DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 3: ADVANCED MATHEMATICAL PHYSICS I

Course Title & Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course
		Lecture	Tutorial	Practical		
Advanced Mathematical Physics I DSE – 3	4	4	0	0	Appeared in Semester 3	DSC courses of Mathematical Physics I and Mathematical Physics III

LEARNING OBJECTIVES

The objective of the course is to impart the concept of calculus of variation and generalized mathematical constructs in terms of algebraic structures mainly vector spaces. Both concepts are extremely useful in physics, engineering, machine learning, economics and even life sciences and social sciences. While linear algebra studies linear vector spaces, linear transformations, and the matrices, calculus of variation is an important mathematical tool in optimization. This course is intended to provide a solid foundation in both topics as used by physicists and has direct applications in classical and quantum mechanics.

LEARNING OUTCOMES

After completing this course, students will be able to,

- Apply the techniques of calculus of variation to real world problems.
- Solve Euler-Lagrange equations for simple cases.
- Understand algebraic structures in n-dimension and basic properties of the linear vector spaces.
- Understand the concept of dual spaces and inner product spaces.
- Represent linear transformations as matrices and understand basic properties of matrices.
- Determine the eigenvalues and eigenvectors of matrices and diagonalise the matrices.
- Determine orthogonal basis for a vector space using Gram-Schmidt procedure.

SYLLABUS OF DSE - 3

THEORY COMPONENT

Unit – I **(18 Hours)**

Calculus of Variation: Functionals and extrema, Euler's equation for (i) one independent and one dependent variable, (ii) several dependent variables and (iii) several independent variables; Variable end-point problems; Application to problems (e.g. geodesics, catenary, minimum area of soap film, brachistochrone, Fermat's principle, Laplace equation etc.); Generalised coordinates and concept of Lagrangian; Hamilton's principle, Euler-Lagrange's equations of motion and its applications to physics problems (e.g. simple pendulum, one dimensional harmonic oscillator and other problems).

Unit – II **(12 Hours)**

Vector Spaces as Algebraic Structures: Definition and examples of groups, rings, fields and vector spaces; real and complex fields, use of ket notation $|\alpha >$ for vectors; Subspaces, linear combination of vectors, linear dependence and independence of vectors, span of a subset of vectors, bases and dimension of vector space, direct sum of spaces, representation of vectors as column matrix with R^n as example.

Inner Product Spaces: Inner product of vectors ($< \alpha|\beta >$) and norm of a vector, Euclidean spaces and unitary spaces, Cauchy-Schwartz inequality, concept of length and distance, metric spaces. Hilbert Space (definition only); linear functional, dual space, dual basis ($< \alpha|$ notation); Orthogonality of vectors, orthonormal basis, Gram-Schmidt procedure to construct an orthonormal basis.

Unit – III **(18 Hours)**

Linear Transformation: Linear mappings and examples, homomorphism and isomorphism of vector space, rank and nullity of a linear mapping, range space and Kernel (null space) of a linear mapping, non-singular transformations.

Matrices as Representations: Matrix representation of linear transformations, composition of linear transformations and matrix multiplication, linear algebra; Algebra of matrices, determinant and trace of matrix and their properties; Non-singular matrices; Rank of a matrix and invertibility of matrices; direct sum and direct product of matrices.

Change of basis transformation, similar matrices; transpose and adjoint of a linear transformation, self-adjoint operators; symmetric and Hermitian matrices; preservation of norms by orthogonal and unitary transformations.

Unit – IV **(12 Hours)**

Eigen-values and Eigenvectors: Eigen-values and eigen vectors of a transformation and corresponding matrix representation; Cayley-Hamilton theorem (statement only), its applications like inverse and powers of a matrix; Eigensystems of Hermitian and unitary matrices; Diagonalization of matrices; Normal matrices; Simultaneous diagonalizability of two matrices.

Use of matrices in solving coupled linear first order ordinary differential equations with constant coefficients; Minimal polynomial, functions of a matrix.

References:

Essential Readings:

1) Mathematical Methods for Physicists, G.Arfken, H. Weber and F. E. Harris, 7th edition, 2012, Elsevier
2) Applied Mathematics for Engineers and Physicists, L. A. Pipes and L. R. Harvill, 1970, McGraw-Hill Inc
3) Calculus of Variations, I. M. Gelfand and S. V. Fomin, 2000, Dover Publications
4) Introduction to Matrices and Linear Transformations, D. T. Finkbeiner, 2011, Dover Publications
5) Schaum's Outline of Theory and Problems of Linear Algebra, S.Lipschutz and M. Lipson, 2017, McGraw Hill Education
6) Linear Algebra, S. H. Friedberg, A. J. Insel, and L. E. Spence, 2022, Pearson Education

Additional Readings:

1) Elementary Linear Algebra with Supplemental Applications, H. Anton and C.Rorres, 2016, Wiley Student Edition
2) A Physicist's Introduction to Algebraic Structures: Vector Spaces, Groups, Topological

Spaces and More, P. B. Pal, 2019, Cambridge University Press
3) Matrices and Tensors in Physics: A.W. Joshi, 2017, New Age International Pvt. Ltd.
4) An Introduction to Linear Algebra and Tensors, M. A.Akivis, V. V. Goldberg, Richard and Silverman, 2012, Dover Publications
5) Linear Algebra and Applications, D. C. Lay, 2002, Pearson Education India
6) Vector Spaces and Matrices in Physics, M.C. Jain, 2000, Narosa
7) Mathematical Methods for Physics and Engineering, K. F. Riley and M. P. Hobson, 2018, Cambridge University Press

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 4: PHYSICS OF DEVICES

Course Title & Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course
		Lecture	Tutorial	Practical		
Physics of Devices DSE – 4	4	2	0	2	Appeared in Semester 3	Knowledge of basic electronics concepts.

LEARNING OBJECTIVES

This paper is based on advanced electronics which covers the devices such as UJT, JFET, MOSFET, CMOS etc. Process of IC fabrication is discussed in detail.

LEARNING OUTCOMES

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

- Develop the basic knowledge of semiconductor device physics and electronic circuits along with the practical technological considerations and applications.
- Understand the operation of devices such as UJT, JFET, MOS, various bias circuits of MOSFET, basics of CMOS and charge coupled devices.
- Learn to analyse MOSFET circuits and develop an understanding of MOSFET I-V characteristics and the allowed frequency limits.
- Learn the IC fabrication technology involving the process of diffusion, implantation, oxidation and etching with an emphasis on photolithography and electron-lithography
- Apply concepts for the regulation of power supply by developing an understanding of various kinds of RC filters classified on the basis of allowed range of frequencies.
- Learn to use semiconductordiode as a clipper and clamper circuit

SYLLABUS OF DSE - 4

THEORY COMPONENT

Unit – I **(7 Hours)**

Semiconductors (P and N type), Energy band diagram, Barrier formation in pn junction diode, Derivation of barrier potential and barrier width, storage and depletion capacitances, current flow mechanism in forward and reverse bias junction, current components in a transistor, tunnel diode, metal-semiconductor contacts, Schottky junction and Ohmic junction

Unit – II **(6 Hours)**

Diode as clipper and clamper circuits, RC Filters: Passive-Low pass and High pass filters, Active (1st order Butterworth)-Low Pass, High Pass, Band Pass, and band reject Filters.

Unit – III **(11 Hours)**

Characteristic and small-signal equivalent circuits of UJT and JFET, introduction to metal oxide semiconductor (MOS) device/MOSFET, MOSFET - their frequency limits,enhancement and depletion mode MOSFETS, basic idea of CMOS and charge coupled devices, importance of power devices: power diode, SCR. Construction and I-V characteristics of DIAC and TRIAC.

Unit – IV **(4 Hours)**
(Basic idea) Basic process flow for IC fabrication,diffusion and implantation of dopants,passivation/oxidation technique for Si,contacts and metallization technique,basic idea of thermal evaporation and sputtering techniques, basic idea ofphotolithography, electron-lithography, SSI, MSI, LSI, VLSI and USI.

Unit – V **(2 Hours)**
Basic idea about sensors (gas/fire) and piezoelectric transducer

References:
Essential Readings:

1) Physics of Semiconductor Devices, S.M.Sze and K.K.Ng, 3rd edition 2008, John Wiley and Sons
2) Electronic Devices and Circuits, A. Mottershead, 1998, PHI Learning Pvt. Ltd.
3) Electronic communication systems, G. Kennedy, 1999, Tata McGraw Hill.
4) Integrated Electronics, J. Millman and C.C. Halkias, 1991, Tata Mc-Graw Hill.
5) Electronics: Fundamentals and Applications, J.D. Ryder, 2004, Prentice Hall.
6) Solid State Electronic Devices, B. G. Streetman and S. K. Banerjee, 7th edition
7) Power Electronics, M. D. Singh and K. B. Khanchandani, 2006, Tata Mc-Graw Hill

Additional Readings:

1) Op-Amps and Linear Integrated Circuits, R.A.Gayakwad, 4th edition, 2000, PHI Learning Pvt. Ltd
2) Introduction to Measurements and Instrumentation, A.K.Ghosh, 4th edition, 2017, PHI Learning
3) Semiconductor Physics and Devices, D.A. Neamen, 4th edition, 2011, Tata McGraw Hill

PRACTICAL COMPONENT

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

At least six experiments to be performed from the following list

1) To design the active low pass and high pass filters of given specification.
2) To design the active filter (wide band pass and band reject) of given specification.
3) To study the output and transfer characteristics of a JFET.
4) To design a common source JFET amplifier and study its frequency response.
5) To study the output characteristics of a MOSFET.
6) To study the characteristics of a UJT and design a simple relaxation oscillator.
7) To study diode as clipper circuit.
8) To study diode as a clamper circuit.
9) Pattern the given structure on silicon wafer by wet chemical etching.

Suggested extra experiment:
1) Deposition of metallic thin films using thermal evaporation technique.

2) Preparation of a pn junction and study its IV characteristics.

References for laboratory work:

1) Advanced PC based instrumentation; Concepts and Practice, N. Mathivanan, 2007, Prentice-Hall of India
2) Basic Electronics: A text lab manual, P.B.Zbar, A.P.Malvino, M.A.Miller,1994, Mc-Graw Hill
3) Introduction to PSPICE using ORCAD for circuits and Electronics, M.H.Rashid,2003, PHI Learning.

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 5: PHYSICS OF EARTH

Course Title & Code	Credits	Credit distribution of the course			Eligibility Criteria	Pre-requisite of the course
		Lecture	Tutorial	Practical		
Physics of Earth DSE – 5	**4**	**4**	**0**	**0**	Appeared in Semester 3	--

LEARNING OBJECTIVES

This course familiarizes the students with the origin of earth in the solar system and various processes occurring in atmosphere, oceans and earth's internal structure.

LEARNING OUTCOMES

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

- Have an overview of structure of the earth as well as various dynamical processes occurring on it.
- Develop an understanding of evolution of the earth.
- Apply physical principles of elasticity and elastic wave propagation to understand modern global seismology as a probe of the Earth's internal structure.
- Understand the origin of magnetic field, geodynamics of earthquakes and the description of seismic sources; a simple but fundamental theory of thermal convection; the distinctive rheological behaviour of the upper mantle and its top.
- Explore various roles played by water cycle, carbon cycle, nitrogen cycles in maintaining steady state of earth leading to better understanding of the contemporary dilemmas (climate change, bio diversity loss, population growth, etc.) disturbing the Earth.
- Develop the problem solving skills by adding numerical and simulations to clarify thefundamental concepts.

SYLLABUS OF DSE - 5

THEORY COMPONENT

Unit – I **(10 Hours)**

The Earth and the Universe:

a) General characteristics and origin of the Universe. The Big Bang Theory. Estimation of age of the Universe and Hubble constant. Formation of Galaxies. Types of galaxies, Milky Way galaxy, Nebular hypothesis, Solar system, The Terrestrial and Jovian planets (Sizes, Acceleration due to gravity, Obliquity, Flatness, Eccentricity, Density, Temperature, Pressure, Atmosphere, Moons, Exceptions in trends). Titius-Bode law. Asteroid belt. Asteroids: origin types and examples, Meteorites.

b) Earth in the Solar system, origin, size, shape, mass, density, rotational and revolution parameters and its age. Earth's orbit and spin, the Moon's orbit and spin.

c) Energy and particle fluxes incident on the Earth.

Unit – II **(15 Hours)**

Structure of Earth:

a) The Solid Earth: topography (Maps, Techniques, Forms of Topographic data).
b) Internal structure: Core, mental, magnetic field. Origin of the Magnetic field. Convection in Earth's core and production of its magnetic field. Dynamo Theory, calculation of magnetic fields, Causes of variation of Magnetic Field and Palaeomagnetism.
c) The Hydrosphere: The oceans, their extent, depth, volume, chemical composition. Ocean circulations. Oceanic current system and effect of Coriolis forces.
d) The Cryosphere: Polar caps and ice sheets. Mountain glaciers, permafrost.

Unit – III **(15 Hours)**

Dynamical Processes:

a) The Solid Earth: Concept of plate tectonics; types of plate movements, hotspots; sea-floor spreading and continental drift.
b) Geodynamic elements of Earth: Mid Oceanic Ridges, trenches, transform faults and island arcs. Continents, mountains and rift valleys.
c) Earthquake and earthquake belts. Types and properties of Seismic waves, Richter scale, geophones.
d) Volcanoes: types, products and distribution.
e) Concepts of eustasy, air-sea interaction; wave erosion and beach processes. Tides. Tsunamis.

Unit – IV **(12 Hours)**

The Atmosphere

a) The Atmosphere: Features of different layers, variation of temperature with altitude; Dry, moist and environmental lapse rate, variation of density and pressure with altitude, Types of clouds and formation.
b) The Atmosphere: Atmospheric circulation. Causes of Atmospheric circulation, Formation of three cells, Easterlies and Westerlies, and ICTZ, Weather and climatic changes. Earth's heat budget. Cyclones and anti-cyclones, tropical storms, hurricanes and tornadoes.
c) Climate: Earth's temperature and greenhouse effect. Paleoclimate and recent climate changes. The Indian monsoon system.

Unit – V **(8 Hours)**

Disturbing the Earth – Contemporary dilemmas

a) Human population growth.
b) Hydrosphere: Fresh water depletion.
c) Geosphere: Chemical effluents, nuclear waste.
d) Biosphere: Biodiversity loss. Deforestation. Robustness and fragility of ecosystems. Water cycle, Carbon cycle. The role of cycles in maintaining a steady state.
e) Air Pollution: Types of air pollutants, Effects on atmosphere and living organisms. Ozone Hole.

References:

Essential Readings:

1) Planetary Surface Processes, H. J.Melosh, 2011, Cambridge University Press.
2) Holme's Principles of Physical Geology, 1992, Chapman &Hall.
3) Planet Earth, Cosmology, Geology and the Evolution of Life and Environment, C. Emiliani, 1992, Cambridge University Press.

4) Physics of the Earth, F. D. Stacey, P. M. Davis, 2008, Cambridge University Press.
5) Environmental Physics: Sustainable Energy and Climate Change, E. Boecker and R.V. Grondelle, 3rd edition, 2011, Wiley, UK
6) Atmospheric Remote Sensing (Principles and Applications, Editors – S. Tiwari and A. K. Singh, Chapter-1 (Composition and thermal structure of the Earth's atmosphere, by S. K. Dhaka and V. Kumar), 1st edition, Elsevier

Additional Readings:

1) The Blue Planet: An Introduction to Earth System Science, B. J. Skinner, S. C. Portere, 1994, John Wiley & Sons.
2) Consider a Spherical Cow: A course in environmental problem solving, J. Harte, University Science Books.
3) Fundamentals of Geophysics, W.Lowrie, 1997, Cambridge University Press.
4) The Solid Earth: An Introduction to Global Geophysics, C. M. R. Fowler, 1990, Cambridge University Press.
5) Climate Change: A Very Short Introduction, M. Maslin, 3rd edition, 2014, Oxford University Press.
6) The Atmosphere: A Very Short Introduction, P. I. Palmer, 2017, Oxford University Press.
7) IGNOU Study material: PHE 15 Astronomy and Astrophysics Block 2