Scientific Reports, 10(13442). https://doi.org/10.1038/s41598- 020-70179-8., S. K. Dhaka,

Chetna, V. Kumar, V. Panwar, A. P. Dimri, N. Singh, P. K. Patra, Y. Matsumi, M. Takigawa, and T. Nakayama (2020)

4. Gravity wave generation in the lower stratosphere due to passage of the typhoon 9426 (Orchid) observed by the MU radar at Shigaraki (34.85 N, 136.10 E), SK Dhaka, M Takahashi, Y. Shibagaki, MD Yamanaka, S Fukao, Journal of Geophysical Research: Atmosphere 108 (D19), 2003.
5. Indian MST radar observations of gravity wave activities associated with tropical convection, SK Dhaka, PK Devrajan, Y Shibagaki, RK Choudhary, S Fukao, Journal of Atmospheric and Solar-Terrestrial Physics 63 (15), 1631-1642.
6. Lidar and its applications, Application of Lidar to study atmospheric phenomenon. Data analysis tools and techniques (https://www.narl.gov.in)

References for the Practical Component

Data sources for radar, lidar, satellite and radiosondes

1. https://www.narl.gov.in
2. http://www.imd.gov.in
3. https://www.ncmrwf.gov.in/
4. https://www.aries.res.in/
5. http://www.rish.kyoto-u.ac.jp/ear/index-e.html

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 15 NANOSCIENCE

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Nanoscience DSE 15	4	2	0	2	

COURSE OBJECTIVES

The syllabus introduces the basic concepts of nanomaterials, their synthesis, properties exhibited by them and finally few applications. Various nanomaterial synthesis/growth methods and characterizations techniques are discussed to explore the field in detail. The effect of dimensional confinement of charge carries on the electrical, optical and structural properties will be discussed. Interesting experiments which shape this filed like conductance quantization in 2DEG (Integer Quantum Hall Effect) and coulomb blockade are introduced. The concept of micro- and nano- electro mechanical systems (MEMS and NEMS) and important applications areas of nanomaterials are discussed.

LEARNING OUTCOMES

On successful completion of the course students should be able to

- Explain the difference between nanomaterials and bulk materials and their property difference.
- Explain various methods for the synthesis/growth of nanomaterials.
- Explain the role of confinement on the density of state function and so on the various properties exhibited by nanomaterials compared to bulk materials.
- Explain the concept of Quasi-particles such as excitons and how they influence the optical properties.
- Explain the direct and indirect bandgap semiconductors, radiative and non-radiative processes and the concept of luminescence.
- Explain the structure of 2DEG system and its importance in quantum transport experiments, like Interger Quantum Hall Effect and conductance quantization.
- Explain the conductance quantization in 1D structure and its difference from the 2DEG system.
- Explain the necessary and sufficient conditions required to observe coulomb blockade, single electron transistor and the scope of these devices.
- Explain how MEMS and NEMS devices are produced and their applications.

SYLLABUS OF DSE 15
THEORY COMPONENT
(Hours: 30)

Unit I **(11 Hours)**

Introduction
Basic Introduction to Nano-Science and Technology - Implications on nanoscience on fields like Physics, Chemistry, Biology and Engineering, Classifications of nanostructured materials as quantum dots (0D), nanowires (1D), Thin films (2D) and Multi-layered materials or super lattices. Introduction to properties like Mechanical, Electronic, Optical, Magnetic and Thermal properties and how they change at Nano scale dimensions to motivate students (qualitative only).
Nanoscale Systems
Brief review of Schrodinger equation and its applications in- Infinite potential well, potential step and potential box problems, Band Structure and Density of states of 3D and 2D systems in detail and qualitatively for 1D and 0D, confinement of charges in nanostructures their consequences on electronic and optical properties.

Unit II **(10 Hours)**

Properties of Nano Scale systems
Time and length scales (diffusion, elastic and inelastic lengths etc.) of electrons in nanostructured materials, Carrier transport in nanostructures: diffusive and ballistic transport.
2D nanomaterials: Conductance quantization in 2DEG in GaAs and integer quantum hall effect (semi-classical treatment)
1D nanomaterials: Conductance quantization in 1D structures using split gate in 2DEG system (Qualitative).
0D nanomaterials: Charging effect, Coulomb Blockade effect, Single Electron Transfer (SET) device.
Basic understanding of excitons in semiconductors and their consequence on optical properties of the material

Unit III **(5 Hours)**

Synthesis of Nanomaterials (Qualitative)
Top-down and Bottom-up approach, Ball milling, Spin Coating
Vacuum deposition: Physical vapor deposition (PVD): Thermal evaporation, Sputtering, Chemical vapor deposition (CVD). Preparation of colloidal solutions of Metals, Metal Oxide nanoparticles

Unit IV **(4 Hours)**

Applications (Qualitative)
Micro Electromechanical Systems (MEMS), Nanoelectromehanical Systems (NEMS). Applications of nanomaterials as probes in medical diagnostics and targeted drug delivery, sunscreen, lotions, and paints and other examples to give broader perspective of applications of nanomaterials.

PRACTICAL COMPONENT: NANOSCIENCE
(Hours: 60)

At least 06 experiments from the following:

1. Synthesis of metal (e.g. Ag) nanoparticles by chemical route and study its optical absorption properties.
2. Synthesis of semiconductor ($CdS/ZnO/TiO_2/Fe_2O_3$ etc) nanoparticles and study its Optical Absorption properties as a function of ageing time.
3. Surface Plasmon study of metal nanoparticles as a function of size by UV-Visible spectrophotometer.
4. Analysis of XRD pattern of given nanomaterial and estimate lattice parameters and particle size.
5. To study the effect of the size nanoparticles on its color.
6. To prepare composite of CNTs with other materials and study their optical absorption/Transmission properties.
7. Growth of metallic thin films using thermal evaporation technique.
8. Prepare a ceramic disc of a given compound and study its I-V characteristics, measure its dielectric constant or any other property.
9. Fabricate a thin film of nanoparticles by spin coating (or chemical route) and study its transmittance spectra in UV-Visible region.
10. Prepare thin film capacitor and measure capacitance as a function of temperature or frequency.
11. Fabricate a PN junction diode by diffusing Al over the surface of N-type Si/Ge and study its V-I characteristic.
12. Fabricate thin films (polymer, metal oxide) using electro-deposition
13. To study variation of resistivity or sheet resistance with temperature of the fabricated thin films using four probe method.

REFERENCES

Essential Readings for the Theory Component

1. C.P. Poole, Jr. Frank J. Owens, Introduction to Nanotechnology 1st edition (2003) Wiley India Pvt. Ltd..
2. S.K. Kulkarni, Nanotechnology: Principles & Practices 2nd edition (2011) (Capital Publishing Company)
3. K. K. Chattopadhyay and A. N. Banerjee, Introduction to Nanoscience and Technology (2009) (PHI Learning Private Limited).
4. Introduction to Nanoelectronics, V. V. Mitin, V.A. Kochelap and M.A. Stroscio,2011, Cambridge University Press.
5. Richard Booker, Earl Boysen, Nanotechnology for Dummies (2005) (Wiley Publishing Inc.).
6. Introductory Nanoscience by Masaru Kuno, (2012) Garland science Taylor and Francis Group

7. Electronic transport in mesoscopic systems by Supriyo Datta (1997) Cambridge University Press.
8. Fundamentals of molecular spectroscopy by C. N. Banwell and E. M. McCASH, 4th edition, McGrawHill.

Additional Readings for the Theory Component

1. Quantum Transport in semiconductor nanostructures by Carla Beenakker and HenK Van Houten (1991) (available at arXiv: cond-mat/0412664) Open Source
2. Sara Cronewett Ph.D. thesis (2001) for extra reading (Available as Arxiv).
3. Solid State Physics by J. R. Hall and H. E. Hall, 2nd edition (2014) Wiley

References for the Practical Component

1. C.P. Poole, Jr. Frank J. Owens, Introduction to Nanotechnology 1st edition (2003) Wiley India Pvt. Ltd..
2. S. K. Kulkarni, Nanotechnology: Principles & Practices 2nd edition (2011) (Capital Publishing Company)
3. K. K. Chattopadhyay and A. N. Banerjee, Introduction to Nanoscience and Technology (2009) (PHI Learning Private Limited).
4. Richard Booker, Earl Boysen, Nanotechnology for Dummies (2005) (Wiley Publishing Inc.).

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 16
NUCLEAR AND PARTICLE DETECTORS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Nuclear and Particle Detectors DSE 16	4	3	1	0	

COURSE OBJECTIVES

This course introduces students to the principles and applications of detectors used in various fields of Physics, including Particle physics, Astrophysics, Nuclear physics and Medical physics. The course covers the theory of detectors, their design and operation including electronic readout systems and signal processing.

LEARNING OUTCOMES

- To understand the different types of detectors used in physics experiments.
- To learn the design construction and operation of detectors.
- To acquire knowledge of electronic readout systems and signal processing.
- To apply the principles of detectors in solving problems in various fields of physics.

SYLLABUS OF DSE 16
THEORY COMPONENT
(Hours: 45)

Unit I **(11 Hours)**

Interaction of Nuclear Radiation with matter
Interaction of radiation for light ions (electrons) and heavy charge particles, neutron and photons with matter. Energy loss due to ionization (Bethe-Block formula), for both light and heavy -ions, Cerenkov radiation. Gamma ray interaction with matter. Neutron interaction with matter.

Introduction to detectors
Definition of detectors, various types of detectors and their classification. Basic principle of detector operation and its modes of operation, pulse height spectra, various detector performance parameters: response time, energy resolution, fano factor, efficiency: intrinsic and extrinsic, dead time.

Unit II **(18 Hours)**

Gas detectors: Detector gases, gas detector characteristics, Different types of detectors: gas filled ionization detectors, proportional counters, multi wire proportional counters (MWPC), Geiger Mueller (GM) counters and Avalanche counters, gaseous multiplication detector.
Scintillation detectors: general characteristics, organic scintillators, inorganics crystals, intrinsic detection efficiency for various radiations. Photomultipliers: basic construction and operation, time response and resolution, noise, gain stability. Scintillation counter operation.
Semiconductor detectors:
Doped semiconductors, np semiconductor junction, depletion depth, detector characteristics of semiconductors. Types of semiconductor detectors with their principle of working: silicon diode detectors, Silicon strip detectors, silicon drift detectors, avalanche photodiodes, germanium detectors, other semiconductor materials.
Neutron detectors: slow neutron detectors: BF3 proportional counter, Boron Loaded scintillators, slow neutron detectors with Lithium. Fast neutron detectors

Unit III **(10 Hours)**

Electronics, signal processing and techniques for data acquisition and analysis
Basic idea of analog and digital signal processing, noise and its types. Instrumentation standards for Nuclear Instruments: NIM, ECL. TTL standards.
Electronics for energy spectroscopy: detector bias supply, preamplifiers, amplifiers, pulse amplitude discriminators, Single channel analyser, Scalers Counters and Timers.
Electronics for Timing with detectors: Timing Filter Amplifier (TFA), Timing single channel Analyser (TSCA), Gate and Delay Generator (GDG).
Electronics for position determination.
Data acquisition system: VME and Digital pulse processing system.

Unit IV **(6 Hours)**

Application of detectors
Application of detectors (two examples each): for nuclear and particle physics experiments, for astrophysics, for medical physics and imaging.

REFERENCES

1. Radiation detection and measurement: G F Knoll, John Wiley & Sons, 2010.
2. Techniques for Nuclear and Particle Physics experiments by WR Leo, Springer, 1994.
3. Nuclear Radiation Detectors: S. S. Kapoor, V. S. Ramamurthy. 1st Edition, John Wiley & Sons.
4. Physics and Engineering of Radiation Detection: S N Ahmed, Academic Press Elsevier, 2007.
5. Semiconductor Detectors: New Developments, E. Gatti and P. Rehak. 2002. Springer.
6. Principles of radiation interaction in matter and detection: C. Leroy and P.G. Rancoita. 3rd ed. World scientific.
7. Radiation Detection for Nuclear Physics Methods and industrial applications: D. Jenkins.

8. Advanced Nuclear Radiation Detectors Materials, processing, properties and applications: Ashok K Batra. IOP Publishing.
9. Measurement and Detection of Radiation: Nicholas Tsoulfanidis Et Al, Fourth Edition, T and F CRC.
10. Principles of nuclear radiation detection: Geoffrey G. Eichholz, John W, Poston. CRC group of publishers.
11. Introduction to Nuclear Radiation Detectors: 2 (Laboratory Instrumentation and Techniques) P. Ouseph, Springer.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 11
RESEARCH METHODOLOGY

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Research Methodology DSE 11	4	3	0	1	Basic ICT related skills

COURSE OBJECTIVES

This course has been designed to explore the basic dimensions of research and to impart quantitative and qualitative knowledge for conducting meaningful research. Starting from the philosophy of research, through awareness about the publication ethics and misconducts, this course covers all the methodological and conceptual issues required for a successful conduct of research. It gives an overview of research techniques, data management and analysis, and commonly used statistical methods in physical sciences.

LEARNING OUTCOMES

After successful completion of this course, students will be trained in the following.

- Skills to review literature and frame research problem.
- Comprehend the relevance of the tools for data collection and analysis.
- Writing a scientific report/research proposal.
- Software tools for research in physical sciences.
- Research integrity and publication ethics.
- Importance of intellectual property rights.
- Role of funding agencies in research.

SYLLABUS OF DSE 11
THEORY COMPONENTS
(Hours: 45)

Unit I **(6 Hours)**

Introduction to research methodology
Brief history of scientific method and research, role and objectives of research, basic tenets of qualitative research; research problem and review of literature: identifying a research problem (philosophy and meaning of research, identification and definition of research problem, formulation of research problem, sources of prejudice and bias); literature survey

(open-source and paid tools for keeping track of the literature)

Unit II **(15 Hours)**

Data collection, analysis and interpretation

Methods of data collection: survey, interview, observation, experimentation and case study; Descriptive statistics: Measures of central tendency (mean, median, mode) and dispersion (range, standard deviation).

Inferential statistics: Hypothesis testing, Z test, T test; regression analysis (basic concepts of multiple linear regression analysis and theory of attributes).

Curve fitting using linear and nonlinear regression (parameter space, gradient search method and Marquardt method).

Role of simulation, calibration methods, error analysis, and background handling in experimental design.

Unit III **(7 Hours)**

Journals, Database and Research Metrics

Journals: Free, open source and paid journals, concept of peer reviewed journals, predatory and fake journals.

Databases: Indexing databases; citation databases (Web of science, Scopus); experimental physics databases (astrophysics (ADS, NED, SIMBAD, VizieR), biophysics (PubMed), particle physics (INSPIRE, CDS), condensed matter physics (X-ray database))

Research Metrics: Journal impact factor, SNIP, SJR, IPP, cite score; metrics (h-index, g index, i10 index, altmetrics), variations in research metrics across various disciplines, other limitations of the research metrics and impact factors

Unit IV **(8 Hours)**

Scientific Conduct and Publication Ethics

Current understanding of ethics; intellectual honesty and research integrity; communicating errors (erratum, correction and withdrawal); records and logs (maintaining records of samples, raw data, experimental protocols, observation logs, analysis calculations, and codes); scientific publication misconducts: plagiarism (concept, importance, methods and ways to detect and avoid plagiarism) and redundant publications (salami slicing, duplicate and overlapping publications, selective reporting and misrepresentation of data); environmental and other clearances (waste management, disposal of hazardous waste).

COPE guidelines on best practices in publication ethics

Unit V **(5 Hours)**

Scientific Writing and Software Tools

Writing a research paper and report: introduction, motivation, scientific problem, its methodology, any experimental set up, data analysis, discussion of results, conclusions

Referencing formats (APA, MLA) and bibliography management

Graphical software (open source, magic plot, gnu plot, origin); presentation tools (beamer)

Unit VI **(4 Hours)**

Intellectual Property Right and Research Funding
Basic concepts and types of intellectual property (patent, copyright and trademark)
Role of funding agencies in research, overview of various funding agencies (DST-SERB, UGC, CSIR, BRNS, DRDO), national and international research project grants and fellowships

PRACTICAL COMPONENT: RESEARCH METHODOLOGY
(Hours: 30)

Students should perform at least 6 experiments from the following list, such that all the units mentioned below are covered.

Unit 1:
1. Identify a research problem, write its brief summary and make a corresponding flow chart
2. Identify a survey-based research problem in physics and create a questionnaire to collect data to perform meaningful research.
3. Write a literature review for a research problem.
4. Create a list of research topics (at least three) and read at least one research paper in each topic.

Unit 2:
1. Attend a research seminar and write a brief summary in 1000 words. Check the extent of plagiarism in this summary by using on-line plagiarism detection tools
2. Read a research paper based on the use of statistics in experimental physics and summarise its importance.
3. Collect publicly available experimental physics data. Identify the independent, dependent and control variables. Fit at least two mathematical models that can describe the data and compare their statistical significance.

Unit 3:
1. Review any three research papers.
   a. List the major strengths and weakness of all of them.
   b. For any one of these, create a referee report assuming you are a reviewer of the paper. Also draft a response to the referee's report assuming you are the author.
2. Review any research paper. Rewrite it as if the work has been done by you for the first time. Use two different referencing and bibliography styles

Unit 4:
1. Take data from any publicly available experimental physics database. Use Microsoft Office tools (such as chart/bar diagrams, equation editor etc. in Word, PowerPoint or Excel) to present, plot and infer relevant information from the data.
2. Write a scientific synopsis of a research paper using LaTeX.
3. Create a presentation using LaTeX and Beamer on any research topic
4. Select a funding agency and any two schemes or fellowships offered by them.

Make a report (using LaTeX) describing the objectives, areas of research support and various components of grants offered by them.

REFERENCES

Essential Readings

1) Management Research Methodology, K. N. Krishnaswamy, A. I. Sivakumar, M. Mathirajan, 2006, Pearson Education, New Delhi.
2) Research Methodology, Methods and Techniques, C. R. Kothari, 2nd edition, 2008, New Age International Publication.
3) Research Methodology, A step by step guide for beginners, R. Kumar, 6th edition, 2009, Pearson Education
4) Data reduction and error analysis for the physical sciences, P. R. Bevington and D. K. Robinson, 3rd edition, McGraw-Hill
5) Intellectual property: Patents, Trademarks, Copyrights, Trade Secrets, C. J. Holland, 2007, Entrepreneur Press

Additional Readings

1) Research Methods, R. Ahuja, 2001, Rawat Publications, New Delhi.
2) Research design: Qualitative, quantitative, and mixed methods approaches, J. W. Creswell, and J. D. Creswell, 2017, Sage Publications.
3) Intellectual Property: Patents, Trademarks and Copyright in a Nutshell, A. R. Miller and M. H. Davis, 2000, West Group Publishers

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 17 SEMICONDUCTOR DEVICES - FABRICATION AND APPLICATIONS

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Semiconductor Devices - Fabrication and Applications DSE 17	4	2	0	2	

COURSE OBJECTIVES

- This course provides a review of basics of semiconductors such as energy bands, doping, defects etc. and introduces students to various semiconductor and memory devices.
- Thin film growth techniques and processes including various vacuum pumps, sputtering, evaporation, oxidation and VLSI processing are described in detail.
- By the end of the syllabus, students will have an understanding of MEMS based transducers.

LEARNING OUTCOMES

At the end of this course, students will be able to achieve the following learning outcomes:

- Learn to distinguish between single crystal, polycrystalline and amorphous materials based on their structural morphology and learn about the growth of single crystals of silicon, using Czochralski technique, on which a present day electronics and IT revolution is based. Students will understand about the various techniques of thin film growth and processes.
- Appreciate the various VLSI fabrication technologies and learn to design the basic fabrication process of R, C, P- N Junction diode, BJT, JFET, MESFET, MOS, NMOS, PMOS and CMOS technology.
- Gain basic knowledge on overview of MEMS (MicroElectro-Mechanical System) and MEMS based transducers.

SYLLABUS OF DSE 17
THEORY COMPONENT
(Hours: 30)

Unit I **(9 Hours)**

Introduction: Review of energy bands in materials. Metal, Semiconductor and Insulator. Doping in Semiconductors, Defects: Point, Line, Schottky and Frenkel. Single Crystal, Polycrystalline and Amorphous Materials. Czochralski technique for Silicon Single Crystal Growth. Silicon Wafer Slicing and Polishing.

Vacuum Pumps: Primary Pump (Mechanical) and Secondary Pumps (Diffusion, Turbomolecular, Cryopump, Sputter - Ion)– basic working principle, Throughput and Characteristics in reference to Pump Selection. Vacuum Gauges (Pirani and Penning).

Unit II **(10 Hours)**

Thin Film Growth Techniques and Processes: Sputtering, Evaporation (Thermal, electronBeam), Pulse Laser Deposition (PLD), Chemical Vapor Deposition (CVD). Epitaxial Growth.
Thermal Oxidation Process (Dry and Wet) Passivation. Metallization. Diffusion.

Unit III **(7 Hours)**

VLSI Processing: Clean Room Classification, Line width, Photolithography: Resolution and Process, Positive and Negative Shadow Masks, Photoresist, Step Coverage, Developer. Electron Beam Lithography. Etching: Wet Etching. Dry etching (RIE and DRIE). Basic Fabrication Process of R, C, P-N Junction diode, BJT, JFET, MESFET, MOS, NMOS, PMOS and CMOS technology. Wafer Bonding, Wafer Cutting, Wire bonding and Packaging issues (Qualitative idea).

Unit IV **(4 Hours)**

Micro Electro-Mechanical System (MEMS): Introduction to MEMS, Materials selection for MEMS Devices, Selection of Etchants, Surface and Bulk Micromachining, Sacrificial Subtractive Processes, Additive Processes, Cantilever, Membranes. General Idea MEMS based Pressure, Force, and Capacitance Transducers.

PRACTICAL COMPONENT: SEMICONDUCTOR DEVICES - FABRICATION AND APPLICATIONS
(Hours: 60)

At least 06 experiments from the following:

1. Fabrication of thin films via dip-coating technique, deposition of metal contacts through thermal evaporation and investigation of their current–voltage (I–V) characteristics.
2. Fabrication of thin films via spin-coating technique, deposition of metal contacts through thermal evaporation and investigation of their current–voltage (I–V) characteristics
3. Fabrication of p-n junction using either p or n type substrate along with appropriate semiconducting layer and study its current-voltage (I-V) Characteristics.
4. Generation of vacuum in small tubes (varying volumes) using a mechanical rotary pump and measurement of pressure using vacuum gauges.
5. Selective etching of Different Metallic thin films using suitable etchants of different concentrations.
6. Wet chemical etching of Si for Micro-Electro-Mechanical Systems (MEMS) applications using different concentrations of etchant.
7. Calibrate semiconductor type temperature sensor (AD590, LM 35, LM 75).

8. To measure the resistivity of a germanium (Ge) semiconductor crystal with temperature (up to 150 ºC) by four-probe method.
9. Capacitance measurements of ceramics using LCR meter.
10. Capacitance measurements of dielectric thin film capacitor using LCR meter

REFERENCES

Essential Readings for the Theory Component

1. Physics of Semiconductor Devices, S. M. Sze. Wiley-Interscience.
2. Fundamentals of Semiconductor Fabrication, S.M. Sze and G. S. May, John-Wiley and Sons, Inc.
3. Introduction to Semiconductor materials and Devices, M. S. Tyagi, John Wiley & Sons VLSI Fabrication Principles (Si and GaAs), S. K. Gandhi, John Wiley & Sons, Inc.

Additional Readings for the Theory Component

Handbook of Thin Film Technology, Leon I. Maissel and Reinhard Glang.

References for the Practical Component

1. The science and Engineering of Microelectronics Fabrication, Stephen A. Champbell, 2010, Oxford University Press.
2. Introduction to Semiconductor Devices, Kelvin F.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC CORE COURSE – DSC 20: ELECTRODYNAMICS

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Electrodynamics DSC 20	4	3	1	0	Vector calculus, Maxwell's equations, and basic Special Relativity

COURSE OBJECTIVES

This course provides a rigorous understanding of the behavior of charges and electromagnetic fields, motion in fields, and the fundamentals of radiation. Students will gain both theoretical insight and computational tools needed in advanced physics.

LEARNING OUTCOMES

After completing this course, students will be able to:

- Apply Maxwell's equations in relativistic contexts.
- Analyze the motion of charged particles in different electromagnetic field configurations.
- Understand and compute radiation fields from various charge-current distributions.
- Use covariant and Lagrangian formulations to express electrodynamics compactly.
- Solve applied problems related to electromagnetic radiation and antenna theory.

SYLLABUS OF DSC 20
THEORY COMPONENT
(Hours: 45)

Unit I **(15 Hours)**

Review of Maxwell's equations, scalar and vector potentials, gauge transformations, Coulomb and Lorentz gauges. Lorentz transformations in 4-vectors notation. Transformation of electric and magnetic fields.
EM field tensor: Construction and interpretation of $F^{\mu\nu}$, Covariance form of Maxwell's equations. Lorentz invariants $E^2 - B^2$ and $\vec{E}.\vec{B}$.

Unit II **(8 Hours)**

Lorentz force in relativistic form. Charged particle trajectories in static electric and magnetic fields. Crossed **E** and **B** fields, guiding center approximation: Velocity and curvature drifts.

Unit III **(14 Hours)**

Green's function for wave equation, retarded potentials using Green's function. Radiation from oscillating charges, radiation zones. Multipole expansion: dipole and quadrupole. Lienard - Wiechert potentials, Lienard's and Larmor's formulas. Angular distribution of radiation. Centre-fed linear antennas.

Unit IV **(8 Hours)**

Lagrangian for free relativistic particles. Systems with infinite degrees of freedom: Classical fields. Lagrangian for charged particles in EM fields and free EM fields. Energy-momentum tensor and conservation laws.

REFERENCES

Essential Readings

1. D.J. Griffiths and D.F. Schroeter, Introduction to Electrodynamics, 4th Edition, Cambridge University Press, 2017.
2. J.D. Jackson, Classical Electrodynamics, 3rd Edition, Wiley, 1998.
3. L.D. Landau and E.M. Lifshitz, The Classical Theory of Fields, Course of Theoretical Physics Vol. 2, 4th Edition, Butterworth-Heinemann (Pergamon), 1975.
4. P. Lorrain and D.R. Corson, Electromagnetic Fields and Waves, 3rd Edition, W.H. Freeman and Company, 1988.
5. C.A. Brau, Modern Problems in Classical Electrodynamics, Oxford University Press, 2004.

Additional Readings

1. M. Schwartz, Principles of Electrodynamics, Dover Publications, 1987.
2. Julian Schwinger, L.L. DeRaad Jr., K.A. Milton, W.-Y. Tsai, Classical Electrodynamics, Westview Press, 1998.
3. L.D. Landau, E.M. Lifshitz, and L.P. Pitaevskii, Electrodynamics of Continuous Media, 2nd Edition, Course of Theoretical Physics Vol. 8, Butterworth-Heinemann, 1984.
4. J.R. Reitz, F.J. Milford, R.W. Christy, Foundations of Electromagnetic Theory, 4th Edition, Addison-Wesley, 1992.
5. A. Zangwill, Modern Electrodynamics, Cambridge University Press, 2013.
6. Jerrold Franklin, Classical Electromagnetism, Addison-Wesley, 2005.
7. J. Panofsky and M. Phillips, Classical Electricity and Magnetism, 2nd Edition, Dover Publications, 2005.
8. Mark A. Heald and Jerry B. Marion, Classical Electromagnetic Radiation, 3rd Edition, Dover Publications, 2012.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 18: ADVANCED QUANTUM MECHANICS - II

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Advanced Quantum Mechanics-II DSE 18	4	3	1	0	Quantum Mechanics (DSC 14), and Advanced Quantum Mechanics-I (DSE 13)

COURSE OBJECTIVES

This course aims to:

- Introduce and develop approximation methods for solving quantum systems where exact solutions are not possible, including both time-independent and time-dependent approaches.
- Strengthen understanding of the interaction picture and its role in quantum dynamics.
- Equip students with the tools of scattering theory, including formal techniques like the Lippmann–Schwinger equation, Green’s functions, and the Born approximation.
- Provide a conceptual and mathematical foundation for advanced topics in quantum physics such as quantum field theory, quantum optics, and condensed matter physics.

LEARNING OUTCOMES

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

- Apply key approximation methods including time-independent perturbation theory, and the variational method to compute approximate energy levels and wavefunctions in stationary quantum systems.
- Analyze quantum systems under time-dependent perturbations using the interaction picture, derive transition probabilities, and apply Fermi’s Golden Rule to systems with a continuum of final states.
- Formulate and solve quantum scattering problems using ket formalism, Lippmann–Schwinger equations, and the Born approximation.
- Perform partial wave analysis and interpret scattering processes through phase shifts, S-matrix properties, and the optical theorem.

SYLLABUS OF DSE 18
THEORY COMPONENT
(Hours: 45)

Unit I **(14 Hours)**

Approximation Methods for Stationary Systems
Time-independent perturbation theory up to second order perturbation for non- degenerate case with applications to perturbed potential wells, linear harmonic oscillator with perturbed force constant ($k \rightarrow (1 + \varepsilon)k$), charged harmonic oscillator in a weak electric field. First order perturbation for anharmonic oscillator with cubic and quartic terms.
Degenerate systems with application to spin-orbit coupling and fine structure of hydrogenic atom, Zeeman effect (weak and strong field).
Variational method and its applications to ground state of simple harmonic oscillator and Helium atom, electron interaction energy and extension of variational method to excited states.

Unit II **(14 Hours)**

Approximation Methods for time-dependent perturbations
Interaction picture. Time-dependent perturbation theory (up to first order perturbation). Transition probabilities, transition to a continuum of final states, Fermi's Golden Rule. Application to constant and harmonic perturbations. Sudden and adiabatic approximations

Unit III **(10 Hours)**

Scattering: Wave packet description of scattering, scattering amplitude, differential and total cross section. Lippmann-Schwinger Equations, Formal treatment of scattering by Green's function method. Born approximation and applications to central potentials. Definition and properties of S-Matrix.

Unit IV **(7 Hours)**

Partial wave analysis: Asymptotic behaviour of partial waves, Phase shifts and angular momentum decomposition, Optical theorem and conservation of probability.

REFERENCES

Essential Readings

1. *Introduction to Quantum Mechanics*, D.J. Griffith, Pearson Education (2005).
2. *Modern Quantum Mechanics*, J. J. Sakurai and Jim Napolitano, Cambridge University Press (2021).
3. *Quantum Mechanics,* Eugene Merzbacher, John Wiley and Sons, Inc (2004).
4. *Quantum Mechanics: Theory and Applications*, Ajoy Ghatak and S. Lokanathan, Laxmi Publications (2019).
5. *Quantum Mechanics,* B. H. Bransden and C. J. Joachain, Prentice Hall (2000).

Additional Readings

11. *Principles of Quantum Mechanics*, R. Shankar, Springer (2008).

12. *Introduction to Quantum Mechanics*, Volume-I and II, C. Cohen-Tannoudji, Bernard Diu, and Franck Laloë, Wiley-VCH (2020).
13. *Introduction to Quantum Mechanics*, R. H. Dicke and J. P. Wittke, Addison-Wesley Publications (1966).
14. *Quantum Mechanics*, Leonard I. Schiff, Tata McGraw Hill (2010).
15. *Quantum Mechanics*, Walter Greiner, Springer (2001).
16. *Quantum Mechanics*, Albert Messiah, Dover Publications Inc. (2014)
17. *Scattering Theory of Waves and Particles*, R. G. Newton, Springer-Verlag Berlin and Heidelberg GmbH & Co. (2014

ADVISORY

The course, Advanced Quantum Mechanics-II, is essential for several courses offered in the one-year M.Sc. program and is also included in the syllabi of various competitive examinations, including CSIR-NET, JEST, and GATE.
Colleges are advised to offer this as a Discipline Specific Elective (DSE). Students who intend to pursue postgraduate studies or appear for competitive exams are strongly encouraged to choose this course as a DSE.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 19: ADVANCED STATISTICAL MECHANICS

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Advanced Statistical Mechanics DSE 19	4	3	1	0	

COURSE OBJECTIVES

- To introduce the fundamental principles and mathematical framework of statistical mechanics.
- To understand the concept of ensembles (microcanonical, canonical, and grand canonical) and their application to physical systems.
- To introduce quantum statistical concepts such as the density matrix and its applications.
- To introduce basic concepts of interacting system with the Ising model

This course provides a strong foundation for advanced study in theoretical and applied physics, and prepares students for research or technical roles in fields involving thermodynamic systems, statistical modelling and complex systems.

LEARNING OUTCOMES

Upon successful completion of this course, students will be able to:

- Understand fundamental concepts and principles of statistical mechanics including macrostates, microstates, and phase space, and their significance in describing physical systems.
- Formulate the microcanonical ensemble and apply it to model systems such as classical and quantum harmonic oscillators and ideal gases.
- Explain the grand canonical ensemble, including equilibrium with a particle-energy reservoir.
- Establish the relationship between canonical and grand canonical partition functions and use them to evaluate thermodynamic properties of systems with variable particle numbers.
- Describe the basic principles of quantum statistical mechanics including the concept of quantum ensembles and density matrix
- Describe basic principles of statistical mechanics of interacting systems with the help of Ising model

SYLLABUS OF DSE 19
THEORY COMPONENT
(Hours: 45)

Unit I **(8 hours)**

Review of Microcanonical and Canonical Ensembles
Macrostates, microstates, phase space, microcanonical ensemble (no derivation), partition function and its use in finding various thermodynamic quantities (no derivation). Examples of systems with finite and infinite energy levels using microcanonical and canonical ensemble approaches.

Unit II **(12 hours)**

Grand Canonical Ensemble
Equilibrium between a system and a particle-energy reservoir, a system in grand canonical ensemble, physical significance of various statistical quantities, density and energy fluctuations in grand canonical ensemble: correspondence with other ensembles, relation between canonical partition function and grand canonical partition function.

Unit III **(12 Lectures)**

Quantum Mechanical Ensembles
Basic idea of quantum-mechanical ensemble theory. Density matrix of microcanonical, canonical and grand canonical ensembles, Particle in a box and quantum harmonic oscillator.

Unit IV **(13 Lectures)**

Interacting Systems
Introduction to the Ising model. Exact solution of Ising model in one dimension. Mean field approximation.

REFERENCES

Essential Readings

1. Statistical Mechanics - R. K. Pathria & Paul D. Beale, 4th Edition, (Academic Press,2021)
2. Introduction to Statistical Physics, Kerson Huang, 2nd Edition, (Taylor and Francis 2009)
3. Statistical Physics of Particles, Mehran Kardar (Cambridge University Press, 2007)
4. Statistical and Thermal Physics: An Introduction, Michael J R Hoch, 2nd Edition (CRC Press, 2021)

Additional Readings

1. Statistical Mechanics An advanced course with problems and solutions R. Kubo, First Edition (Elsevier, 2014)
2. Thermodynamics and Statistical Mechanics, Greiner, Neise and Stocker, Springer 1995.
3. Fundamentals of Statistical and Thermal Physics, F. Reif, McGraw-Hill, Inc., 1967
4. Statistical and Thermal Physics: With Computer Applications, Harvey Gould and Jan Tobochnik

ADVISORY

The course, Advanced Statistical Mechanics, is essential for several courses offered in the one-year M.Sc. program and is also included in the syllabi of various competitive examinations, including CSIR-NET, JEST, and GATE.
Colleges are advised to offer this as a Discipline Specific Elective (DSE). Students who intend to pursue postgraduate studies or appear for competitive exams are strongly encouraged to choose this course as a DSE.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 20: DIGITAL SIGNAL PROCESSING

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Digital Signal Processing DSE 20	4	2	0	2	

COURSE OBJECTIVES

- This paper describes the discrete-time signals and systems, Fourier Transform Representation of Aperiodic Discrete-Time Signals.
- This paper also highlights the concept of filters and realization of Digital Filters.
- At the end of the syllabus, students will develop an understanding of Discrete and fast Fourier Transform.

LEARNING OUTCOMES

At the end of this course, students will be able to develop following learning outcomes:

- Students will learn basic discrete-time signal and system types, convolution sum, impulse and frequency response concepts for linear time-invariant (LTI) systems.
- The student will be in position to understand use of different transforms and analyze the discrete time signals and systems. They will learn to analyze a digital system using z-transforms and discrete time Fourier transforms, region of convergence concepts, their properties and perform simple transform calculations.
- The student will realize the use of LTI filters for filtering different real world signals. The concept of transfer Function and difference-Equation System will be introduced. Also, they will learn to solve Difference Equations.
- Students will develop an ability to analyze DSP systems like linear-phase, FIR, IIR, All-pass, averaging and notch Filter etc.
- Students will be able to understand the discrete Fourier transform (DFT) and realize its implementation using FFT techniques.
- Students will be able to learn the realization of digital filters, their structures, along with their advantages and disadvantages. They will be able to design and understand different types of digital filters such as finite & infinite impulse response filters for various applications.

SYLLABUS OF DSE 20
THEORY COMPONENT
(Hours: 30)

Unit I **(7 Hours)**

Discrete-Time Signals and Systems: Classification of Signals, Transformations of the Independent Variable, Periodic and Aperiodic Signals, Energy and Power Signals, Even and Odd Signals, Discrete-Time Systems, System Properties. Impulse Response, Convolution Sum; Graphical and Analytical Method, Properties of Convolution (General Idea); Sum Property System Response to Periodic Inputs, Relationship Between LTI System Properties and the Impulse Response.

Unit II **(9 Hours)**

Discrete-Time Fourier Transform: Fourier Transform Representation of Aperiodic Discrete-Time Signals, Periodicity of DTFT, Properties; Linearity; Time Shifting; Frequency Shifting; Differencing in Time Domain; Differentiation in Frequency Domain; Convolution Property. The z-Transform: Bilateral (Two-Sided) z-Transform, Inverse z- Transform, Relationship Between z-Transform and Discrete-Time Fourier Transform, z-plane, Region-of-Convergence; Differentiation in the z-Domain; Power Series Expansion Method (General Idea). Transfer Function and Difference-Equation System.

Unit III **(10 Hours)**

Filter Concepts: Phase Delay and Group delay, Zero-Phase Filter, Linear-Phase Filter, Simple FIR Digital Filters (only qualitative treatment).
Discrete Fourier Transform: Frequency Domain Sampling (Sampling of DTFT), Discrete Fourier Transform (DFT) and its Inverse, DFT as a Linear transformation, Properties; Periodicity; Linearity; Circular Time Shifting; Circular Frequency Shifting; Circular Time Reversal; Multiplication Property; Parseval's Relation (general idea), Linear Convolution Using the DFT (Linear Convolution Using Circular Convolution).

Unit IV **(4 Hours)**

Realization of Digital Filters: FIR Filter structures; Direct-Form; Cascade-Form
Finite Impulse Response Digital Filter: Advantages and Disadvantages of Digital Filters, Types of Digital Filters: FIR Filters.

PRACTICAL COMPONENT: DIGITAL SIGNAL PROCESSING
(Hours: 60)

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 and application to the specific experiments done in the lab.

At least 06 experiments from the following using Scilab/Matlab/Python.

1. Write a program to generate and plot the following sequences: (a) Unit sample sequence $\delta(n)$, (b) unit step sequence *u(n)*, (c) ramp sequence *r(n)*, (d) real valued exponential sequence $x(n) = (0.8)^n u(n)$ for $0 \leq n \leq 50$.
2. Write a program to compute the convolution sum of a rectangle signal (or gate function) with itself for N = 5

$$x(n) = \mathrm{rect}\left(\frac{n}{2N}\right) = \prod \left(\frac{n}{2N}\right) = \{1 \quad -N \leq n \leq N \; 0 \quad \text{otherwise}$$

3. An LTI system is specified by the difference equation: y(n)=0.8y(n-1)+x(n)
   (a) Determine $H(e^{jw})$
   (b) Calculate and plot the steady state response y(n) to $x(n) = \cos\cos(0.5\pi n)\, u(n)$
4. Given a casual system y(n)=0.9y(n-1)+x(n)
   (a) Find H(z) and sketch its pole-zero plot
   (b) Plot the frequency response $|H(e^{jw})|$ and $\angle H(e^{jw})$
5. Design a digital filter to eliminate the lower frequency sinusoid of *x(t)=sin7t+sin200t*. The sampling frequency is 500 Hz. Plot its pole zero diagram, magnitude response, input and output of the filter.
6. Let *x(n)* be a 4-point sequence:
   $x(n) = \{1,1,1,1\} = \{1 \;\; 0 \leq n \leq 3 \; 0 \;\; otherwise$
   ↑
   Compute the DTFT $X(e^{jw})$ and plot its magnitude
   (a) Compute and plot the 4 point DFT of *x(n)*
   (b) Compute and plot the 8 point DFT of *x(n)* (by appending 4 zeros)
   (c) Compute and plot the 16 point DFT of *x(n)* (by appending 12 zeros)
7. Let *x(n)* and *h(n)* be the two 4-point sequences,
   x(n)={1,2,2,1} *h(n)={1,-1,-1,1}*
   ↑ ↑
   Write a program to compute their linear convolution using circular convolution.
8. Using a rectangular window, design a FIR low-pass filter with a pass-band gain of unity, cut off frequency of 1000 Hz and working at a sampling frequency of 5 KHz. Take the length of the impulse response as 17.

9. Design an FIR filter to meet the following specifications:

   Passband edge F_p=2 KHz
   Stopband edge F_s=5 KHz
   Passband attenuation A_p=2 dB
   Stopband attenuation A_s=42 dB
   Sampling frequency F_{sf}=20 KHz

10. The frequency response of a linear phase digital differentiator is given by

$$H_d(e^{jw}) = jwe^{-j\tau w} \; |w| \leq \pi$$

   Using a Hamming window of length M = 21, design a digital FIR differentiator. Plot the amplitude response

REFERENCES

Essential Readings for the Theory Component

1. Digital Signal Processing, Tarun Kumar Rawat, 2015, Oxford University Press, India
2. Digital Signal Processing, S. K. Mitra, McGraw Hill, India.
3. Principles of Signal Processing and Linear Systems, B.P. Lathi, 2009, 1st Edn. Oxford University Press.
1. Fundamentals of signals and systems, P.D. Cha and J.I. Molinder, 2007, Cambridge University Press.
2. Digital Signal Processing Principles Algorithm & Applications, J.G. Proakis and D.G. Manolakis, 2007, 4th Edn., Prentice Hall.

Additional Readings for the Theory Component

1. Digital Signal Processing, A. Anand Kumar, 2nd Edition, 2016, PHI learning Private Limited.
2. Digital Signal Processing, Paulo S.R. Diniz, Eduardo A.B. da Silva, Sergio L. Netto, 2nd Edition, 2017, Cambridge University Press.

References for the Practical Component

1. A Guide to MATLAB, B.R. Hunt, R.L. Lipsman, J.M. Rosenberg, 2014, 3rd Edn., Cambridge University Press.
2. Fundamentals of Digital Signal processing using MATLAB, R.J. Schilling and S.L. Harris, 2005, Cengage Learning.
3. Getting started with MATLAB, Rudra Pratap, 2010, Oxford University Press.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 21: GROUP THEORY AND ITS APPLICATIONS

Course Title and Code	Credits	Credit Distribution of the Course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Group Theory and Application DSE 21	4	3	1	0	Knowledge of Linear Algebra is recommended

COURSE OBJECTIVES

- To introduce students to the fundamental structures and operations of group theory.
- To develop the ability to construct and classify groups, subgroups, and their representations.
- To prepare students to apply group theoretical methods to problems in quantum mechanics, molecular physics, and crystallography.
- To provide a rigorous foundation in both finite and continuous groups relevant to advanced physics.

LEARNING OUTCOMES

After completing this course, students will be able to:

- Identify and classify groups, subgroups, and conjugacy classes.
- Understand and use homomorphisms, isomorphisms, and quotient structures.
- Construct and analyze matrix representations of groups.
- Apply character theory and the Great Orthogonality Theorem.
- Analyze symmetries in quantum systems using SU(2), SU(3), and SO(n) groups.
- Interpret and utilize point groups and space groups in solid-state and molecular systems.

SYLLABUS OF DSE 21
THEORY COMPONENT
(Hours: 45)

Unit I **(13 Hours)**

Basics of Group Theory
Symmetry and Groups, Properties of groups, Abelian and non-abelian groups. Cayley Table and Diagram. Concept of Subgroup, cyclic subgroups, center of a group. Cosets and Lagrange's Theorem. Direct Sum and Direct Product of Groups.
Homomorphism and Isomorphism of Groups. Kernel and Image of Homomorphism. Representations of Groups.

Unit II **(12 Hours)**

Finite Groups and Representations
Permutation Groups, Cayley's Theorem (Statement only). Normal subgroups, Quotient Groups and Simple groups. Conjugate Subgroups and conjugacy classes. Dihedral Groups. Classes, Unitary representations, Reducible and Irreducible representations of finite groups. Schur's Lemma. Great Orthogonality Theorem and Character Table. Dimensionality Theorem. Direct product of representation and representation of Direct Product Groups.

Unit III **(10 Hours)**

Continuous Groups
U (1) group, Lie Groups and Generators of Group. Lie Algebra and Jacobi Identity. Orthogonal Lie Groups. Rotation group in 2 and 3 dimensions: SO(2), SO(3) and their generators. Unitary Lie Groups: SU(2), SU(3) and their generators. Homomorphism of SU(2) and SO(3). Homogenous Lorentz Group.

Unit IV **(10 Hours)**

Applications in Physics
SU(2) and quantum spin: Irreducible representation of SU(2) and their relation to spin. Direct Product of representations and Addition of Angular momentum. Clebsch-Gordan Decomposition and Coefficients.
Crystal Symmetry: Point Groups and examples, Point group C_{4v} and its character table. Significance of character table in studying crystal properties.
Space Groups and examples, Space Group P4mm corresponding to the point group C_{4v}.

REFERENCES

Essential Readings

1. Mathematical Methods for Physicists, H. J. Weber and G. B. Arfken, Elsevier (2010).
2. Mathematical Methods for Physics and Engineering, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge University Press (2006).
3. Mathematical Physics with Applications, Problems and Solutions, V. Balakrishan, Ane Books (2017).

4. Group Theory and its Applications to Physical Problems, by Morton Hamermesh, Dover Publications (1989).
5. Introduction to Mathematical Physics: Methods & Concepts, Chun Wa Wong, Oxford University Press (2012).
6. Mathematical Methods for Physicists: A Concise Introduction, Tai L. Chow, Cambridge University Press (2000).
7. Groups, Representations and Physics, H. F. Jones, Taylor & Francis (1998).
8. Group Theory in Physics: An Introduction to Symmetry Principles, Group Representations, and Special Functions in Classical and Quantum Physics, Wu-Ki Tung, World Scientific Publishing Co. Pte. Ltd. (2003).
9. Group Theory in a Nutshell for Physicists, A. Zee, Princeton University Press (2016).

Additional Readings

1. Introduction to Mathematical Physics: Methods and Concepts, Chun Wa Wong, Oxford University Press (2012).
2. Group Theory: A Physicist's Survey, Pierre Ramond, Cambridge University Press (2010).
3. A Physicist's Introduction to Algebraic Structures: Vector Spaces, Groups, Topological Spaces and More, Palash B Pal, Cambridge University Press (2019).
4. Schaum's outline of Group Theory, B. Baumslag and B. Chandler, McGraw Hill Education (1968).
5. Contemporary Abstract Algebra, Joseph A Gallian, 9th ed, Brooks/Cole Cengage Learning (2017).
6. Group Theory in a Nutshell for Physicists, A. Zee, Princeton University Press (2016).
7. Group Theory in Physics: An Introduction with a Focus on Solid State Physics, Jörg Bünemann, Springer Nature (2024).
8. Group Theory in Physics: An Introduction, J. F. Cornwell, Academic Press (1997).
9. Classical groups for physicists, B.G. Wybourne, Wiley
10. Chemical Applications of Group Theory, F A Cotton, John Wiley and Sons (1990).
11. Lie Algebras in Particle Physics, H. Georgi, CRC Press (1999).
12. Group Theory in Physics: An Introduction with a Focus on Solid State Physics, Jörg Bünemann, Springer Nature (2024).

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE - DSE 22: NUCLEAR AND PARTICLE PHYSICS

Course Title and Code	Credits	Credit Distribution of the Course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Nuclear and Particle Physics DSE 22	4	3	1	0	

COURSE OBJECTIVE

The objective of the course is to impart the understanding of the sub atomic particles and their properties. It will emphasize to gain knowledge about the different nuclear techniques and their applications in different branches Physics and societal application. The course will focus on the developments of problem-based skills.

LEARNING OUTCOMES

- To be able to understand the basic properties of nuclei: Nuclear charge and mass density, size, magnetic and electric moments
- To appreciate the formulations and contrasts between different nuclear models such as Liquid drop model, Fermi gas model and Shell Model and evidences in support.
- Familiarization with different types of nuclear reactions, Q- values, compound and direct reactions.
- To know about energy losses due to ionizing radiations, energy losses of electrons, gamma ray interactions through matter and neutron interaction with matter.
- To understand classification of fundamental forces based on their range, time-scale and mediator mass.
- To understand Scattering cross-sections of 2 to 2 processes and their inherent symmetries.
- Angular and energy distributions for three body decay process.
- Discrete symmetries of nature and associated conservation laws and Colour triplet

SYLLABUS OF DSE 22
THEORY COMPONENT
(Hours: 45)

Unit I **(15 Hours)**

General Properties of Nuclei and Nuclear Models: Constituents of nucleus and their Intrinsic properties. Fermi gas model (degenerate fermion gas, nuclear symmetry potential in Fermi gas). Single Particle Shell Model (Concept of mean field and spin orbit coupling), Estimation of Spin parity and electromagnetic moments for ground state configuration for even- even, even -odd and odd-odd nuclei. Basic concept of Collective Model and deformed shell model.

Unit II **(10 Hours)**

Nuclear Reactions: Types of Reactions, Units of related physical quantities, Conservation Laws, Kinematics of reactions, Q-value, Reaction rate, Reaction cross section, Concept of compound and direct reaction, Coulomb scattering (Rutherford scattering).

Unit III **(8 Hours)**

Interaction of Nuclear Radiation with matter: Interaction of radiation for light ions (electrons) and heavy charge particles, neutron and photons with matter. Energy loss due to ionization (Bethe-Block formula), for both light and heavy-ions, Cerenkov radiation. Gamma ray interaction with matter. Neutron interaction with matter.

Unit IV **(12 Hours)**

Particle Physics: Overview of Particle spectrum and their interactions in the Standard Model. Range, time-scale and relative strength of interactions. Interactions at a distance mediated by virtual particles (Exchange Force).
Requirement of High Energy Colliders to probe the constituents of nucleon, Linear and circular colliders, Inelastic collisions at Hadron colliders. Brief idea about Large Hadron Collider experiment and Indian ALICE and CMS and collaborations.
Kinematics for $2 \rightarrow 2$ scattering processes and Crossing symmetries of scattering amplitudes. Angular and energy distributions of decaying particles in $1 \rightarrow 3$ decay processes (muon decay / beta decay).
Lepton and Baryon quantum numbers. Isospin, Strangeness and Hypercharge. Gell-Mann-Nishijima formula. Parity and Charge conjugation of a particle state. Time Reversal and General CPT theorem.
Valence quark model of Murray Gell-Mann and Yuval Ne'eman, current and constituent masses of quarks, flavor symmetry Isospin triplets, Baryon octet and decuplet, Meson octet. Antisymmetric Δ^{++} state and necessity for color quantum number. Evidence for color triplet quarks from $\mathbf{e^+e^-}$ annihilation experiment.

REFERENCES

Essential Readings

For Nuclear Physics

1. Basic ideas and concepts in Nuclear Physics: An introductory approach by K Heyde, third edition, IOP Publication, 1999.
2. Introductory Nuclear Physics by K S Krane, Wiley-India Publication, 2008.
3. Nuclear Physics by S N Ghoshal, First edition, S. Chand Publication, 2010.
4. Nuclear Physics: principles and applications by J Lilley, Wiley Publication, 2006.
5. Concepts of Nuclear Physics by B L Cohen, Tata McGraw Hill Publication, 1974.
6. Radiation detection and measurement, G F Knoll, John Wiley & Sons, 2010.

For Particle Physics

7. Modern Particle Physics by Mark Thompson, Cambridge University Press, 2013.
8. Particles and Nuclei: An Introduction to the Physical Concepts by Bogdan Povh, Klaus Rith, Christoph Scholz, Frank Zetsche, Werner Rodejohann, Springer-Verlag 2015.
9. An Introductory Course of Particle Physics, Palash B. Pal (CRC Press, 2015)
10. Introduction to High Energy Physics by D H Perkins, 4^{th} edition, Cambridge University Press, 2000.
11. Introduction to elementary particles by D J Griffiths, Wiley, 2008.
12. Quarks & Leptons, F. Halzen and A. D. Martin (John Wiley, 1984)

References for Tutorials

13. Problems and Solutions in Nuclear and Particle Physics by Sergio Petreta, Springer, 2019.
14. Schaum's Outline of Modern Physics, McGraw-Hill, 1999.
15. Schaum's Outline of College Physics, by E. Hecht, 11th edition, McGraw Hill, 2009.
16. Problems and Solutions on Atomic, Nuclear and Particle Physics by Yung-Kuo Lim, World Scientific, 2000.
17. Nuclear Physics "Problem-based Approach" Including MATLAB by Hari M. Aggarwal, PHI Learning Pvt. Ltd. (2016).

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE - DSE 23: PLASMA PHYSICS

Course Title and Code	Credits	Credit Distribution of the Course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Plasma Physics DSE 23	4	3	1	0	DSC 13 - Electromagnetic Theory (Sem. V) and DSC 8 - Thermal Physics (Sem. III) of this program or its equivalent.

COURSE OBJECTIVES

This course presents the characteristic plasma properties and theoretical approaches to plasma physics. It treats single charged-particle motion in electromagnetic fields, collisions, electrical conductivity and diffusion, and plasma waves. Applications to controlled thermonuclear fusion, plasma processing, and astrophysical plasmas will serve to illustrate when and where the various theories are applicable.

LEARNING OUTCOMES

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

- define, using fundamental plasma parameters, under what conditions an ionised gas consisting of charged particles (electrons and ions) can be treated as a plasma.
- know various applications of plasma physics.
- determine the drift velocities of charged particles moving in electric and magnetic fields that are either uniform or vary slowly in space and time.
- distinguish the single particle approach, fluid approach to describe different plasma phenomena and formulate the conditions for a plasma to be in a state of perfect thermodynamic equilibrium.
- apply the conservation laws and Maxwell's equations to describe dynamical processes like wave propagation in a plasma.

SYLLABUS OF DSE 23
THEORY COMPONENT
(Hours: 45)

Unit I **(12 Hours)**

Introduction to plasma: Basics of gas dynamics, occurrence of plasma in nature, concept of temperature and density of plasma, Saha's equation, quasineutrality in plasma, collective behaviour, Debye shielding, Microscopic Properties (resistivity and conductivity).

Unit II **(8 Hours)**

Plasma applications and measurement: Gas discharge, industrial plasma, ionosphere plasma, solar plasma, plasma processing of materials, laser ablation, laser-driven fusion, magnetic fusion, plasma propulsion. Basics of Plasma production in laboratory and diagnostics

Unit III **(13 Hours)**

Particle confinement: Single particle motion in the presence of uniform and non-uniform electric and magnetic field, Grad-B drift, curvature drift, polarization drift, Magnetic mirrors and concept of earth magnetic mirror, Basic concept of controlled thermonuclear fusion.

Unit IV **(12 Hours)**

Fluid description of plasma: Set of fluid equations of plasmas, diamagnetic drift of plasma, plasma approximation, waves in cold plasmas, plasma oscillations, electron plasma wave, ion acoustic wave, electromagnetic wave in unmagnetized plasma.

REFERENCES

1. Introduction to Plasma Physics and Controlled Fusion by F. F. Chen (Third Edition 2016).
2. The Physics of Plasmas, by T. J. M. Boyd and J. J. Sanderson. Cambridge University Press, 2003.
3. Introduction to Plasma Physics, R.J. Goldston and P. H. Rutherford (IOP, 1995).
4. Fundamentals of Plasma Physics -J. A. Bittencourt, Springer, New York, NY (Third edition).
5. The physics of fluids and plasmas: an introduction for astrophysicists – Arnab Rai Choudhuri, Cambridge University Press (1998)
6. Principles of Plasma Physics, N.A. Krall and A.W. Trivelpiece, Mc Graw Hill (1973).
7. Principles of Plasma Discharges and Materials Processing (Second Edition, 2005) by Lieberman, Lichtenberg.

B.Sc. (Honours) Physics

DISCIPLINE SPECIFIC ELECTIVE COURSE - DSE 24: SENSORS AND DETECTORS

Course Title and Code	Credits	Credit Distribution of the Course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Sensors and Detectors DSE 24	4	3	0	1	DSC 13 - Electromagnetic Theory (Sem. V) and DSC 8 - Thermal Physics (Sem. III) of this program or its equivalent.

COURSE OBJECTIVES

To make students familiar with the constructions and working principle of different types of sensors and transducers. To make students aware about the measuring instruments and the methods of measurement and the use of different transducers.

LEARNING OUTCOMES

At the end of the course, a student will be able to:

- Use concepts in common methods for converting a physical parameter into an electrical quantity.
- Classify and explain with examples of transducers, including those for measurement of temperature, strain, motion, position and light.
- Choose proper sensor comparing different standards and guidelines to make sensitive measurements of physical parameters like pressure, flow, acceleration, etc.
- Predict correctly the expected performance of various sensors.
- Locate different type of sensors used in real life applications and paraphrase their importance.
- Set up testing strategies to evaluate performance characteristics of different types of sensors and transducers and develop professional skills in acquiring and applying the knowledge outside the classroom through design of a real-life instrumentation system.

<u>SYLLABUS OF DSE 24</u>
<u>THEORY COMPONENT</u>
(Hours: 45)

Unit I **(13 Hours)**

Transducers, Classification of transducers on different basis, Types of transducers (Basic idea of Mechanical, resistive, capacitive, inductive, piezoelectric, optical and digital).
Sensor, Components of sensor, Direct and complex sensor (Basic idea)
Distinction between Sensor and Transducer, Characteristics of Transducers/Sensor: Static characteristics and static calibration (Calibration accuracy and component error), Dynamic characteristics.
Inductive sensor: Variable Inductance Sensors, Plunger type displacement sensor, Variable Gap Sensor, LVDT: Construction, working, output characteristics. Idea of RVDT (Qualitative).
Capacitive sensors: Variable distance-parallel plate type, variable area- parallel plate (serrated plate/teeth type), variable dielectric constant type; Sensitivity of capacitive sensors, Stretched diaphragm type

Unit II **(9 Hours)**

Magnetic Sensors: Magnetoresistive Sensors and Hall effect sensor (performance and characteristics).
Temperature sensor: RTD (construction, working and temperature coefficient), thermistor, categories of thermistor (PTC and NTC: material, shape, ranges, RT curve and accuracy specification), Thermo emf sensor (thermoelectricity generation, thermos-emf measurement, Thermocouples (construction, characteristics), and Pyroelectric sensors (pyroelectric effect and output voltage-temperature relationship).

Unit III **(13 Hours)**

Pressure sensors: Direct versus indirect pressure measurement, Different types of gauges and their working range, Mechanical gauges (McLeod Gauge), Thermal Conductivity Gauges (Thermocouple and Pirani gauges) and Ionization gauges (hot & cold cathode), advantages and limitations of various types of gauges, Gauge calibration (Static: Manometric method and dead-beat tester, dynamic calibration).
Radiation Sensors: Basic Characteristics (Concept of Work Function, Spectral Sensitivity, Spectral threshold, Quantum yield, time lag, linearity, Status and dynamic response), Types of Photodetectors: Photoemissive Cell, Photo Multiplier, Photo conductive Cell (LDR), Photovoltaic cells, photodiodes. Detection of Nuclear Radiation: Qualitative treatment of Geiger Muller counters and Scintillation detectors.

Unit IV **(10 Hours)**

Applications of Sensors and detectors: Basic principles of Remote sensing, Introduction to LiDAR (principles, applications and benefits), Types of LiDAR (air-borne and ground based) Applications of motion sensors in accelerometers and gyroscopes (qualitative analysis of working principle).
Biomedical Sensor: Electrochemical sensor (electrochemical cell, cell potential, three electrodes system, working principle).

PRACTICAL COMPONENT: SENSORS AND DETECTORS
(Hours: 30)

At least 5 experiments to be done from the list below:

1. Characteristics of LDR as a function of distance from light source.
2. Light characteristics of Photodiode.
3. Measurement of Strain using Strain Gauge.
4. To study the characteristics of a Linear Variable Differential Transformer (LVDT).
5. To study the characteristics of a Resistance Temperature Device (RTD).
6. To study the frequency response of a loudspeaker.
7. Determine characteristics of an Infrared (IR) emitter-receiver module.
8. Create vacuum in a small chamber using a mechanical (rotary) pump and/or secondary pump and measure the chamber pressure using a pressure gauge – Pirani and/or CC gauge.
9. Measurement of thermos-emf in thermopile and to calculate the Seebeck coefficient.
10. Study the pyroelectric effect and generation of induced voltage with temperature change.

REFERENCES

Essential Readings for the Theory Component

1. Experimental Methods for Engineers, J.P. Holman, McGraw Hill
2. Introduction to Measurements and Instrumentation, A.K. Ghosh, PHI Learning Pvt. Ltd.
3. 3.Transducers and Instrumentation, D.V.S. Murty, 2nd Edition, PHI Learning Pvt. Ltd.
4. Instrumentation Devices and Systems, C.S. Rangan, G.R. Sarma, V.S.V. Mani, Tata
5. McGraw Hill
6. Electronic circuits: Handbook of design & applications, U.Tietze, Ch.Schenk, Springer
7. Electronic Instrumentation by H. S. Kalsi (Mc Graw Hill Publisher)
8. Sensors and Transducers, D Patranabis, PHI Learning Pvt. Ltd.
9. An Introduction to Sensors and Instrumentations, Sobnath Singh, Narosa
10. Handbook of Modern Sensors, Jacob Fraden, Springer
11. Handbook of Thion film Technology, Maissel and Glang, Tata McGraw Hill
12. Instrumentation, Measurement and Analysis, Nakra and Chaudhry, McGraw Hill

Additional Readings for the Theory Component

1. Radiation detection and measurement, G.F. Knoll, Wiley
2. Measurement, Instrumentation and Experiment Design in Physics & Engineering, M.Sayer and A. Mansingh, PHI

References for the Practical Component

1. Electronic circuits: Handbook of design and applications, U. Tietze and C. Schenk, Springer
2. Basic Electronics: A text lab manual, P. B. Zbar, A. P. Malvino, M. A. Miller, McGraw