Department of Mathematics and Statistics

School of Mathematical and Physical Science

Curriculum Framework
Ph.D. Course Work Mathematics

Date of BoS -11/06/2024

Doctor Harisingh Gour Vishwavidyalaya
(A Central University)
Sagar-Madhya Pradesh-470003

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Introduction

Mathematics and Statistics Profession

Mathematics and Statistics are the backbone of all sciences. Along with many other branches mathematics concerns with algebra, vectors, calculus, differential, partial and integral equations, theory of estimation, Inference, Mathematical finance, which are frequently used in all physical sciences and discrete mathematics in computer sciences and Industry etc.

Students possessing Ph. D degree in Mathematics / Statistics have a very large numbers of job opportunities in the fields of banking, teaching, software engineering, Actuaries, Defence and as operations research analyst, computer system analyst etc. The course is so designed that the students can also take employment worldwide.

1. **Name of the Programme:** Ph. D. in Mathematics.
2. **Duration of Programme:** The duration of programme (Ph.D. coursework) is one semester spread over a period of not less than 90 working days for a semester. The minimum duration, rules and regulation for completion of Ph.D. degree shall be as per the university ordinance.
3. **Structure of Programme:** The course (Elective and Core) of study for Ph.D. coursework includes the subject, no. of hours per week devoted to each subject and credits for theory and review papers as per scheme attached.

Students having M.A./M.Sc. in Mathematics will be awarded Ph.D. in Mathematics and the students having M.A./M.Sc. in Statistics will be awarded Ph.D. in Statistics.

4. **Medium of the instructions:** English
5. Each course of Ph.D. coursework is marked as a core/ compulsory / elective courses etc.
6. **Credit Allotted**: 18

(i) Core course :	10
(ii) Elective course :	04
(iii) Review course :	04

7. **Scheme of Examination:**

(i) Mid Sem Exam :	20 Marks
(ii) Internal Assessment :	20 Marks
(iii) End Semester Exam :	60 Marks
Total :	100 Marks

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Summary of Ph. D. Course Work in Mathematics

Semester-I

Paper Code	Title of Paper	Credit
RPE-CC-140	Research & Publications Ethics	2
MTS-CC-141	Research Methodology with Computer Applications	4
MTS-CC-142	History of Mathematics and Modeling	4
MTS-CC-143	Review of Published Research Work	4
Opt any one from the following		
MTS-EC-1402	Fixed Point Theory and Application	4
MTS-EC-1403	Mathematical Modelling in Biological Systems	4
MTS-EC-1404	Calculus on Manifolds	4
MTS-EC-1405	Theory of Linear Operators	4
MTS-EC-1406	Advanced Numerical Analysis	4
MTS-EC-1407	Inventory Modelling and Optimization	4
MTS-EC-1408	Nonlinear Analysis and Optimization	4
MTS-EC-1409	General Relativity and Cosmology	4

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Ph. D. Course Work -I Semester

		L	T	P	C	
RPE-CC -140	**Research & Publications Ethics**	**2**	**0**	**0**	**2**	**IA(Mid)-40** **EA(End Sem)-60**

Lectures Hrs: 30

Objectives: (1) To understand the concept of research.
(2) To learn about methodology and data collection and implementation.
(3) To learn about MATLAB.
(4) To find out the appropriate tool box of MATLAB to solve a specific problem.
(5) To learn about Mathematical writing using Latex.

Unit–I: Introduction to philosophy: definition, nature and scope, branches Ethics: definition, moral philosophy, nature of moral judgments and reactions.
Unit–II: Ethics with respect to science and research. Intellectual honesty and research integrity. Scientific misconducts: Falsification, Fabrication, and Plagiarism (FFP)
Unit–III: Redundant publications: duplicate and overlapping publications, salami slicing. Selective reporting and misrepresentation of data. Publication ethics: definition, introduction and importance.
Unit–IV: Best practices/standards setting initiatives and guidelines: COPE, WAME, etc. Conflicts of interest. Publication misconduct: definition, concept, problems that lead to unethical behavior and vice versa, types.
Unit–V: Violation of publication ethics, authorship and contributor ship. Identification of publication misconduct, complaints and appeals. Predatory publishers and journals.

Books Recommended:

1. Bird, A (2006). Philosophy of Science. Routledge.
2. Macintyre, Alasdair (1967) A Short History of Ethics: London.
3. P. Chaddah, (2018) Ethics in Cometitive Research: Do not get scooped; do not get plagiarized, ISBN: 978-387480865
4. National Academy of Sciences, National Academy of Engineering and Institute of Medicine. (2009). On Being a Scientist: A Gude to Responsible Conduct in Research: Third Edition. National Academies Press.
5. Resnik, D.B. (2011) What is ethics in research & why is t/it important National Institute of Environmental.
6. Health Sciences 1-10 Retrieved from http://www.nih.gov/research/resources/bioethics/whatis/index.cfm
7. https://doi.org/101038/489179a
8. Indian national Science Academy (INSA), ethics in Science Education, Research and Governance (2019), ISBN:978-81939482-1-7. http://www.insaindia.res.in/pdf/EthicsBookpdf

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Ph. D. Course Work -I Semester

MTS-CC-141	**Research Methodology with Computer Applications**	**L**	**T**	**P**	**C**	**IA(Mid)-40**
		4	**0**	**0**	**4**	**EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) To understand the concept of research.
(2) To learn about methodology and data collection and implementation.
(3) To learn about MATLAB.
(4) To find out the appropriate tool box of MATLAB to solve a specific problem.
(5) To learn about Mathematical writing using Latex.

Unit–I: Objectives and Motivation of research. Types of research: descriptive vs. analytical, Applied vs. fundamental, Quantitative vs qualitative, Conceptual vs empirical. Research formulation. Research design and methods.
Unit–II: Data collection and analysis. Observation and Collection of data. Method of data collections. Sampling method. Scientific report and thesis writing. Application of results and ethics, Copy right-royalty, intellectual property rights and patent law. Plagiarism, citations and acknowledgement.
Unit–III: Mathematical and Statistical Softwares: MATLAB – Introduction to MATLAB. MATLAB basics. Branching statements and loops.
Unit–IV: User-defined functions, Solving differential equations in MATLAB, SPSS (Statistical Software). Basics of MATHEMATICA.
Unit–V: Latex -Text and Maths, words, sentences, paragraphs. Command and environment. Document structure. Article class. Comments and footnotes. Change font characters. List environment. Style and size environment. Bibliography using Latex, Research paper writing. Thesis writing. Presentation using beamer class.

Learning Outcomes: After completion of this course the students will be able to understand the concept of Research. They will be able to write the synopsis report and can apply the Mathematical software in own research works.

Essential Readings:

1. George Gratzer, More Maths into Latex, 4th edition, Springer, 2007.
2. Brian R. et al., A guide to Matlab for beginners and experienced users, CUP, 2001.

Suggested Readings:

1. C.R. Kothari, Research Methodology: Methods and Techniques, New Age International Pub., 1990.
2. B.L. Wadehra, Law relating to patents, trademarks, copy right, designs and geographical indications, Universal law publishing, 2000.
3. Stephen J. Chapman, Matlab programming for engineers, 2003.
4. Leslie Lamport, Latex: A document preparation system, Addison Wesley Publishing Comp., 1994.

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Ph. D. Course Work -I Semester

		L	T	P	C	
MTS-CC-142	History of Mathematics & Modeling	4	0	0	4	IA(Mid)-40 EA(End Sem)-60

Lectures Hrs: 60

Objectives: (1) To introduce the origin of Mathematics and Statistics.
(2) To teach modeling of Phenomenon.
(3) To acquainted with application of Mathematics and Statistics.
(4) To introduce Numerical techniques.
(5) To provide the knowledge of item inventory and optimization.

Unit–I: History of Mathematics and Statistics: Origins and counting in Mathematics, Babylon; 1700 to 300 B.C. Contributions of Indian Statisticians and Mathematician.
Unit – II: Development of Vedic mathematics, Jaina tradition and astronomy tradition.
Unit – III: Application Mathematical modeling, need, techniques. Classifications. Mathematical modeling through different equations.
Unit – IV: Mathematical modeling through mathematical programming. Application of Statistical tools : calculus in daily life, different equations, Rocket launch trajectory analysis.
Unit –V: Numerical analysis: curve fitting, Interpolation etc. Operations Research and optimization. Inventory control for factory parts, different inventory models, reliability and uncertainty of large scale physical simulations.

Learning Outcomes: After completion of this course the students will be able to understand the origin of Mathematics and Statistics, Mathematical modeling, application of Mathematical and Statistical tools, concepts of numerical analysis, techniques of curve fitting, forecasting through interpolation and optimization in Operations Research.

Essential Readings:

1. B.O.' Neill, Semi-Riemannan Geometry with application to Reliability, Academic Press,1983.
2. Oscar, E. Fernandez: Everyday Calculus: Discovering the Hidden Math All around Us, Printsasia, University Press, 2014.

Suggested Readings

1. Jacqueline Stedall: The History of Mathematics: A Very Short Introduction, Printsasia, New York.
2. B.B. Datta and A.N. Singh: History of Hindu Mathematics, A Source Book, (2 volumes), Motilal Banarasidas, 1935 (Part I) and 1938 (Part II), Asia Publishing House, Bombay, 1962 (reprint), Bharatiya Kala Prakashan.
3. B. N. Mandal, A. Chakrabarti: Applied Singular Integral Equation. CRC, 2011.
4. J. N. Kapoor: Mathematical modeling: New Age International Publishers, New Delhi.

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Ph. D. Course Work -I Semester

MTS-EC-1402	**Fixed Point Theory and Application**	**L**	**T**	**P**	**C**	**IA(Mid)-40**
		4	**0**	**0**	**4**	**EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) To study the basic features of Metric Spaces.
(2) To introduce Fixed point theory.
(3) To explain use of Banach Contraction Principle.
(4) To introduce Hilbert Spaces.
(5) To learn properties of Topological Fixed-Point Theory.

Unit – I: Introduction: Definition of Metric Spaces, Neighborhood, Interior point, Limit point, Open and Closed sets, Subspaces of metric spaces, Completeness.
Unit – II: Cantor's Intersection Theorem, Banach Space. Fixed point theory: Definition and examples of Fixed point and Common Fixed point.
Unit – III: Contraction mapping, Contractive mapping, non-Expansive mapping, Lipschitz mapping, Banach Contraction Principle and its Generalization.
Unit – IV: Fixed point of Brouwer and Schaunder, Fixed point theorem for multifunction, Hilbert Spaces.
Unit – V: Fuzzy sets, Fuzzy metric spaces, Menger spaces, Compatible mapping, Topological Fixed Point Theory.

Learning Outcomes: After completion of this course the students will be able to comprehend fixed point theory and one can apply it in various cases of interest.

Essential Readings:

1. An Introduction to Metric Spaces and Fixed Point Theory By Mohamed A. Khamsi and William A. Kirk in John Wiley, 2001.
2. The lefschetz fixed point theorem By R. F. Brown, in Scott, Foresman, London, 1971.

Suggested Readings:

1. Functional Analysis With Applications By B.Choudhary And Sudarsan Nanda; Wiley Eastern Limited.
2. Fixed Point Theorems By D.R. Smart, in Cambridge University Press, Cambridge,1974.

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Ph. D. Course Work -I Semester

MTS-EC-1403	**Mathematical Modelling in Biological Systems**	**L**	**T**	**P**	**C**	**IA(Mid)-40**
		4	**0**	**0**	**4**	**EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) To understand the concept of stability theory.
(2) To learn about interacting species modeling.
(3) To learn oscillatory behavior of interacting species models.
(4) To find out mathematical models using discrete differential equations.
(5) To learn about epidemic mathematical modeling.

Unit – I: Introduction to mathematical models. Stability of linear and nonlinear systems. Phase Plane method and qualitative solutions. Continuous Models: growth models, harvesting model, delay models, age distribution models, interaction populations models,
Unit – II: Lotka-Volterra models, competition models, mutualism models. Harvesting in two species models.
Unit – III: Models for molecular events. Limit cycles, oscillations and excitable systems. May's Model, ratio dependent model of two interacting species, two prey-one predator system with ratio-dependent.
Unit – IV: Discrete dynamics: linear models, graphical solutions of difference equations, equilibrium analysis, periodic-doubling and chaotic behavior, system of two difference equations. Food chain and Food web models. Stage-structured models. Introduction to Modelling Epidemics: Plague, Measles, T.V., Cancer, Malaria
Unit – V: Simple Epidemics Models: SI, SIS, SIR, SIRS, SEIS, SEIR. Stability of simple epidemics models. Models for disease with no immunity. Compartment Models in Epidemiology. Models for demographic effect, Disease as population control, Infective period of fixed length. Impulsive control in continuous and Discrete systems. Impulsive pest control models. Pulse vaccination epidemic models.

Learning Outcomes: After completion of this course the students will be able to solve real world problems from ecology and epidemiology using stability theory and they can also study the complex dynamics of the systems.

Essential Readings:

1. Fred Brauer and Carlos Castillo-Chavez, Mathematical Models in Population Biology and Epidemiology.
2. N.T.J. Bailey, The mathematical theory of infectious diseases and its applications. 2nd edition, 1975.

Suggested Readings and Links :

1. S.A. Levin, Frontiers in Mathematical Biology, Springer-Verlag, 1994.
2. Nicholas F. Britton, Essential Mathematical Biology, Springer, 2002.
3. J.D. Murray, Mathematical Biology, Springer (3rd Ed.), 2002.

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Ph. D. Course Work -I Semester

		L	T	P	C	
MTS- EC-1404	**Calculus on Manifolds**	4	0	0	4	**IA(Mid)-40** **EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) To teach the concept of continuity, differentiability on Euclidean spaces.
(2) To introduce inverse function theorem.
(3) To explain the Poincare lemma.
(4) To teach Fubini's theorem & Stoke's theorem.
(5) To explain the concept of orientations, integration on manifolds.

Unit–I: Functions on Euclidean spaces, continuity, differentiability; partial and directional derivatives, chain rule, inverse function theorem, implicit function.
Unit–II: Measure zero, content zero, integrable function, Fubini's theorem, partition of unity, change of variables. **Unit–III:** Integration on chains, tensors, differential forms, Poincare lemma, singular chains.
Unit–IV: Stoke's theorem for integrals of differential forms on chains, fundamental theorem of calculus. Differential manifolds (as subspaces of Euclidean spaces).
Unit–V: Differential functions on manifolds, tangent spaces, vector fields, differential forms on manifolds, orientations, integration on manifolds, Stoke's theorem on manifolds.

Learning Outcomes: After completion of this course, students will know the definitions of standard terms in differential manifolds. The students will able to know how to use and apply calculus on manifolds. They will know a variety of examples and counterexamples in differential manifolds with application.

Essential Readings:
1. L.H. Loomis and S. Sternberg, Advanced Calculus, Jones and Bartlett Publishers, 1990.

Suggested Readings:
1. M.Spivak: Calculus on Manifolds, Addison-Wesley, 1965.
2. J.R. Munkres: Analysis on Manifolds, Addison-Wesley, 1991.

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Ph. D. Course Work -I Semester

MTS-EC-1405	**Theory of Linear Operators**	**L**	**T**	**P**	**C**	**IA(Mid)-40**
		4	**0**	**0**	**4**	**EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) Discuss the spectral properties of bounded linear operators in normed linear spaces.
(2) Importance of Spectral mapping theorem for polynomials.
(3) Understanding of Banach algebras and compact linear operators.
(4) Applications of compact linear operators in the operator theory.
(5) Idea to introduce Fredholm theory in the functional analysis.

Unit – I: Spectral theory in normed linear spaces, Resolvent set and spectrum, Spectral properties of bounded linear operators.
Unit - II : Properties of resolvent set and spectrum, Spectral mapping theorem for polynomials, Spectral radius of a bounded linear operator on a complex Banach space.
Unit – III: Elementary theory of Banach algebras, General properties of compact linear operators.
Unit – IV: Spectral properties of compact linear operators on normed spaces, Behaviors of compact linear operators with respect to solvability of operator equations.
Unit – V: Fredholm type theorems, Fredholm alternative theorem, Fredholm alternative for integral equations.

Learning Outcomes: In the end of the course, students will able to understand the spectrum of bounded linear operators. They learn to use compact linear operator and also, know the technique of solving operator equations using Fredholm Theory.

Essential Readings:

1. P.R. Halmos, Introduction to Hilbert Space and the Theory of Spectral Multiplicity, Second-Edition, Chelsea Publishing Co., N. Y. 1957.N. Dunford and J.T. Schwarz, Linear Operators-3 parts, Inter science / Wiley, New York, 1958-71.
2. N.I. Akhiezer and I.M. Glazman, Theory of Linear in Hilbert space, Frederick Ungar Pub. Co., N.Y. Vol. I (1961), Vol. II (1963).

Suggested Readings:

1. E. Kreyszig, Introductory Functional Analysis with applications, John-Wiley & Sons, New York, 1978.
2. G. Bachman and L. Narici, Functional Analysis, Academic Press, New York, 1966.

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		L	T	P	C	
MTS-EC-1406	**Advanced Numerical Analysis**	4	0	0	4	**IA(Mid)-40** **EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) To teach the Approximation of functions, Least square & Pade's approximation.
(2) To introduce family of Runge-Kutta methods to solve IVP.
(3) To explain Finite difference method, cubic spline method to solve BVB.
(4) To solve Parabolic, Elliptic and Hyperbolic partial differential numerically.
(5) To introduce finite element method, Galerkin method.

Unit – I: Approximation of functions, General function spaces, Least square approximation, Minimax approximation, orthogonal polynomials, approximation with rational functions, Pade's approximation.
Unit – II: Nonlinear system of differential equations- method of successive approximations, Use of Pade's approximation. Solution of initial value problems of ordinary differential equations, family of Runge-Kutta methods.
Unit – III: Boundary Value Problems, Finite difference method, cubic spline method. Difference scheme based on quadrature formulas, solution of tridiagonal system, moving boundary conditions, boundary conditions at infinity, Non-linear boundary value problems, convergence of difference schemes, linear Eigen-value problems. Numerical solution of integral equation.
Unit – IV: Partial Differential Equations: Parabolic, Elliptic and Hyperbolic differential equations subject to Dirichlet's, Neumann (or flux) and mixed (or Robin or Radiation) conditions, Stefan problem, Basic concept of finite element method, weak formulation of BVP, Ritz Method.
Unit – V; Piecewise polynomial spaces and finite element method, Computer implementation of FEM.,Galerkin method, Weighted residuals, method, initial boundary value problems of partial differential equations.

Learning Outcomes: After completion of this course, students will learn the several numerical techniques for the numerical solution of initial value and boundary value problems. They can learn specially learn Runge-Kutta methods, Finite difference method, cubic spline method for BVP. They can also learn finite element method, Galerkin method for BVP in partial differential equations. They will know a variety of numerical examples and derivation of several numerical methods.

Essential Readings:

1. M.K. Jain: Numerical solution of differential equations, Wiley Eastern, 2nd Ed. 1979.
2. S.C. Chapra and P.C. Raymond: Numerical Methods for Engineers, Tata McGraw Hill, New Delhi
3. C. S. Desai and John F.Abel.. Introduction to Finite Elements Method, Litton Educational Publishing Inc.

Suggested Readings:

1. C.F. Gerald and P.O. Wheatley : Applied Numerical Methods, Low- priced edition, Pearson Education Asia, Sixth Edition, 2002
2. Kendall E. Atkinson. An Introduction to Numerical Analysis, John Wiley & Son.
3. M. K. Jain, S. R. K. Iyengar and R.K. Jain: Numerical methods for scientific and engineering computation, Wiley Eastern Ltd. Third Edition, 1993
4. J. N. Reddy, Finite Element Method, Tata Mc Graw Hill.

E book links:

1. https://ndl.iitkgp.ac.in/document/yrkSXQ8kY7bdDL5Wta9S52nGjiSWUgsZ2ra-aRFr7frtpV05RPPZulKj0MobziF2#0.
2. https://ndl.iitkgp.ac.in/result?q={%22t%22:%22search%22,%22k%22:%22Applied%20Numerical%20Methods%2C%20C.F.%20Gerald%20and%20P.O.%20Wheatley%22,%22s%22:[],%22b%22:{%22filters%22:[]}}

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Ph. D. Course Work -I Semester

		L	T	P	C	
MTS-EC-1407	**Inventory Modeling and Optimization**	**4**	**0**	**0**	**4**	**IA(Mid)-40** **EA(End Sem)-60**

Lectures Hrs: 60

Objectives:

(1) To understand importance of inventory and production system
(2) To develop replenishment policy
(3) How to make production policy
(4) To develop probabilistic inventory model
(5) Formulation of setup cost model.

Unit – I: Inventory & Production Management**:** Deterministic inventory models of uniform rate of demand and non- uniform rate of demand.
Unit – II: Economic lot-size with finite rate of replenishment. Economic order quantity models with constant rate of demand. Production lot size model with shortage
Unit – III: Buffer stock. Production planning and inventory control.
Unit – IV: Probabilistic inventory models, Fixed order quantity model.
Unit – V: Probabilistic order–level system with constant lead time. Instantaneous demand no set-up cost model and Uniform demand no set-up cost model.

Learning Outcomes: The course is building capabilities in the students for analyzing different situations in the industrial/ business scenario involving limited resources and finding the optimal solution within constraints. After completion the course student, be able to design new inventory models by incorporating new parameters. This course has been designed for research purpose in this way the researcher may identify new inventory problems and formulae them to get optimal solution.

Essential Readings :

1. H. A. Taha: Operations Research- An Introduction, Macmillan publishing INC., New-York.
2. S. D. Sharma: Operations Research, Kedar Nath Ram Sons co.Publisher Meerut thirteenth - edition) 2001.
3. Kanti Swarup, P.K. Gupta & Man Mohan: Operations Research, Sultan Chand & sons, New Delhi.
4. Edward A. Silver, David F. Payke and Rein Peterson: Inventory Management and Production Planning and Schedeling, (third edition). John Wiley & Sons.
5. Khedlekar U K and Shukla, D, Advanced Inventory Models: Aman Prakashan Sagar MP.
6. S. C. Sharma: Operations Research inventory control and Queuing theory, Discovery publishing house Delhi.

Suggested Reading and Links

1. **Video lecture** on Inventory Management | Concepts, Examples and Solved Problems
   Link https://www.youtube.com/watch?v=2n9NLZTIlz8
2. Video lecture on Probabilistic Model (Inventory Model)
   Link https://www.youtube.com/watch?v=9qtgQK3BQTk

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Ph. D. Course Work -I Semester

		L	T	P	C	
MTS-EC-1408	**Nonlinear Analysis and Optimization**	**4**	**0**	**0**	**4**	**IA(Mid)-40** **EA(End Sem)-60**

Lectures Hrs: 60

Objectives: (1) To inculcate the basic features convex analysis and Optimization.
(2) To teach convex functions and its properties.
(3) To acquainted with Optimality conditions in nonlinear programming.
(4) To introduce Fritz John and KKT conditions.
(5) To teach Lagrangian duality and constraint qualifications.

Unit – I: Convex sets, convex hulls, closure and interior of a set, separation and support of sets, convex cones and polarity, polyhedral sets, extreme points, and extreme directions, Linear programming and the Simplex method.
Unit-II: Convex functions and generalizations, definitions and basic properties, sub gradients of convex functions, differentiable convex functions, minima and maxima of convex functions, generalizations of convex functions.
Unit-III: Optimality conditions and duality, the Fritz John and Karush-Kuhn-Tucker optimality conditions, unconstrained problems, problems with inequality constraints.
Unit – IV: Problems with equality constraints, second-order necessary and sufficient optimality conditions for constrained problems. Constraint qualifications, cone of tangents, other constraint qualifications, problems with inequality and equality constraints.
Unit – V: Lagrangian duality and saddle point optimality conditions Lagrangian dual problem, duality theorems and saddle point optimality conditions, properties of the dual function, formulating and solving the dual problem, getting the primal solution, Linear and Quadratic programs

Learning Outcomes: After completion of this course the students will be able to understand the convex functions and its properties, Optimality conditions in nonlinear optimization, two important optimality conditions: Fritz John and KKT conditions and they will learn various notions constraint qualifications.

Essential Readings:

1. **R. T. Rockafellar:** Convex Analysis, Princeton University Press, 1970.
2. **O. L. Mangasarian:** Nonlinear Programming, SIAM, 1994.
3. **D. P. Bertsekas, A. Nedic, A. E. Ozdaglar:** *Convex Analysis and Nonlinear Optimization*, Athena Scientific, 2003.

Suggested Readings:

1. **M. S. Bazaraa, H. D. Sherali, C. M. shetty:** Nonlinear Programming, Theory and Algorithms, John Wiley & Sons, 2006.
2. **Edwin K. P. Chong and Stanislaw H. Zak:** An Introduction to Optimization, John Wiley & Sons, 2001.
3. **E book links:** National Digital Library

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Department of Mathematics and Statistics
Ph. D. Course Work -I Semester

		L	T	P	C	
MTS- EC-1409	General Relativity and Cosmology	4	0	0	4	IA(Mid)-40 EA(End Sem)-60

Lectures Hrs: 60

Objectives: (1) To study curvature tensor & Geodesic postulate.
(2) To understand Einstein's field equations.
(3) To explain models of the Universe.
(4) To study the expanding Universe & its properties.
(5) To understand Dark energy & matter & Cosmic inventory.

Unit-I: Metric tensor, Christoffel symbols, Covariant differentiation, Riemannian curvature tensor, Covariant curvature tensor, Mach's principle, Geodesic postulate.
Unit-II: Newtonian approximation of equation of motion, Einstein's field equation for matter and empty space.
Unit III: The standard model: The expanding universe, The Hubble diagram, Big bang Nucleosynthesis, The cosmic Microwave Background, Beyond the standard Model.
Unit-IV: The Smooth and Expanding Universe: General Relativity, Distances.
Unit-V: Evolution of Energy, Cosmic inventory, Photons, Baryons, Matter, Neutrinos, Dark energy.

Learning Outcomes : After completion of this course the students will be able to understand about Universe and it will understand how Universe is expand & how to generate Einstein field equations of the models.

Essential Readings:

1. **Einstein, A.(1955):** The meaning of Relativity, Princeton University Press Princeton , New Jersey.
2. **Narlikar, J. V. (2002):** Introduction to Cosmology, Cambridge University Press, Cambridge.
3. **Misner, C.W., Thorne, K.S. and Wheeler, J.A. (1970):** Gravitation, Freeman, San Fransisco.

Suggested Readings:

1. **Narlikar, J. V:** An Introduction to Relativity, Cambridge University Press, New Delhi.
2. **Roy, S.R. and Bali, R.:** Theory of Relativity, Jaipur Publishing House, Jaipur.
3. **Dodelson, S. :** Modern Cosmology, Academic Press, California, USA.
4. **Eisenhart, L.P. (1949) :** Riemannian Geometry, Princeton University Press, Princeton.

E book links: National Digital Library

11-6-24

Passed by Board of Studies Dated 11/06/24

DOCTOR HARISINGH GOUR VISHWAVIDYALAYA, SAGAR
(A Central University)
Department of Mathematics and Statistics
Ph. D. Course Work -I Semester

MTS- CC-143	**Review of Published Research Work**	**L**	**T**	**P**	**C**	**IA(Mid)-40**
		4	**0**	**0**	**4**	**EA(End Sem)-60**
Concern Research Advisor/Supervisor						

Lectures Hrs: 60

Passed by Board of Studies Dated. 11/06/24

School Board Meeting held on 14th June, 2024

The School Board has approved the minute of meeting of BOS of Department of Mathematics and Statistics held on 11/06/2024.

Prof. A.K. Saxena
External Member
Department of Mathematics, Maharaja Chhatrasal University, Chhatarpur (M.P.)

Prof. K.S. Varsney
External Member
HoD Physics, D.S. College, Aligarh, U.P.

Prof. Narendra Pandey
External Member
Department of Physics,
University of Lucknow (U.P.)

Prof. Diwakar Shukla
Member
HoD, Department of Mathematics & Statistics
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. Ashish Verma
Member
HoD, Department of Physics
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. R.K. Rawat
Member
Department of Applied Geology,
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. Ranveer Kumar
Member
Department of Physics
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. U.K. Patil
Member
Department of Pharmaceutical Science,
Dr. Harisingh Gour V.V., Sagar (M.P.)

Dr. Abhishek Bansal
Member & Associate Professor
HoD, Department of Computer Science & Applications
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. U.K. Khedlekar
Member & Associate Professor
Department of Mathematics & Statistics,
Dr. Harisingh Gour V.V., Sagar (M.P.)

Dr. Rekha Garg Sonaki
Member & Associate Professor
Department of Physics
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. Kamal Kant Ahirwar
Member & Assistant Professor
Dept. of Computer Science & Applications
Dr. Harisingh Gour V.V., Sagar (M.P.)

Dr. Mahesh Kumar Yadav
Member & Assistant Professor
Department of Physics
Dr. Harisingh Gour V.V., Sagar (M.P.)

Dr. Maheshwar Panda
Member & Assistant Professor
Department of Physics
Dr. Harisingh Gour V.V., Sagar (M.P.)

Ms. Shivani Khare
Member & Assistant Professor
Department of Vedic Studies
Dr. Harisingh Gour V.V., Sagar (M.P.)

Prof. R.K. Tangele
Chairman, School Board & Dean, SMPS
Dr. Harisingh Gour V.V., Sagar (M.P.)