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.

<u>SYLLABUS OF DSE – 9</u>
<u>THEORY COMPONENT</u>
(Credits: 3; 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.

<u>References</u>

Essential Readings

1) Vector Analysis and Cartesian Tensors, 3rd 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, 2nd 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, 3^{rd} edition, 2009, Wiley Publication.
4) A Primer in Tensor Analysis and Relativity, I. L. Shapiro, 1^{st} 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.

B.SC. (HONOURS) PHYSICS

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
(Credits: 3; 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 **(15 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 **(15 Hours)**

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.
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)

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.

SYLLABUS OF DSE 13
THEORY COMPONENT
(Credits: 3; Hours: 45)

Unit I **(18 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.
Postulates of quantum mechanics. Continuous basis, position and momentum representations. Degenerate eigenvalues and complete set of commuting observables. Generalized uncertainty principle.

Unit II **(12 Hours)**

Quantum Dynamics
Unitary time-evolution and Schrödinger equation in ket notation and correspondence with wave mechanics. Momentum as generator of translation in space and Hamiltonion 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.
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.

Unit III **(15 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.
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 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.

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
(Credits: 3; 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 **(7 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.

Unit III **(6 Hours)**

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 IV **(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 V **(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.

References

Essential Readings

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

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)

PRACTICAL COMPONENT: ATMOPHERIC PHYSICS AND CLIMATE CHANGE
(Credit:1; 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

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

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.

<u>SYLLABUS OF DSE 15</u>
<u>THEORY COMPONENT</u>
(Credits: 2; Hours: 30)

Unit I (3 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).

Unit II (8 Hours)

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 III (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 IV (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 V **(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.

References:

Essential Readings:

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:

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

PRACTICAL COMPONENT: NANOSCIENCE
(Credits: 2; Hours: 60)

At least 06 experiments from the following:

1. Synthesis of metal (e.g. Au/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 XRD and 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 XRD/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 XRD and 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

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
(Credits: 3; Hours: 45)

Unit I **(6 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 II **(5 Hours)**

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 III **(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 IV **(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 V **(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
(Credits: 3; 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

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

PRACTICAL COMPONENT: RESEARCH METHODOLOGY
(Credit: 1; 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.

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
(Credits: 2; 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.

References

Essential Readings

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

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

PRACTICAL COMPONENT: SEMICONDUCTOR DEVICES FABRICATION AND APPLICATIONS
(Credits: 2; 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 ^{o}C) by four-probe method.
9. Capacitance measurements of ceramics using LCR meter.
10. Capacitance measurements of dielectric thin film capacitor using LCR meter

References

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