RAMAKRISHNA MISSION VIVEKANANDA CENTENARY COLLEGE

RAHARA, KOLKATA-700118

DEPARTMENT OF MATHEMATICS

SESSION 2018-19

Syllabus for M.Sc. Mathematics Under CBCS

The course of M. Sc. Mathematics is introduced under CBCS syllabus, 2018 vide BOS resolution dated 23.03.2018 with 100% modification

PROGRAMME OUTCOMES

After completion of the M.Sc. Degree programme, the students will be able to

PO No.	PROGRAMME OUTCOMES	Cognitive Level
PO 1	Outline and demonstrate the basic concepts by acquiring a comprehensive knowledge in the newer emerging field of knowledge.	R, U
PO 2	Perform experiments, analyse & interpret the obtained accurate results and thus gain the ability to solve problems.	Ap, An, E
PO 3	Apply and evaluate the basic ideas to their thoughts, actions, and interventions for the societal benefits through the development of entrepreneurships.	Ap, E
PO 4	Develop the ability to involve in critical, independent, and inventive thinking for the engagement in research and development on the emerging topics.	C

R= remembering, U = understanding, Ap = applying, An = analysing, E = evaluating, and C = creating

PROGRAM SPECIFIC OUTCOME

At the end of the program, the student will be able to:

PSO No.	Program Specific Outcome	Cognitive Level
PSO1	Understand the nature of abstract mathematics and explore the concepts in further details.	R, U
PSO2	Apply the knowledge of mathematical concepts (both pure and applied mathematics) in interdisciplinary fields.	Ap
PSO3	Continue to acquire mathematical knowledge and skills appropriate to professional activities and demonstrate highest standards of ethical issues in mathematics.	R, An
PSO4	Apply the knowledge of mathematical software and tools for treating complex mathematical problems and scientific investigations and explore ideas of mathematics for propagation of knowledge and popularization of mathematics in society.	Ap, E
PSO5	Model the real-world problems into mathematical equations and draw the inferences by finding appropriate solutions.	E, C
PSO6	Comprehend and write effective reports and articles and design documentation related to mathematical research and literature, make effective presentations.	C

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Course Structure: Semester-wise distribution of Courses

Semester-I		
Course Code	**Title**	**Credits**
PGMATHCC101	Algebra-I	4
PGMATHCC102	Real Analysis	4
PGMATHCC103	Complex Analysis	4
PGMATHCC104	Ordinary & Partial Differential Equations	4
PGMATHCC105	Numerical Analysis	4
PGMATHCC106	Computer Programming in C++ and Numerical Practical using GNU Octave/Scilab /Matlab	4
Soft Skill-1		
PGMATHSS01	YOGA	1
Semester-II		
PGMATHCC201	Algebra-II	4
PGMATHCC202	Measure and Integration	4
PGMATHCC203	General Topology	4
PGMATHCC204	Classical Mechanics & Theory of Relativity	4
PGMATHCC205	Linear Algebra & Multivariate Calculus	4
PGMATHCC206	Integral transforms and Integral Equations	4
Soft Skill-2		
PGMATHSS02	Communicative English	1
Semester-III		
CC(Core Course)		
PGMATHCC301	Functional Analysis	4
PGMATHCC302	Dynamical System Analysis	4
CE(Core Elective-Any Three)		
PGMATHCE301	Advanced Real Analysis-I	4
PGMATHCE302	Advanced Complex Analysis-I	4
PGMATHCE303	Algebraic Topology-I	4
PGMATHCE304	Differential Manifold-I	4
PGMATHCE305	Cosmology-I	4
PGMATHCE306	Mathematical Biology-I	4
PGMATHCE307	Operation Research-I	4
PGMATHCE308	Continuum Mechanics (Solid)-I	4
Under CBCS a student from our department / Courses will be taught as AE (Allied Elective) by Computer Science Department.		
PGMATHAE301	Programming in PYTHON & LaTex	4
Soft Skill-3		
PGMATHSS03	VE & IC	1
Semester-IV		
CC (Core Course)		

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PGMATHCC401	Number theory	4
PGMATHCC402	Discrete Mathematics	4
CE (Core Elective-Any Three)		
PGMATHCE401	Advanced Real Analysis-II	4
PGMATHCE402	Advanced Complex Analysis-II	4
PGMATHCE403	Algebraic Topology-II	4
PGMATHCE404	Differential Manifold-II	4
PGMATHCE405	Cosmology-II	4
PGMATHCE406	Mathematical Biology-II	4
PGMATHCE407	Operation Research-II	4
PGMATHCE408	Continuum Mechanics (Fluid)-II	4
Project Work		
PGMATHCC403	Project Work (Viva Voce + Dissertation)	4
Soft Skill-4		
PGMATHSS04	Seminar Presentation	1
Total Credits (Semester-I+II+III+IV)		**200**

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Semester-wise detailed syllabus

SEMESTER – I	
Name of the Course: **ALGEBRA-I**	
Course Code: **PGMATHCC101**	
Full Marks: 50	Credits: 4
Theory	Credits:4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC101)

The prime objectives of the course are:

- To give students a foundation for all future mathematics courses.
- Understand the fundamentals of algebraic problem-solving.
- Explore the foundations of Algebraic structures, Groups, Rings, Ideals, Fields, Homomorphisms, etc.
- To make students aware of the applicability of abstract mathematics in real world problems.

Course Content

Algebra-I

Unit-I: Isomorphism theorems of groups, external direct product and internal direct product of groups, direct product of cyclic groups, semi direct products, classification of all groups of order $\leq$ 12, group actions, Cayley's theorem, extended Cayley's theorem, Burnside theorem, conjugacy classes, class equation. [12]

Unit-II: Cauchy's theorem on finite groups, p-group, Centre of p-groups. Sylow's theorems, some applications of Sylow's theorems, Simple groups, non-simplicity of groups of order p^n (n > 1), pq, p^2q, p^2q^2 (p, q are primes), determination of all simple groups of order ≤ 60, non-simplicity of A_n ($n \geq 5$). [12]

Unit-III: Finite groups, structure theorem for finite Abelian groups, normal and subnormal series, composition series, Jordan–Holder theorem, solvable groups and nilpotent groups. [10]

Unit-IV: Ideal, quotient ring, ring embeddings, Euclidean domain, principal ideal domain, prime elements and irreducible elements, maximal ideals, maximal ideals in some familiar rings of functions, maximal ideals space of a ring, prime ideals, primary ideals. [14]

Unit-V: Polynomial ring and factorization of polynomials over a commutative ring with identity, the division algorithm in K[x] where K is a field, K[x] as Euclidean domain, unique factorization domain (UFD), if D is UFD then so are D[x] and D [x1, x2, . . . , xn]. [14]

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Question Pattern for End Semester Examination (Course Code: PGMATHCC101)

Part A (Algebra-I, 25 Marks)

1. Attempt 5 questions out of 7 questions and each question carries 2 marks $=5\times2=10$
2. Attempt 3 questions out of 5 questions and each question carries 5 marks $=3\times5=15$

Part B (Algebra-I, 25 Marks)

3. Attempt 5 questions out of 7 questions and each question carries 2 marks $=5\times2=10$
4. Attempt 3 questions out of 5 questions and each question carries 5 marks $=3\times5=15$

Course Outcomes (PGMATHCC101)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Define algebraic structures	R	PO1	PSO1
CO2	Construct substructures	Ap	PO2, PO3	PSO2
CO3	Analyse a given structure in detail	An	PO1, PO2	PSO3
CO4	Compare structures viz. Groups, rings, fields	E	PO2, PO3	PSO4
CO5	Develop new structures based on given structures	C	PO4	PSO6

Recommended Books

1. I.N. Herstein . Topics in Algebra. Wiley Eastern Ltd. New Delhi 1975. 2.J. B. Fraleigh, Basic Algebra, Narosa pub.
2. Joseph A. Gallian, Contemporary Abstract Algebra, Narosa Pub.
3. Books for Reference:
4. P.B. Bhattacharya, S.K.Jain and S.R. Nagpaul. Basic Abstract Algebra (2nd Edition) Cambridge University, Press Indian Edition 1997.
5. M. Artin Algebra, Prentice-Hall of India 1991
6. N. Jacobson, Basic Algebra Vols I and II Freeman 1988 (Kalse Published by Firncustan Publishing Company.)
7. S. Lang Algebra 3rd edition. Addison-Westely 1993
8. O. S. Luther and I.B.S. Passi, Algebra Vol. I-Groups. Vol. II-Rings, Narosa Publishing House (Vol 1-1996 Vol. II 1- 1999)
9. D. S. Malik & N. Mordeson and M. K. Sen Fundametnals of Abstract Algebra, Mc. Graw Hill International Edition, 1997.

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SEMESTER – I	
Name of the Course: **Real Analysis**	
Course Code: **PGMATHCC102**	
Full Marks: 60	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC102)

The prime objectives of the course are:

- To provide a deeper and rigorous understanding of fundamental concepts viz. metric spaces, continuous functions, sequences and series of numbers as well as functions, and the Riemann-Stieltjes integral etc.
- To provide a theoretical foundation of the above said concepts and it will cultivate the rigorous mathematical logics and skills in the students.
- To develop the concept of open ball in Euclidean space $\mathbb{R}$n, covering of a set through open balls and some basic results of metric space, continuity and differentiability in $\mathbb{R}$n in addition to the concept of bounded variation and its properties.
- To develop the understanding of uniform convergence and Riemann Stieltjes integral and its properties.

Course Content

REAL ANALYSIS

Unit-1: Cardinal numbers, ordering of cardinal numbers, Schröder- Bernstein theorem, arithmetic of cardinals, axiom of choice, continuum hypothesis. [10]

Unit-II: Functions in $\mathbb{R}$: Convex functions and its simple properties, absolutely continuous functions and its properties, Weierstrass approximation theorem and its consequences. [10]

Unit-III: Lebesgue measure: Concept of algebra and σ -algebra generated by a class of subsets, Borel sets, Lebesgue outer measure on $\mathbb{R}$, Caratheodory extension procedure of measure approximation of Lebesgue measurable sets by topologically well-known sets, existence of non-measurable sets, Cantor sets, Lebesgue's criterion of Riemann integrability of a bounded function on [a, b] and its simple properties. [15]

Unit-IV: Derivatives: Concept of Vitali covering and statement of Vitali covering theorem, Application of Vitali covering on the derivative of absolutely continuous functions, Weierstrass non-differentiable function, Dini's derivatives and its basic properties, Riemann- Stielljes integral on [a,b] and its properties. [15]

Unit-V: Metric Spaces: Completeness and Baire Category theorem, Totally boundedness, Compactness, Continuity and uniform continuity, Banach fixed point theorem. [10]

Question Pattern for End Semester Examination (Course Code: PGMATHCC102)

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Part A (REAL ANALYSIS, 25 Marks)

1. Attempt 5 questions out of 7 questions and each question carries 2 marks =5×2 = 10
2. Attempt 3 questions out of 5 questions and each question carries 5 marks =3×5 = 15

Part B (REAL ANALYSIS, 25 Marks)

3. Attempt 5 questions out of 7 questions and each question carries 2 marks =5×2 = 10
4. Attempt 3 questions out of 5 questions and each question carries 5 marks =3×5 = 15

Course Outcomes (PGMATHCC102)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Demonstrate an understanding of limits and how that are used in sequences, series and differentiation.	R, U	PO1	PSO1
CO2	Appreciate how abstract ideas and region methods in mathematical analysis can be applied to important practical problems.	U, Ap	PO2, PO3	PSO2
CO3	Describe fundamental properties of the real numbers that lead to the formal development of real analysis.	An	PO1, PO2	PSO3
CO4	Comprehend regions arguments developing the theory underpinning real analysis	E	PO2, PO3	PSO4
CO5	Construct rigorous mathematical proofs of basic results in real analysis.	C	PO3, PO4	PSO5

Recommended Books

1. Mathematical Analysis (5th edition) – T. Apostol, Addison-Wesley; Publishing Company, 2001.
2. Measure Theory and Integration- G. De. Berra,
3. Real Analysis- A. Bruckner, J. Bruckner and B. Thomson,
4. Theory of functions of a real variable, Vol. I, II - I.P. Nantanson,
5. Basic Real and Abstract Analysis- J.F. Randolph,
6. Principles of Mathematical Analysis (5th edition) – W. Rudin, McGraw Hill Kogakusha Ltd., 2004.
7. The Elements of Real Analysis (3rd edition) – R. G. Bartle, Wiley International i Edition, 1994.
8. Introduction to Real Analysis (3rd edition) – R. G. Bartle and D. R. Sherbert, John Wiley & Sons, Inc., New York, 2000.
9. Basic Real Analysis – H.H. Sohrab, Birkhäuser (2003).
10. Introduction to Topology and Modern Analysis (4th edition) – G. F. Simmons, McGraw Hill Kogakusha Ltd., 2000.
11. An Introduction to Measure and Integration- I.K. Rana,
12. Metric Spaces- P.K. Jain and K. Ahmad,
13. Lebesgue Measure and Integration- P.K. Jain and V.P.Gupta.

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SEMESTER – I	
Name of the Course: Complex Analysis	
Course Code: PGMATHCC103	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC103)

The prime objectives of the course are:

- To introduce and develop a clear understanding of the fundamental concepts of Complex Analysis such as analytic functions, Cauchy-Riemann relations and harmonic functions.
- To enable students to acquire skill of contour integration to evaluate complicated real integrals via residue calculus.
- To provide an introduction to the theories for functions of a complex variable.
- Equip students with the understanding of the fundamental concepts of complex variable theory.

Course Content

COMPLEX ANALYSIS

Pre-requisite: Functions of a Complex Variable, Mappings, Limits, Theorems on Limits, Limits Involving the Point at Infinity, Continuity, Derivatives, Cauchy–Riemann Equations, Sufficient Conditions for Differentiability, Polar Coordinates, Analytic Functions, Harmonic Functions, Uniquely Determined Analytic Functions. [5]

Unit I: Derivatives of Functions, Definite Integrals of Functions, Contour Integrals, Branch Cuts, Upper Bounds for Moduli of Contour Integrals, Antiderivatives, Cauchy–Goursat

Theorem, Simply Connected Domains, Cauchy Integral Formula, Morera's Thorem, Liouville's Theorem and the Fundamental Theorem of Algebra, Maximum Modulus Principle, Schwarz's lemma, Convergence of Sequences and series, Taylor Series, Laurent Series, Absolute and Uniform Convergence of Power Series, Runge Theorem. [25]

Unit II: Isolated Singular Points, Residues, Cauchy's Residue Theorem, Residue at Infinity, The Three Types of Isolated Singular Points, Residues at Poles, Zeros of Analytic Functions, Zeros and Poles, Behaviour of functions near isolated singular points, Casorati-Weirstrass Theorem, Evaluation of Improper Integrals, Jordan's Lemma, Definite Integrals Involving Sines and Cosines, Argument Principle, Rouche's Theorem, Contour integration. [20]

Unit III: Linear Transformations, The Transformation $w = 1/z$, Mappings by $1/z$, Linear Fractional Transformations, An Implicit Form, Mappings of the Upper Half Plane, The Transformation $w = \sin z$, Mappings by z2 and Branches of z1/2. [10]

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Question Pattern for End Semester Examination (Course Code: PGMATHCC103)

Part A (COMPLEX ANALYSIS, 50 Marks)

1. Attempt 2 questions out of 3questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCC103)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Represent functions as Taylor, power and Laurent series, classify singularities and poles, find residues and evaluate complex integrals using the residue theorem	R, U	PO1	PSO1
CO2	Apply the theory into application of the power series expansion of analytic functions, and understand the basic methods of complex integration and its application in contour integration	Ap	PO2, PO3	PSO2
CO3	Analyse the concept of metric space and some important theorem on complex analysis for solving different problems	An	PO1, PO2	PSO3
CO4	Evaluate complex contour integrals directly and by the fundamental theorem, apply the Cauchy integral theorem in its various versions, and the Cauchy integral Formula	Ap, E	PO2, PO3	PSO4
CO5	Compute Laurent series and its examples, absolute and uniform convergence of power series	C	PO4	PSO6

Recommended Books

1. R.V. Churchill and J.W. Brown, Complex Variables and Applications (eighth edition), Mc Graw Hill Publication
2. Foundation of Complex Analysis- S. Ponnusamy, Narosa Publication,Second Edition.
3. Functions of one Complex Variable - John B. Convey, Narosa Publishing House.
4. Complex Analysis - L. V. Ahlfors, Mc Graw Hill.
5. Functions of Complex Variables - H. Silverman
6. Complex Analysis - T.W. Gamelin, Springer Publications.

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SEMESTER – I	
Name of the Course: **Ordinary and Partial Differential Equations**	
Course Code: **PGMATHCC104**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC104)

The prime objectives of the course are:

- To introduce ordinary differential equations and fundamental theorems for existence and uniqueness.
- Explains the analytic techniques in computing the solutions of various ordinary differential equations appearing in various fields of science and technology.
- To learn quantitative information and qualitative methods which provide a good geometric understanding of ODE.
- Learn to solve boundary value problems including Sturm Liouville Problem and Green's function.
- To learn theory of partial differential equations, solution methods and nature of PDEs like parabolic, elliptic, hyperbolic.

Course Content

ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS

Unit- I: Power series solutions - Solution near ordinary and regular singular point. Convergence of the formal Power series, applications to Legendre, Bessel, Hermite, Laguerre and Hypergeometric differential equations with their properties. [12]

Unit –II: Boundary value problems - Transforming Boundary value problem of PDE and ODE, Sturm - Liouvile system, eigen values and eigen functions, simple properties, expansion in eigen functions, Parseval's identity, Green's function method. [12]

Unit-III: Classification of second order PDE, one dimensional wave equation, Laplace equation, Theory of Green's function for Laplace equation, Heat conduction problem, Duhamel's principle. [12]

Unit -IV: Fourier Series: Piecewise Continuous Functions, Fourier Cosine Series, Fourier Sine Series, Fourier series, adaptations to other intervals. [12]

Unit -V: Convergence of Fourier Series: One-Sided Derivatives, A Property of Fourier Coefficients, Two lemmas, A Fourier Theorem, Discussion of the theorem and its corollary, convergence on other intervals, A Lemma, Absolute and Uniform Convergence of Fourier Series, Differentiation of Fourier Series, Integration of Fourier Series. [12]

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Question Pattern for End Semester Examination (Course Code: PGMATHCC104)

Part A (ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCC104)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Identify real phenomena as models of partial derivative equations.	U	PO1	PSO1
CO2	Classify differential equations and solve them.	An	PO1, PO2	PSO3
CO3	Apply specific methodologies, techniques and resources to conduct research and produce innovative results in the area of specialisation.	Ap, E	PO2, PO3	PSO4
CO4	Extract information from partial derivative models in order to interpret reality.	E	PO2, PO3	PSO4
CO5	Solve the basic application problems described by differential equations.	E, C	PO3, PO4	PSO5

Recommended Books

1. T. Amarnath: An elementary course in PDE (2nd edition), Narosa Publishing House.
2. R.V. Churchill and J. Brown.: Fourier Series and Boundary Value Problems, 7th edition, McGraw-Hill Book Company.
3. G. F. Simmons, Differential Equations with Applications and Historical Notes, (2nd edition) Mc Graw Hill Book Co.
4. G. Birkhoff and G. C. Rota, Ordinary Differential Equations, John Wiley and Sons.
5. W.E. Williams: "Partial Differential Equations", Claredon Press Oxford.
6. E.T. Copson: "Partial Differential Equations", Cambridge University Press
7. E. A. Coddington and N. Levinson – Theory of Ordinary Differential equations, Tata McGraw-Hill, New Delhi.
8. R. Courant and D. Hilbert – Methods of Mathermatical Physics, Vol. I. & II, Tata McGraw-Hill, New Delhi, 1975.
9. I. N. Sneddon – Theory of Partial differential equations, McGraw-Hill, International Student Edition.

SEMESTER – I	
Name of the Course: **Numerical Analysis**	
Course Code: **PGMATHCC105**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC105)

The prime objectives of the course are:

- To introduce the basic concepts of Numerical Mathematics.
- Learn to solve the problems arising in various fields of application, for example in science, engineering and economics etc. that are difficult to deal with analytically.
- Develop and analyse the application of different numerical methods to solve the problems, viz. system of linear & nonlinear equations, numerical initial and boundary value problems of ordinary differential equations etc.

Course Content

NUMERICAL ANALYSIS

Unit 1: Numerical Solution of System of Linear Equations: Triangular factorisation methods, Matrix inversion method, Operation counts, Iterative methods, Convergence condition of Gauss- Seidel method, Successive-Over-Relaxation (SOR) method. Eigenvalues and Eigenvectors of Real Matrix: Power method for extreme eigenvalues and related eigenvectors, Jacobi's method for symmetric matrix (algorithm only), Given's method and Hosue-holder's reflections; QR method. [20]

Unit 2: Solution of Non-linear Equations: Modified Newton-Raphson method; Aitken's δ2-method and Steffensen's iteration; Bairstow's method. Non-Linear Systems of Equations: Newton's method, Quasi-Newton's method. [10]

Unit 3: Polynomial Interpolation: Runge's phenomena, piecewise polynomial interpolation; Cubic spline interpolation. Approximation of Functions: Least squares polynomial approximation, Approximation with orthogonal polynomials, Chebyshev polynomials economization, Harmonic analysis. [10]

Unit 4: Numerical Integration: Problem of approximate quadrature, Trapezoidal and Simpson's rule with error formula; Newton-Cotes formulae, Gauss-Legendre and Gauss-Chebyshev quadratures, Euler-Maclaurin summation formula, Richardson extrapolation, Romberg integration, Simpson's adaptive quadrature, Double integrals and Cubature formula of Simpson Type, Improper integrals. [10]

Unit 5: Numerical Solution of Initial Value Problems for ODE:

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First Order Equation: Runge-Kutta methods, Multistep predictor-corrector methods, Adams-Bashforth method, Adams-Moulton method, Milne's method, Convergence and stability. Higher Order Equations: Stiff differential equations.

Two-point Boundary Value Problems for ODE: Finite difference methods, Shooting method. Numerical Solution of PDE by Finite Difference Methods: Parabolic equation in one dimension (Heat equation). Explicit finite difference method, Implicit Crank-Nicolson method, Hyperbolic equation in one-space dimension (Wave Equation); Method of characteristics, Consistency, Convergence and Stability. [10]

Question Pattern for End Semester Examination (Course Code: PGMATHCC105)

Part A (NUMERICAL ANALYSIS, 25 Marks)

1. Attempt 5 questions out of 7 questions and each question carries 2 marks $=5\times2 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 5 marks $=4\times5 = 20$

Part B (NUMERICAL ANALYSIS, 25 Marks)

3. Attempt 4 questions out of 6 questions and each question carries 5 marks $=4\times5 = 20$

Course Outcomes (PGMATHCC105)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Understanding the theoretical and practical aspects of the use of numerical analysis.	U	PO1	PSO1
CO2	Understanding of common numerical analysis and how they are used to obtain approximate solutions to otherwise intractable mathematical problems.	R, U	PO1	PSO1
CO 3	Proficiency in implementing numerical methods for a variety of multidisciplinary applications.	R, An	PO1, PO2	PSO3
CO4	Establishing the limitations, advantages, and disadvantages of numerical analysis.	E	PO2, PO3	PSO4
CO5	Deriving numerical methods for various mathematical operations and tasks, such as interpolation, differentiation, integration, the solution of linear and nonlinear equations and the solution of differential equations.	E, C	PO3, PO4	PSO5

Recommended Books

1. Numerical Methods for scientific and Engineering computation – M. K. Jain, S. R. K. Iyenger and R. K. Jain, New Age international publishers, New Delhi, 2003.
2. Fundamental of Computer Numerical Analysis – M. Friedman and A. Kandel, CRC Press, Boca Raton, 1993.
3. Applied Numerical Analysis (5th edition) – C. F. Gerald and P. O. Wheatley, Addison-Wesley, New York, 1998.
4. Introduction to Numerical Analysis (2nd edition) – K. E. Atkinson, John Wiley, 1989.

5. Elementary Numerical Analysis: An Algorithmic Approach (3rd edition) – S. D. Conte and C. de Boor, McGraw Hill, New York, 1980.
6. Numerical Mathematical Analysis – J. B. Scarborough, Oxford & IBH Publishing Co., 2001.
7. Computer Oriented Numerical Analysis – V. Rajaraman , Prentice-Hall of India Pvt. Ltd., 2002.

SEMESTER – I	
Name of the Course: **Computer Programming in C++ and Numerical Practical using Gnu- Octave / Scilab / Matlab**	
Course Code: **PGMATHCC106**	
Full Marks: 50	Credits: 4
Practical	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives(PGMATHCC106)

The prime objectives of the course are:

- To provide understanding of implementation of basic numerical methods for solving different problems viz. nonlinear equations, system of linear equations, interpolation and extrapolation, numerical differentiation and integration, numerical initial and boundary value problems of ordinary differential equations etc.
- To develop programming skills in the students in order to write and implement their own computer programs for solving problems arising in science, engineering and economics.
- Learn to develop GNU-OCTAVE/SCILAB/MATLAB programs that perform operations using derived data types.

Course Content

COMPUTER PROGRAMMING IN C++ AND NUMERICAL PRACTICAL USING GNU- OCTAVE / SCILAB / MATLAB

Unit 1: Programming in C++

Character set, Keywords, Datatypes (character, integer, floating point, etc.), Constants, Variables, Operators (arithmetic, assignment, relational logical increment, etc.),

Expressions, Data input and output (The functions like printf, scanf, etc.), Header files

Branching and Looping (The statements like if-else, while, do-while, for, switch, break, ontinue, etc.)

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User-defined functions

Arrays, Strings, Pointers, Structures and Unions [30]

Unit 2: GNU Octave / SciLab / MatLab

Constants, Variables, Operators, Functions, Relational expressions, Data input and output, Matrices and Matrix operations, In-built functions

Looping, User-defined functions

Handling System of Linear Equations and Eigen systems

Solution of non-linear equations

Differentiation and Integration

Solution of ODEs

Graphics (2D & 3D)

Curve-fitting

Handling Optimization problems

Applications of Symbolic Toolboxes [30]

Course Outcomes (PGMATHCC106)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Reading, understanding and tracing the execution of programs written in C++ language.	R, U	PO1	PSO1
CO2	Solving a linear system of equations using an appropriate numerical method.	Ap	PO2, PO3	PSO2
CO3	Performing an error analysis for a given numerical method.	E, C	PO3, PO4	PSO5
CO4	Developing programs GNU-OCTAVE/SCILAB/MATLAB that perform operations using derived data types.	E, C	PO3, PO4	PSO5
CO5	Solving an algebraic or transcendental equation using an appropriate numerical method.	An, C	PO4	PSO6
CO6	Developing the C++ code for a given algorithm.	C	PO4	PSO6

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SEMESTER – II	
Name of the Course: **Algebra – II**	
Course Code: **PGMATHCC201**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC201)

The prime objectives of the course are:

- To give students a foundation for advanced study in Algebra.
- Understand the fundamental theorems of algebraic structures.
- Explore the concepts of Polynomial rings, Field extensions, Galois extensions etc.
- Understand to apply the concepts of algebra in real-life situations.

Course Content

ALGEBRA - II

Unit I: Introduction to Extension fields, field adjunctions, Algebraic and Transcendental elements, Simple extensions, Finite extensions, Algebraic extensions, Roots of Polynomials, Multiple roots, Splitting field, Uniqueness of Splitting field, Separable elements, Separable extensions, Perfect field. Finite fields and its applications. Solvability by radicals, Totally inseparable extensions, Cyclotomic extensions. [20]

Unit II: The elements of Galois theory, Automorphism of Fields, Fixed fields, Group of Automorphisms of a field K relative to subfield F of K, Normal extension, Galois group, Fundamental theorem of Galois theory. [15]

Unit III: Infinite dimensional vector spaces. Dual spaces. Eigenvalues and eigenvectors. Diagonalisation. Canonical forms. Invariant subspaces. Direct sum decomposition. The Jordan canonical form. [15]

Unit-IV: Free Modules, and Bases. Factor Modules. Generators and Relations for Modules. The Structure Theorem for Abelian Groups. Application to Linear Operators. Modules over Principal Ideal Domain. [10]

Question Pattern for End Semester Examination (Course Code: PGMATHCC201)

Part A (ALGEBRA - II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

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Course Outcomes (PGMATHCC201)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Understand the Matrix theory, determinants and their application to systems of linear Equations	U	PO1	PSO1
CO 2	Apply the knowledge of Eigenvalues, diagonalization of matrices and reduction of systems of linear equations into simpler systems of easily tractable nature.	Ap	PO2, PO3	PSO2
CO3	Apply the concept of Vector theory: subspace, basis, linear independence, inner product spaces etc. in real-world problems	Ap, E	PO2, PO3	PSO4
CO4	Comprehend the applications of matrix algebra.	C, E	PO3, PO4	PSO5

Recommended Books

1. Herstein I.N.: Topics in Algebra, Wiley Eastern Ltd., Second ed. 1993.
2. J.B. Fraleigh: A first course in Abstract Algebra, Narosa Pub. Co.
3. P.B. Bhattacharya, S.K. Jain and S.R. Nagpaul. Basic Abstract Algebra (2nd Edition) Cambridge University, Press Indian Edition 1997.
4. M. Artin, Algebra, Prentice-Hall of India 1991
5. N. Jacobson, Basic Algebra Vols I and II Freeman 1988 (Kalse Published by Firncustan Publishing Company.)
6. S. Lang, Algebra 3rd edition. Addison-Westely 1993
7. O.S. Luther and I.B.S. Passi, Algebra Vol. I-Groups. Vol. II-Rings, Narosa Publishing House (Vol 1- 1996 Vol. II 1- 1999)
8. D.S. Malik & N. Mordeson and M. K. Sen Fundametnals of Abstract Algebra, Mc. Graw Hill International Edition, 1997
9. Joseph Galian , Contemporary Abstract Algebra.

SEMESTER – II	
Name of the Course: **Measure and Integration**	
Course Code: **PGMATHCC202**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC202)

The prime objectives of the course are:

- To develop the concept of countable, uncountable sets, Canter set, measurable sets, measurable functions, Lebesgue integral, and the Lebesgue Lp spaces.
- Understand the concept of Lebesgue Lp Spaces, and some important related theorems.

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- Teach the concepts of integration of simple functions, Lebesgue integral of a bounded function over a set of finite measures, comparison between- Riemann and Lebesgue integrals.

Course Content

MEASURE AND INTEGRATION

Unit-I: Measure spaces: Measurable sets and measure spaces, properties of measurable sets, finite and σ - finite measures, complete measure space; [12]

Unit-II: Measurable functions or measurable space: Definitions and examples, properties of measurable functions, simple functions, measurable function approximated by a sequence of simple functions; [8]

Unit-III: Mode of convergence of sequences in a measure space, convergence in measure, almost uniform convergence, Riesz Theorem relating to convergence in measure, E goroff's Theorem, Luzin's theorem; [14]

Unit-IV: Integration: Integration of simple functions, Lebesgue integral of a bounded function over a set of finite measures, comparison between- Riemann and Lebesgue integrals , Integration of non-negative functions and basic properties, Monotone convergence theorem and its applications, Fatou's lemma, general integrals on a measure space and dominated convergence theorem, characterization of absolutely continuous function in connection with Lebesgue integration (Fundamental theorem of Lebesgue integral) [20]

Unit-V: The Space Lp: The class Lp(μ), Lp(μ) as Banauch spaces, properties of Lp(μ), Spaces, The Hölder and Minkowski inequality;

Unit-VI: Product Measure spaces: Product measure, Fubini's Theorem. [6]

Question Pattern for End Semester Examination (Course Code: PGMATHCC202)

Part A (MEASURE AND INTEGRATION, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCC202)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Conceptualisation of simple functions.	R, U	PO1	PSO1
CO2	Apply the concepts of integration for the study in subsequent chapters namely, signed and product measure.	Ap	PO2, PO3	PSO2
CO3	Generalize the classical Lebesgue integral on real sets.	An, E	PO2, PO3	PSO4
CO4	Integration of functions on arbitrary measure space and bounded functions on sets of finite measure.	C	PO4	PSO6

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Recommended Books

1. Mathematical Analysis (5th edition) – T. Apostol, Addison-Wesley; Publishing Company, 2001.
2. Measure Theory and Integration- G. De. Berra,
3. Real Analysis- A. Bruckner, J. Bruckner and B. Thomson,
4. Theory of functions of a real variable, Vol. I, II - I.P. Nantanson,
5. Basic Real and Abstract Analysis- J.F. Randolph,
6. Principles of Mathematical Analysis (5th edition) – W. Rudin, McGraw Hill Kogakusha Ltd., 2004.
7. The Elements of Real Analysis (3rd edition) – R. G. Bartle, Wiley International Edition, 1994.
8. Introduction to Real Analysis (3rd edition) – R. G. Bartle and D. R. Sherbert, John Wiley & Sons, Inc., New York, 2000.
9. Basic Real Analysis – H.H. Sohrab, Birkhäuser (2003).
10. Introduction to Topology and Modern Analysis (4th edition) – G. F. Simmons, McGraw Hill Kogakusha Ltd., 2000.
11. An Introduction to Measure and Integration- I.K. Rana,
12. Metric Spaces- P.K. Jain and K. Ahmad,
13. Lebesgue Measure and Integration- P.K. Jain and V.P. Gupta.

SEMESTER – II	
Name of the Course: **General Topology**	
Course Code: **PGMATHCC203**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC203)

The prime objectives of the course are:

- Introduce the basic definitions and standard examples of topological spaces.
- Illustrate a variety of topological properties such as like compactness, connectedness and separation axioms.
- Explore the idea of topological equivalence and define homeomorphisms.

Course Content

GENERAL TOPOLOGY

Unit-I: Definition and examples of topological spaces, closed sets, closure, dense subsets, neighbourhood, interior, exterior and boundary, accumulation point, derived set, bases and

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subbases, subspace topology, finite product of topological spaces, alternative methods for defining a topology in terms of Kuratowski closure operator and neighbourhood system. Open, closed and continuous functions and homeomorphism, topological invariants, isometry and metric invariants. Countability Axioms: First and second countability, separability and Lindel¨of property. Separation Axioms: Ti-property (i = 0, 1, 2, 3, $3\frac{1}{2}$, 4, 5), regularity, complete regularity, normality and complete normality; their characterizations and basic properties, Urysohn's lemma, Tietze's extension theorem, T5-property of a metric space. [30]

Unit-II: Characterizations and basic properties, Alexander subbase theorem, compactness and separation axioms, compactness and continuous functions, sequentially, Frechet and countably compact spaces, compactness in metric spaces. Connected sets and their characterizations, connectedness of the real line, components, totally disconnected space, locally connected space, path connectedness, path components, locally path connected space. Convergence and cluster points, Hausd¨orffness, continuity, limit point of sets and compactness in terms of them, canonical way of converting nets to filters and vice-versa, ultrafilter, subnets and ultranet. Tych¨onoff product topology in terms of standard sub-base and its characterizations, projection maps, product spaces vis-`a-vis separation axioms, 1st and 2nd countability, separability,

Lin-del¨ofness, connectedness, local connectedness, path connectedness and compactness (Tych¨onoff theorem), embedding lemma and Tych¨ on off embedding theorem. Compactification, Local compactness and one point comptification. Quotient spaces: Definitions and examples of quotient topology and quotient maps, quotient spaces of a space X determined by relation on X and associated properties. [30]

Question Pattern for End Semester Examination (Course Code: PGMATHCC203)

Part A (GENERAL TOPOLOGY, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCC203)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Define and illustrate the concept of countable set and uncountable set, cardinal numbers and cardinal arithmetic, Zorns lemma and ordinal numbers.	R, U	PO1	PSO1
CO 2	Define and illustrate the concept of topological spaces and continuous functions, product topology and quotient topology, metric topology and Baire category theorem.	R, U	PO1	PSO1
CO3	Define connectedness, compactness, and totally bounded spaces and prove a selection of related theorems.	R, Ap	PO2, PO3	PSO2
CO4	Analyse topological spaces and some important theorem.	An	PO1, PO2	PSO3

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Recommended Books

1. N. Bourbaki; General Topology Part-I (Transl.); Addison Wesley, Reading(1966).
2. J. Dugundji; Topology; Allyn and Bacon, Boston,1966(Reprinted in India by Prentice Hall of India Pvt. Ltd.).
3. R. Engelking; General Topology; Polish Scientific Publishers, Warsaw (1977).
4. J. G. Hocking and C. S. Young; Topology; Addison-Wesley, Reading (1961).
5. S. T. Hu; Elements of General Topology; Holden-Day, San Francisco (1964).
6. K. D. Joshi; Introduction to Topology; Wiley Eastern Ltd. (1983).
7. J. L. Kelley; General Topology; Van Nostrand, Princeton (1955).
8. M. J. Mansfield; Introduction to Topology; D-van Nostrand Co. Inc, Princeton N.Y. (1963).
9. B. Mendelson; Introduction to Topology; Allyn and Becon Inc, Boston (1962).
10. James R. Munkress; Topology (2nd edit.); Pearson Education (2004).
11. W. J. Pervin; Foundations of General Topology; Academic Press, N.Y. (1964).
12. George F. Simmons; Introduction to Topology and Modern Analysis; McGraw-Hill, N.Y.(1963).
13. L. Steen and J. Seebach; Counterexamples in Topology; Holt, Rinechart and Winston, N.Y. (1970).
14. W. J. Thron; Topological Structures; Holt, Rinehart and Winston, N.Y. (1966).
15. Stephen Willard; General Topology; Addison-Wesley, Reading (1970).

SEMESTER – II	
Name of the Course: **Classical Mechanics & Theory of Relativity**	
Course Code: **PGMATHCC204**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC204)

The prime objectives of the course are:

- Expose the students to the concept of functional and extremum path and the application of the knowledge in solving some fundamental problems.
- Understand the fundamental concepts in the dynamics of system of particles and Lagrangian and Hamiltonian formulation of mechanics.
- Learn to represent the equations of motion for complicated mechanical systems using the Lagrangian and Hamiltonian formulation of classical mechanics.
- To develop the understanding of moments of inertia and its applications in the dynamics of a rigid body rotating about a fixed point.

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- To develop the understanding of the concept of geometrical equations and Lagrange's equations of motion of a rigid body, principles of Hamiltonian, Liouville's Theorem and introduction to Lagrange and Poisson brackets and its applications.

Course Content

CLASSICAL MECHANICS & THEORY OF RELATIVITY

Group-A (CLASSICAL MECHANICS)

Unit-1: Lagrangian Formulation: Generalised coordinates. Holonomic and non holonomic systems. Scleronomic and rheonomic systems. D'Alembert's principle. Lagrange's equations. Energy equation for conservative fields. Cyclic (ignorable) coordinates. Generalised potential.

Moving Coordinate System: Coordinate systems with relative translational motions. Rotating coordinate systems. The Coriolis force. Motion on the earth. Effect of Coriolis force on a freely falling particle. Euler's theorem. Euler's equations of motion for a rigid body. Eulerian angles.

Unit-2: Variational Principle: Calculus of variations and its applications in shortest distance, minimum surface of revolution, Brachistochrone problem is a perimetric problem, geodesic. Hamilton's principle. Lagrange's undetermined multipliers. Hamilton's equations of motion.

Unit-3: Canonical Transformations: Canonical coordinates and canonical transformations. Poincaré theorem. Lagrange's and Poisson's brackets and their variance under canonical transformations, Hamilton's equations of motion in Poisson's bracket. Jacobi's identity. Hamilton-Jacobi equation.

Unit-4: Small Oscillations: General case of coupled oscillations. Eigen vectors and Eigen frequencies. Orthogonality of Eigen vectors. Normal coordinates. Two-body problem.

Group-B (THEORY OF RELATIVITY)

Unit-I: The special theory of relativity: inertial frames of reference; postulates of the special theory of relativity; Lorentz transformations; length contraction; time dilation; variation of mass; composition of velocities; relativistic mechanics; world events, world regions and light cone; Minkowski space-time; equivalence of mass and energy.

Unit –II: Energy-momentum tensors: the action principle; the electromagnetic theory; energy-momentum tensors (general); energy-momentum tensors (special cases); conservation laws.

Unit –III: General Theory of Relativity: introduction; principle of covariance; principle of equivalence; derivation of Einstein's equation; Newtonian approximation of Einstein's equations.

Unit- IV: Solution of Einstein's equation and tests of general relativity: Schwarzschild solution; particle and photon orbits in Schwarzschild space-time; gravitational red shift; planetary motion; bending of light; radar echo delay.

Unit –V: Brans-Dicke theory: scalar tensor theory and higher derivative gravity; Kaluza-Klein theory.

Question Pattern for End Semester Examination (Course Code: PGMATHCC204)

Prasenjit Kr. Kar.

Part A (CLASSICAL MECHANICS, 25 Marks)

1. Attempt 5 questions out of 7 questions and each question carries 5 marks $=5\times5=25$

Part B (THEORY OF RELATIVITY, 25 Marks)

2. Attempt 5 questions out of 7 questions and each question carries 5 marks $=5\times5=25$

Course Outcomes (PGMATHCC204)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Explain Lagrangian and Hamiltonian formulation of Classical Mechanics.	U	PO1	PSO1
CO 2	State the conservation principles involving momentum, angular momentum and energy and understand that they follow from the fundamental equations of motion.	R, U	PO1	PSO1
CO3	Understand Newton's laws and motion of particle under central force field.	U	PO1	PSO1
CO4	Describe the basic concepts of the theory of relativity.	R, U	PO1	PSO1
CO5	Differentiate facts from wrong general public ideas about the theory of relativity.	An	PO1, PO2	PSO3
CO6	Discuss postulates of the special theory of relativity and their consequences.	R, An	PO1, PO2	PSO3

Recommended Books

1. E. T. Whittaker: A Treatise of Analytical Dynamics of Particles and Rigid Dynamics.
2. Donald T. Greenwood: Classical Dynamics
3. F. Chorlton: Dynamics.
4. Edward John Routh: Dynamics.
5. H. Lamb: Dynamics.
6. R. G. Takwale and P. S. Puranik: Introduction to Classical Mechanics.
7. H. Goldstein: Classical Mechanics.
8. The Theory of Relativity (2nd edition) – R.K. Pathria, Hindustan Publishing co. Delhi, 1994.
9. General Relativity & Cosmology (2nd edition) – J.V. Narlikar, Macmillan co. of India Limited, 1988.
10. Aspects of Gravitational Interactions – S. K. Sriva stava and K. P. Sinha, Nova Science Publishers Inc. Commack, New York , 1998.
11. Essential Relativity – W. Rindler, Springer-Verlag, 1977.
12. General Relativity – R.M. Wald, University of Chica go Press, 1984.

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SEMESTER – II	
Name of the Course: **Linear Algebra & Multivariate Calculus**	
Course Code: **PGMATHCC205**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives(PGMATHCC205)

The prime objectives of the course are:

- Understand the core of linear algebra comprising the theory of linear equations in many variables, the theory of vector spaces and linear maps.
- To introduce some advance material in Linear algebra.
- Visualize the idea of Linear transformations on a finite dimensional inner product space, Riesz representation of the linear functional on inner product space.
- Learn to use the concept of eigenvalues and eigenfunctions.

Course Content

LINEAR ALGEBRA & MULTIVARIATE CALCULUS

Group-A (LINEAR ALGEBRA-30L)

$PA = LU$ and LDU factorization of a matrix, its application in solving $Ax = b$, rank factorization of a matrix, rank cancellation. Fundamental theorem of Linear Algebra, part I and II, existence and uniqueness of solutions to $Ax = b$, a matrix transforms its row space toits column space. Matrix of orthogonal projection, least square solution of over determined system $Ax = b$, Moore-Penrose inverse [through rank factorization].

Duality and transposition, linear forms or linear functionals, dual space V^d, bi-dual space V^{dd},dual basis, natural isomorphism between V^d and V^{dd}, Annihilators W° of a nonempty of a vector space V, subset W dim W dim$W^* = \dim V - \dim W$, transpose T^t of a linear transformation T, $T^{tt} = T$, $(T^{-1})^t = (T^t)^{-1}$, if T is an isomorphism,$(\text{Im } T)^\circ = \text{Im } T^t$,. dim ker T = dim ker T^t, dim Im T = dim Im T^t.

Eigenvalues and eigenvectors, characteristic polynomial of a linear transformation, eigen values and eigenvectors of a linear transformation, diagonalisation, annihilating polynomials, invariant subspace, simultaneous trangulisation and diagonalization, direct sum decomposition, invariant direct sum, primary decomposition theorem.

Linear transformations on a finite dimensional inner product space, Riesz representation of the linear functional on inner product space, adjoint T^* of a linear operator $T: V \longrightarrow V$, matrix representation of T^*, normal and self-adjoint operators, eigen values of a self-adjoint operator are real, unitary and orthogonal operators and their matrices, orthogonal projections, the spectral theorem and its consequences.

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Group-B (MULTIVARIATE CALCULUS)

Unit-1: Differentiation on $\mathbb{R}^n$ Directional derivatives and continuity, the total derivative and continuity, total derivative in terms of partial derivatives, the matrix transformation of $T:\mathbb{R}^n \to \mathbb{R}^n$. The Jacobian matrix. [8]

Unit-2: The chain rule and its matrix form. Mean value theorem for vector valued function. Mean value inequality. A sufficient condition for differentiability. A sufficient condition for mixed partial derivatives. [8]

Unit-3: Functions with non-zero Jacobian determinant, the inverse function theorem, the implicit function theorem as an application of Inverse function theorem. Extreme of real valued functions of several variables, Extremum problems with side conditions – Lagrange's necessary conditions as an application of Inverse function theorem. [8]

Unit 4: Integration on $\mathbb{R}^n$. Integral of $f:A\to\mathbb{R}$ when $A\subset\mathbb{R}$ is a closed rectangle. Condition of integrability. Integrals $f:C\to\mathbb{R}, C\subset\mathbb{R}^n$ is not rectangle. Pappaus theorem, green's theorem and its applications. [6]

Question Pattern for End Semester Examination (Course Code: PGMATHCC205)

Part A (LINEAR ALGEBRA, 25 Marks)

1. Attempt 5 questions out of 7 questions and each question carries 5 marks $=5\times5=25$

Part B (MULTIVARIATE CALCULUS,25 Marks)

2. Attempt 5 questions out of 7 questions and each question carries 5 marks $=5\times5=25$

Course Outcomes (PGMATHCC205)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Characterize a set of vectors and linear systems using the concept of linear independence.	R, U	PO1	PSO1
CO2	Visualize and manipulate multivariable and vector valued functions presented in graphical, numeric, and symbolic form.	An	PO1, PO2	PSO3
CO3	Identify and construct linear transformations of a matrix and characterize them as onto, one-to-one.	E, C	PO3, PO4	PSO5
CO4	Solve linear systems represented as linear transforms and express them in other forms, such as matrix equations and vector equations.	C	PO4	PSO6
CO5	Differentiate multivariate functions in all directions and learn several applications of multivariate derivatives.	C	PO4	PSO6

Recommended Books

1. I N Herstein: Topics in Algebra", 2^{nd} edition, by John Wiley and sons, StudentEdition, New York (2004).

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2. Lenneth Hoffman, Ray Kunze, Linear Algebra, 2nd edition Prentice Hall of India, New Delhi (1971).
3. S. K. Pundir, Advanced Abstract Algebra, Krishna Prakashan Media (P) Ltd. Meerut
4. P B Bhattacharya, Phani Bhusan Bhattacharya, S K Jain, S R Nagpaul, First course inSteven Roman, Advanced linear algebra, New Age International Ltd Publishers, New Delhi (2008).
5. Steven Roman, Advanced linear algebra, 3rd edition, Springer (2008)
6. S. Kumaresan: Linear Algebra, a geometric approach, prentice Halls, India,2001
7. T. M. Apostol, Mathematical Analysis Narosa publishing House;
8. M. Spivak: Calculus on Manifolds, Benjamin, N.Y;
9. Sudhir R. Ghorpade and Balmohan V. Limaye, "A course in Multivariate Calculusand Analysis", Springer Verlag;
10. J. E. Marsden, A. J. Tromba, A. Weinstein, Basic Multivariable Calculus, Springer Internationsl Edition, Springer Verlag;
11. Sean Dineen, Multivariate Calculus and Geometry, Springer Verlag;
12. Devinatz, "Advanced Calculus";
13. C. Goffman: Calculus of several variables; Hesper International student reprint,1965;
14. W. Ruddin: Principle of Mathematical Analysis, MCgraw-Hill,N.Y.1964.

SEMESTER – II	
Name of the Course: **Integral Transforms & Integral Equations**	
Course Code: **PGMATHCC206**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC206)

The prime objectives of the course are:

- Learn to use Fourier Transforms of functions to solve different problems.
- Learn to use Laplace Transforms for solving initial value problem, integral equation, etc.
- Know the types of integral equation and Kernels and relation between integral equation and boundary value problems, green's function.
- Explore the concept of iterated kernels, Neumann series for Volterra integral equation, Abel's integral equation and Cauchy principal for integrals.

Course Content

INTEGRAL TRANSFORMS & INTEGRAL EQUATIONS

Unit I: Fourier Transforms: - Definition, properties evaluation of Fourier and inverse Fourier transforms of functions, Convolution theorem for Fourier Transform, Sine and Cosine Fourier transforms, solving integral equations using Fourier Transform.

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Laplace Transform: - Definition, properties, evaluation of Laplace and Inverse Laplace transforms of functions, Convolution theorem for Laplace Transforms, solving initial value problem using Laplace Transforms, solving integral equation using Laplace Transforms. [15]

Unit II: Types of integral equation, Types of Kernels, Eigen values and eigen functions, convolution integral, relation between differential equation and integral equation, relation between integral equation and boundary value problems, green's function. [15]

Unit III: Solution of Homogeneous Fredholm integral equation of the second kind with separable kernel, Fredholm theorem, iterated kernel, method of successive approximations,an approximate method, complex Hilbert spaces, orthonormal system of functions, Riesz- Fischer theorem, Hilbert – Schmidt theorem and its application for the solution of Fredholm integral equation with symmetric kernel. [15]

Unit IV: Iterated kernels, Neumann series for Volterra integral equation, singular integral equation solution of Abel's integral equation, weakly singular kernel, Cauchy principal for integrals, Cauchy type integrals, solution of Cauchy type singular integral equation. [15]

Question Pattern for End Semester Examination (Course Code: PGMATHCC206)

Part A (INTEGRAL EQUATIONS, 25 Marks)

1. Attempt 1 questions out of 2 questions and each question carries 5 marks $=1\times5=5$
2. Attempt 2 questions out of 3 questions and each question carries 10 marks $=2\times10=20$

Part B (INTEGRAL TRANSFORMS,25 Marks)

3. Attempt 1 questions out of 2 questions and each question carries 5 marks $=1\times5=5$
4. Attempt 2 questions out of 3 questions and each question carries 10 marks $=2\times10=20$

Course Outcomes (PGMATHCC206)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understand the Calculus of Variations, Euler-Lagrange's equations.	U	PO1	PSO1
CO2	Obtain solution of a boundary value problem using integral equations.	Ap, E	PO2, PO3	PSO4
CO3	Obtain minimum surface of revolution from a variational formulation.	E	PO2, PO3	PSO4
CO4	Obtain the solution of Wave, Heat and Laplace equations using integral transform technique.	E, C	PO3, PO4	PSO5
CO5	Construct Green's function and master the concept of various Integral Equations: Fredholm and Voltera type.	C	PO4	PSO6

Recommended Books

1. Ram P. Kanwal, Birkhauser Linear Integral Equations (Theory andTechnique)
2. M. D. Raisinghania: Advanced Differential Equations (12th Revised Ed), S. Chand

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pub.

3. A.M. Wazwaz: A First course in integral equations - (world Scientific);
4. A.J. Jerri: Introduction to Integral Equation with Applications (2nd edition) - (Wiley Inter science);
5. Earl D. Rainville: Elementary Differential Equations, published 1962.

SEMESTER – III	
Name of the Course: **Functional Analysis**	
Course Code: **PGMATHCC301**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC301)

- Develop a deeper and rigorous understanding of fundamental concepts of functional analysis, their properties and related theorems.
- Introduce normed spaces, linear operators and derive their properties.
- Elaborate basic theorems like open and closed mapping theorem, implicit function theorem and spectral theorem.
- Understand and learn to work with Fredholm and other integral operator as a linear operator.

Course Content

FUNCTIONAL ANALYSIS

Unit-I

Normed linear space (n.l.sp.), Banach space with examples, quotient space. Bounded linear transformation, its equivalence with continuity, space of bounded linear transformations, equivalence of two norms in a linear space, equivalence of anytwo norms in a finite dimensional vector space, other important properties of a finite dimensional n. l. sp. Bounded linear functionals on various n. l. sp., Hahn-Banach theorems andconsequences, dual and 2nd dual of a n.l.sp., separability and reflexivity of n. l. sp. Open mapping theorem, closed graph theorem and uniform boundedness principle,some applications of these theorems. Weak and weak*-convergence, Banach-Alaoglu theorem. Determination of dual of some familiar normed linear spaces. [30]

Unit-II

Inner product space, Hilbert space, orthonormality, orthogonal complement, orthonormal basis, Bessel's inequality, Parseval's equation, Gram-Schmidt orthonomalisation process, Riesz representation theorem , reflexivity of Hilbert space,separable and non-separable Hilbert space,

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Introduction to operator theory: Compact operator and its characterisation, space of compact operators, weak- convergence and compact operator, rank of compact operator. Adjoint of an operator on Hilbert space, properties of adjoint operation, self- adjoint operator and its characterisation, positive operator and non- singularity, concept of normal operator and its characterisation, unitary operator and its characterisation. General model of all Hilbert spaces (up to isometric isomorphism) — $l^2(S)$, for any nonempty set S. Introduction to spectral theory: Resolvent set, spectrum and spectral radius of operators on Banach space, spectral mapping theorem for polynomials. [30]

Question Pattern for End Semester Examination (Course Code: PGMATHCC301)

Part A (FUNCTIONAL ANALYSIS, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10=40$

Course Outcomes (PGMATHCC301)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Work with a complete orthogonal set in a Hilbert space, weak and weak * topologies on normed linear spaces.	Ap	PO2, PO3	PSO2
CO2	Compare the differences between basis and Schauder basis.	An	PO1, PO2	PSO3
CO3	Investigate the best approximation of a given vector by vectors in given subspace.	An	PO1, PO2	PSO3
CO4	Work with Fredholm and other integral operator as a linear operator.	Ap, E	PO2, PO3	PSO4
CO5	Compute the dual spaces of certain Banach spaces.	C	PO4	PSO6

Recommended Books

1. Bachman and Narici; Functional Analysis; Academic Press (1966).
2. G. F. Simmons; Introduction to Topology and Modern Analysis; McGraw-Hill Book Company (1963).
3. Goffman and Pedrick; First Course in Functional Analysis; Prentice-Hall, Inc.
4. Walter Rudin; Functional Analysis; Tata McGraw-Hill (1974).
5. John B. Conway; A Course in Functional Analysis; Springer, (1990).
6. A. E. Taylor; Introduction to Functional Analysis; John Wiley & Sons. (1958).
7. B. V. Limaye; Functional Analysis; New Age International Ltd.
8. M. Thamban Nair; Functional Analysis; Prentice-Hall of India Pvt. Ltd., New Delhi (2002).
9. Jain, Ahuja and Ahmad; Functional Analysis; New Age International (P) Ltd. (1997).

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SEMESTER – III	
Name of the Course: **Dynamical System Analysis**	
Course Code: PGMATHCC302	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC302)

- To develop an understanding of continuous and discrete dynamical systems, Autonomous systems in $\mathbb{R}^n$, Orbits and Trajectories.
- Explore the linear systems in two and higher dimensions and their stability.
- Learn to work with Bifurcation and Chaos at non-hyperbolic equilibrium points, Saddle-node, Transcritical, Pitchfork and Hopf bifurcations.

Course Content

DYNAMICAL SYSTEM ANALYSIS

Unit-I:- Dynamical system: Definition, Continuous and discrete dynamical systems, Autonomous systems in $\mathbb{R}^n$, Orbits, Trajectories, Applications to Biology and Physics.

Linear systems and stability: Equilibrium points, Linearization, Stability of equilibriumpoints for one dimensional system.

Linear systems in two and higher dimensions: Trajectories and vector fields, Stability of equilibrium points, Phase-portrait, Invariance of Stable, Unstable and Centre subspaces.

Unit-II: Non-linear systems and stability: Linearization, Hartman-Grobman Theorem, Linear stability theory, Hyperbolic and non-hyperbolic type equilibrium points, Saddle, Nodes, Foci,and centre, Stable manifold theorem.

Stability of non-hyperbolic equilibrium points: Center manifold theorem, Lyapunov functions, Global Stability.

Invariant manifolds: Stable, Unstable and Center manifold for equilibrium points of non- linear systems,

Limit Sets and Attractors, Periodic orbits, Poincare –Bendixson Theorem, Poincare sphere and behaviour at infinity, Stability analysis of Lorentz equations.

Unit-III: Bifurcation and Chaos: Bifurcation at non-hyperbolic equilibrium points, Saddle-node bifurcation, Transcritical bifurcation, Pitchfork bifurcation for one and two dimensional flows, Hopf bifurcations, One dimensional Logistic map and Chaos.

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Question Pattern for End Semester Examination (Course Code: PGMATHCC302)

Part A (DYNAMICAL SYSTEM ANALYSIS, 30 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 4 questions out of 6 questions and each question carries 5 marks $=4\times5=20$

Part B (DYNAMICAL SYSTEM ANALYSIS, 20 Marks)

3. Attempt 4 questions out of 6 questions and each question carries 5 marks $=4\times5=20$

Course Outcomes (PGMATHCC302)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Describe the main features of dynamical systems and realise as systems of ordinary differential equations	R, U	PO1	PSO1
CO2	Understand the origin of dissipation and its effect on the orbits of dynamical systems, abstract dynamical system, discrete dynamical system and chaotic dynamical system	U	PO1	PSO1
CO3	Use a range of specialised analytical techniques which are required in the study of dynamical systems	Ap	PO2, PO3	PSO2
CO4	Identify fixed points of simple dynamical systems, and study the local dynamics around these fixed points, in particular to discuss their stability and bifurcations	R, An	PO1, PO2	PSO3
CO5	Explain and prove special properties of finite-dimensional Hamiltonian systems, in particular conservation laws, Liouville's Theorem and Poincare's Recurrence Theorem	E	PO2, PO3	PSO4

Recommended Books

1. Differential Equations and Dynamical systems—Lawrence Perko.
2. Nonlinear Dynamics and Chaos—Steven H. Strogatz.
3. Introduction to Applied Non-linear Dynamical systems and Chaos—Stephen Wiggins.
4. Differential Equations, Dynamical Systems and an Introduction to Chaos— M. W.Hirsch, S. Smale, and R.L.Devaney.

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SEMESTER – III	
Name of the Course: **Advanced Real Analysis**	
Course Code: **PGMATHCE301**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE301)

The prime objectives of the course are:

- Introduce the students to ordinal numbers, their comparability and consequences.
- Learn to use the properties of sets, perfect set, sets of first category and second category, residual sets
- Understand the concepts of Borel sets.
- Learn about functions of some special classes, Banach–Zarecki theorem, Dini's derivates and their simple properties.

Course Content

ADVANCED REAL ANALYSIS -I

Unit-I: Ordinal numbers: Well ordered sets, order types, ordinal number, Initial segments, limit ordinals, Transfinite induction, Comparability of ordinal numbers and their consequences, any ordinal number α can be uniquely written as $\alpha = \beta + \eta$,where β, η is a limit ordinal and finite nonnegative integer, first uncountable ordinal.

Unit-II: Descriptive properties of sets: Points of condensation of a set, perfect sets, Description of closed set interms of a perfect set, sets of first category and second category, Residual sets, characterization of a residual set in a complete space, concepts of Borel sets of types F_α and G_α , α being ordinal and its basic properties, Density point of sets, Lebesgue Density theorem.

Unit-III: Functions of some special classes: Lower and upper semi continuous functions and their properties, Functions of Baire class, being finite ordinal, set of points of discontinuity of Baire one function, comparison of Baire function of class α and Borel classes of sets of typeF_α and G_α,where is a finite ordinal, approximately continuous functions and some basic properties, measurability of approximately continuous function.

Unit-IV: Derivatives: The vitali covering theorem, absolutely continuous functions, Banach–Zarecki theorem, Dini's derivates and their simple properties, derivative of an increasing function and also absolutely continuous function. Integrability of approximately continuous function.

Question Pattern for End Semester Examination (Course Code: PGMATHCE301)

Part A (ADVANCED REAL ANALYSIS -I, 50 Marks)

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1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10=40$

Course Outcomes (PGMATHCE301)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understand the concept of extended real numbers, Lebesgue and Borel measures on real line.	R, U	PO1	PSO1
CO2	Understand the measurability of real sets.	U	PO1	PSO1
CO3	Understand the measurability of extended real valued functions.	U	PO1	PSO1
CO4	Solve problems relating to determinations of measures of finite, infinite sets.	Ap, E	PO2, PO3	PSO4
CO5	Construct different Borel sets.	C	PO4	PSO6
CO6	Construct measurable, non-measurable sets and functions.	C	PO4	PSO6

Recommended Books

1. G. De. Berra: Introduction to measure theory, Van Nostrand Reinhold company, N.Y.1974.
2. S.K. Berberian: Measure and Integration, Chelsea, N.Y.1965.
3. A.M. Bruckner, J. B. Bruckner & B.S. Thomson: Real Analysis, Prentice-Hall, N.Y.1997.
4. G.B. Folland: Real Analysis-Modern techniques and their Applications, John Willeyand Sons, N.Y.1984.
5. R. L. Jeffery: The theory of functions of Real variables, Toronto University press,1953.
6. I.P. Natanson: Theory of Function of Real variables Vol-I & II, Frederic-Unger publishing,1953.
7. J.F. Randolph: Basic Real and Abstract Analysis –Academic Press, N. Y.1968.
8. W.F. Pfeffer: Integral and Measure, Marcel Dekker, Inc, N.Y,1977
9. H.L. Roydon : Real Analysis, Macmillan company N.Y.1988.
10. A.E.Taylor : General theory of functions and integration, Blain dell.ub. company, N. Y. 1965.
11. F.G. Friedlander: Introduction to the theory of Distributions, Cambridge university,press, 1982.
12. P.Y.Lee: Lanzhon Lectures on Henstock Integration, world scientific press,1989
13. W. Sierpinski: Cardinal and ordinal numbers.
14. Charles Swartz: Introduction to Gauge Integral, world scientific.
15. M.A. Al-Gwaiz: Theory of Distributions, Marcel-Dekker, N.Y.1992.

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SEMESTER – III	
Name of the Course: Advanced Complex Analysis –I	
Course Code: PGMATHCE302	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Tutorial	Credits: 0 Full Marks: 0
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objective (PGMATHCE302)

The prime objectives of the course are:

- Provide the students the basic ideas of infinite products of complex numbers and some associated important theorems.
- Understand the Spherical metrics, Montel's Theorem and Marty's Theorem.
- Exposure to open mapping theorem and Picard's Theorem.

Course Content

ADVANCED COMPLEX ANALYSIS –I

Unit-I: Basic ideas of Infinite products of complex numbers. Mittag-Leffler Theorem and its applications, Gamma functions and its properties, Riemann Zeta functions, Runge's theorem Factorization of Entire Functions, Weierstrass' Factorization Theorem and its applications. [20]

Unit-II: Spherical metrics, Normal Convergence, Montel's Theorem, Marty's Theorem,Picard's Little Theorem, Picard's Great Theorem, [20]

Unit-III: Open Mapping Theorem, Hurwitz's Theorem, Inverse Function Theorem, TheRiemann Mapping Theorem. [20]

Question Pattern for End Semester Examination (Course Code: PGMATHCE302)

Part A (ADVANCED COMPLEX ANALYSIS –I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE302)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understand Infinite products of complex numbers.	U	PO1	PSO1

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CO2	Understand the concept of Spherical metrics, Normal Convergence, Picard's Theorem.	R, U	PO1	PSO1
CO3	Use the Mittag-Leffler Theorem, Gamma functions, Weierstrass' Factorization.	Ap, E	PO2, PO3	PSO4

Recommended Books

1. Functions of one complex variable – J. B. Conway, Springer International Student edition, Narosa Publishing House, New Delhi, 2000.
2. Elementary Theory of Analytic Functions of one or several complex variables – H. Cartan, Courier Dover Publications, New York, 1995.
3. Complex Analysis (2nd Edition) – L. V. Ahlfors, McGraw-Hill Internationa l Student Edition, 1990.
4. Complex Variables and applications – R. V. Churchil l, McGraw-Hill, 1996.
5. An Introduction to the Theory of functions of a complex Variable – E. T. Copson, Oxford university press, 1995.
6. An Introduction to Complex Analysis – A. R. Shastri, Macmillan India Ltd., 2003.
7. Complex Variables and Applications – S. Ponnusamy, and H. Silverman, Birhkäuser, 2006.
8. Complex Analysis: S. Lang, Springer-Verlag; 1999

SEMESTER – III		
Name of the Course: **Algebraic Topology-I**		
Course Code: **PGMATHCE303**		
Full Marks: 50		Credits: 4
Theory	Credits: 4 Full Marks: 50	
Number of classes required: 60		
This course has been newly introduced vide BOS meeting dated 23/03/2018		

Course Objectives(PGMATHCE303)

The prime objectives of the course are:

- To provide the knowledge of Topological Spaces and their importance.
- To acquaint students with the concept of Homotopy, Homology and the topological properties.
- To understand the important mathematical concepts which can be generalized in topological spaces, so that students may learn and appreciate the nature of abstract Mathematics.

Course Content

ALGEBRAIC TOPOLOGY-I

Unit I: Homotopy Theory:

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Homotopy between continuous maps, homotopy relative to a subset, homotopy class, null homotopy, contractibility of spaces, homotopy equivalent spaces, homotopy properties.

Deformability, deformation retracts, strong deformation retracts, homotopy between paths, product of paths, fundamental group $\Pi(X, x)$ of a space X based at the point $x \in X$, induced homomorphism and related properties, simply connected space, special Van Kampan theorem and fundamental group of S^n $(n \geq 2)$

Fundamental Group of S^1, fundamental group of the product and of Torus, $\mathbb{R}^2$ and $\mathbb{R}$ $(n > 2)$ are not homeomorphic.

Fundamental theorem of algebra and Brouwer fixed point theorem, covering projection, covering spaces, lifting of paths and homotopies, the fundamental group of a covering space. the Monodromy theorem, the Borsuk-Ulam theorem and Ham-Sandwich theorem. [30]

Unit II: Homology Theory:

Elements of simplicial homology: Barycentric co-ordinates, simplex, geometric complexes and polyhedrons, simplicial mappings and simplicial approximation theorem. Oriented complexes, incidence numbers, chains, cycles and boundaries; Simplicial homology groups, computation of simplicial homology groups, the decomposition theorems for abelian groups, Betti numbers and torsion coefficients. CW-complex, sub-complex and CW-pairs; Euler characteristic, Euler- Poincare theorem.

Singular homology, computation of singular homology groups, Mayer-Victoris sequence; Homotopy invariance; Equivalence of simplicial and singular homology; Relation between fundamental group and first homology group; Relative homology and Excision theorem; Computation of homology of CW-complex. [30]

Question Pattern for End Semester Examination (Course Code: PGMATHCE303)

Part A (ALGEBRAIC TOPOLOGY-I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE303)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understanding the fundamental concepts and methods in algebraic topology.	R, U	PO1	PSO1
CO2	Explain particular homotopy and homology theory.	U	PO1	PSO1
CO3	Formulate and solve problems of a geometrical and topological nature in mathematics.	Ap, E	PO2, PO3	PSO4

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Recommended Books

1. A. Dold; Lectures on Algebraic Topology; Springer-Verlag (1972).
2. W. Fulton; Algebraic Topology: A First Course; Springer-Verlag (1995).
3. M. Greenberg; Lectures on Algebraic Topology; W.D. Benjamin, N.Y. (1967).
4. Allen Hatcher; Algebraic Topology; Cambridge Univ. Press (2002).
5. C. Kosniowski; A First Course in Algebraic Topology; Cambridge University Press(1980).
6. W. S. Massey; Algebraic Topology: An Introduction; Springer-Verlag, N.Y. (1990).
7. James R. Munkres; Topology (2nd Edit.); Pearson Education Inc. (2004).
8. E. H. Spanier; Algebraic Topology; McGraw Hill Book Co. N.Y. (1966).
9. C. T. C. Wall; A Geometric Introduction to Topology; Addison-Wesley Publ. Co. Inc (1972).
10. G.E. Bredon; Topology and Geometry; Springer-Verlag GTM 139 (1993).
11. William S. Massey; A Basic Course in Algebraic Topology; Springer-Verlag, New YorkInc. (1993).
12. C.R.F. Maunder; Algebraic Topology; Dover Pub. N.Y. (1996).
13. J.J. Rotman; An Introduction to Algebraic Topology; Springer-Verlag, N.Y. (1988).
14. H. Schubert; Topology; Macdonald Technical and Scientific, London (1964).
15. James W. Vick; Homology Theory: An introduction to Algebraic Topology; Springer-Verlag, N. Y. (1994).

SEMESTER – III	
Name of the Course: Differential Manifold-I	
Course Code: PGMATHCE304	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE304)

The prime objectives of the course are:

- To familiarize students with the detailed knowledge of Surfaces, Geodesic, Geodesic curvature, Gaussian Curvature and Developable Surface.
- Understand the concept of Surface in Space.
- Introduce the concept of Differentiable Manifold, Jacobian Map and parameter group of transformations.

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Course Content

DIFFERENTIAL MANIFOLD-I

Unit-1: Surface: First fundamental form, Angle between two intersecting curves on a surface, Geodesic,Geodesic curvature, Gaussian Curvature, Developable Surface. [20]

Unit-2: Surface in Space: Tangent and Normal Vector on a Surface, Second Fundamental Form, Gauss's Formula, Weingarten Formula, Third Fundamental Form, Gauss and Codazzi Equations, Principal Curvature, Lines of Curvature, Asymptotic lines. [20]

Unit-3: Manifold: Introductory remarks, Smooth functions, Coordinate functions, Differentiable Manifold, Differentiable Mapping, Differentiable Curve, Tangent Vector, Vector Field, Lie Brackets, Lie Algebra of Vector Fields, Integral curves, Jacobian Map (Differential Map), f-related Vector fields, One parameter group of transformations, Local 1- parameter group of transformations, Cotangent Space, r-form, Exterior Product, Exterior Differentiation, Pull-Back Differential Form. [20]

Question Pattern for End Semester Examination (Course Code: PGMATHCE304)

Part A (DIFFERENTIAL MANIFOLD-I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE304)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Realize the behaviours of different surfaces, normal curvatures, principle curvatures, Gaussian and mean curvatures.	R, U	PO1	PSO1
CO2	Understand the first and second fundamental forms.	U	PO1	PSO1
CO3	Evaluate 1st and 2nd fundamental forms of surface patches.	E	PO1	PSO1
CO4	Analyse and characterize different curves and surfaces.	R, An	PO1, PO2	PSO3
CO5	Construct differential maps between smooth surfaces.	E, C	PO2, PO3	PSO4

Recommended Books

1. I. S. Sokolnikoff: Tensor Analysis, Theory and Applications to Geometry and Mechanicsof Continua, 2nd Edition, John Wiley and Sons., 1964.
2. B. Spain: Tensor Calculus, John Wiley and Sons, 1960.
3. M. Spivak: A Comprehensive Introduction to Differential Geometry, Vols I-V, Publishor Perish, Inc. Boston, 1979.
4. Kobayashi & Nomizu: Foundations of Differential Geometry, Vol-I, Inter sciencePublishers,

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1963.
5. K. Yano and M. Kon: Structure on Manifolds, World Scientific, 1984.
6. S. Helgason: Differential Geometry, Lie Groups and Symmetric Spaces, Academic Press,1978.
7. W. M. Booth by: An Introduction to Differentiable Manifolds and Riemanian Geometry, Academic Press, Revised, 2003.
8. W. D. Curtis and F. R. Miller: Differential Manifolds and Theoretical Physics, AcademicPress, 1985.
9. B. Oneill, Elementary Differential Geometry.

SEMESTER – III	
Name of the Course: Cosmology-I	
Course Code: **PGMATHCE305**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives(PGMATHCE305)

The prime objectives of the course are:

- Familiarise students to our galaxy and the standard model of universe.
- Understand the basics of Tensor Analysis and the General Theory of Relativity.
- Learn the relation between Thermodynamics and cosmology
- Learn to analyze the size, age, structure, and motion of the universe overall.

Course Content

COSMOLOGY-I (60L)

Cosmology: An Introduction

Review of Tensor Analysis and the General Theory of Relativity

Fundamental Observations

The standard model of the universe and beyond

Cosmic dynamics

Measuring the cosmological parameters

Thermodynamics and cosmology

Question Pattern for End Semester Examination (Course Code: PGMATHCE305)

Part A (COSMOLOGY-I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$

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2. Attempt 4 questions out of 6 questions and each question carries 10 marks $= 4\times10 = 40$

Course Outcomes(PGMATHCE305)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understanding of our galaxy.	U	PO1	PSO1
CO2	Contrast and compare our galaxy with other galaxies as to type, contents, age, luminosity, motion, and size.	R, An	PO1, PO2	PSO3
CO3	Using cosmological models to analyze the size, age, structure, and motion of the universe overall.	An	PO1, PO2	PSO3

Recommended Books

1. Space-time and Geometry Sean M. Carroll
2. A Relativist's Toolkit: The Mathematics of Black-HoleMechanics Eric Poisson
3. Modern Cosmology---Scott Dodelson
4. Introduction to Cosmology--- Barbara Ryden
5. Cosmology, Steven Weinberg
6. Principles of Physical Cosmology P. J. E. Peebles
7. Introducing Einstein's Relativity Ray d'Inverno

SEMESTER – III	
Name of the Course: **Mathematical Biology-I**	
Course Code: **PGMATHCE306**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE306)

The prime objectives of the course are:

- Aware the students about the effect of nutrients on autotrophy-herbivore interaction.
- Introduce to the dynamics of Phytoplankton-Zooplankton system.
- Understand the Microbial population model and other Mathematical models in ecology.

Course Content

MATHEMATICAL BIOLOGY-I

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Unit-I: Effect of Nutrients on autotrophy-herbivore interaction: Introduction, Models onnutrient recyclingand its stability. Effect of nutrients on autotrophy herbivore stability, Models on herbivore nutrientre cycling on autotrophic production.

Unit-II: Dynamics of Phytoplankton-Zooplankton system: Introduction, Models on phytoplankton-zooplankton system and its stability, Bio-control in plankton models with nutrient recycling.

Unit-III: Microbial population model: Microbial growth in a chemostat. Stability of steady states. Growth of microbial population. Product formation due to microbial action. Competition for a growth-rate limiting substrate in a chemostat.

Unit-IV: Mathematical models in ecology: Discrete and Continuous population models for single species. Logistic models and their stability analysis. Lag factor and stability of population steady states.

Question Pattern for End Semester Examination (Course Code: PGMATHCE306)

Part A (MATHEMATICAL BIOLOGY-I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE306)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Use sophisticated mathematical techniques in the analysis of mathematical models in biology.	Ap	PO2, PO3	PSO2
CO2	Apply and extend classical models in mathematical biology.	Ap, E	PO2, PO3	PSO4
CO3	Construct mathematical models for biological systems like phytoplankton-zooplankton system, Microbial population model, Discrete and Continuous population models.	C	PO4	PSO6

Recommended Books

1. K. E. Watt: Ecology and Resource Management-A Quantitative Approach.
2. R. M. May: Stability and Complexity in Model Ecosystem.
3. Y. M. Svirezhev and D. O. Logofet: Stability of Biological Communities.
4. A. Segel: Modelling Dynamic Phenomena in Molecular Biology.
5. J. D. Murray: Mathematical Biology. Springer and Verlag.
6. N. T. J. Bailey: The Mathematical Approach to Biology and Medicine.
7. L. Perko (1991): Differential Equations and Dynamical Systems, Springer Verlag.
8. F. Verhulust (1996): Nonlinear Differential Equations and Dynamical Systems, Springer Verlag.
9. H. I. Freedman - Deterministic Mathematical Models in Population Ecology.
10. Mark Kot (2001): Elements of Mathematical Ecology, Cambridge Univ. Press

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SEMESTER – III		
Name of the Course: **Operation Research-I**		
Course Code: **PGMATHCE307**		
Full Marks: 50		Credits: 4
Theory	Credits: 4 Full Marks: 50	
Number of classes required: 60		
This course has been newly introduced vide BOS meeting dated 23/03/2018		

Course Objectives (PGMATHCE307)

The prime objectives of the course are:

- To introduce basic optimization techniques in order to get best results from a set of several possible solutions of different problems.
- Learn to formulate of real world phenomena from its physical considerations and implementation of optimization algorithms for solving these problems.
- Learn to solve linear programming problems, transportation problem, assignment problem and unconstrained and constrained problems etc.
- Acquaint students to deal with non-linear programmings.

Course Content

OPERATION RESEARCH-I

Extension of Linear Programming Methods: Theory of Revised Simplex Method and algorithmic solution approaches to linear programs, Dual-Simplex Method, Decomposition principle and its use to linear programs for decentralized planning problems.

Integer Programming (IP): The concept of cutting plane for linear integer programs, Gomory's cutting plane method, Gomory's All-Integer Programming Method, Branch-and- Bound Algorithm for general integer programs.

Sequencing Models: The mathematical aspects of Job sequencing and processing problems, Processing n jobs through Two machines, processing n jobs through m machines.

Nonlinear Programming (NLP): Convex analysis, Necessary and Sufficient optimality conditions, Cauchy's Steepest descent method, Karush-Kuhn-Tucker (KKT) theory of NLP, Wolfe's and Beale's approaches to Quadratic Programs.

Sensitivity Analysis: Changes in price vector of objective function, changes in resource requirement vector, addition of decision variable, addition of a constraint.

Parametric Programming: Variation in price vector, Variation in requirement vector.

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Replacement and Maintenance Models: Failure mechanism of items, General replacement policies forgradual failure of items with constant money value and change of money value at a constant rate over thetime period. Selection of best item

Dynamic Programming (DP): Basic features of DP problems, Bellman's principle of optimality, Multistage decision process with Forward and Backward recursive relations, DP approach to stage-coach problems.

Non-Linear Programming (NLP): Lagrange Function and Multipliers, Lagrange Multipliers methods for nonlinear programs with equality and inequality constraints.

Separable programming, Piecewise linear approximation solution approach, Linear fractional programming.

Question Pattern for End Semester Examination (Course Code: PGMATHCE307)

Part A (OPERATION RESEARCH-I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10=40$

Course Outcomes (PGMATHCE307)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Show the Kuhn-Tucker optimality conditions.	U	PO1	PSO1
CO2	Formulate and solve problems as networks and graphs.	E, C	PO3, PO4	PSO5
CO3	Construct linear integer programming models and discuss the solution techniques.	An, C	PO4	PSO6
CO4	Develop linear programming (LP) models for shortest path, maximum flow, minimal spanning tree, critical path, minimum cost flow, and transhipment problems.	C	PO4	PSO6
CO5	Solve the problems using special solution algorithms.	C	PO4	PSO6

Recommended Books

1. Linear Programming – G. Hadley.
2. Mathematical Programming Techniques – N. S. Kambo.
3. Nonlinear and Dynamic Programming – G. Hadley.
4. Operations Research – K. Swarup, P. K. Gupta and Man Mohan.
5. Operations Research – H. A. Taha.
6. Introduction to Operations Research – A. Frederick, F. S. Hillier and G. J. Lieberman.
7. Engineering Optimization: Theory and Practice – S. S. Rao.
8. Principles of Operations Research – Harvey M. Wagner.
9. Operations Research – P. K. Gupta and D. S. Hira.
10. Nonlinear and Mixed-Integer Optimization – Christodoulos A. Floudas.
11. Operations Research: Theory and Applications – J. K. Sharma.
12. Operations Research: S.D. Sharma

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SEMESTER – III	
Name of the Course: Continuum Mechanics-I	
Course Code: PGMATHCE308	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE308)

The prime objectives of the course are:

- To provide a treatment of advanced topics in solid mechanics.
- Learn to apply the techniques of continuum mechanics in deriving important results and in research problems.
- To provide the student with knowledge of the elastostatics and elastodynamics and an appreciation of their application to real world problems.

Course Content

CONTINUUM MECHANICS-I

SOLID MECHANICS

Elastostatics: Orthogonal curvilinear coordinates. Strain and rotation components, dilatation. Equations of motion in terms of dilatation and rotation. Stress equations of motion. Radial displacement. Spherical shell under internal and external pressures, gravitating sphere.Displacement symmetrical about an axis. Cylindrical tube under pressure, rotating cylinder. Problems of semi-infinite solids with displacements or stresses prescribed on the planeboundary. Variational methods. Theorems of minimum potential energy. Betti-Raylegh reciprocal theorem. Use of minimum principle in the case of deflection of elastic string of central line of a beam. Equilibrium of thin plates. Boundary conditions. Approximate theory of thin plates. Application to thin circular plates.

Elastodynamics: Waves in isotropic elastic solid medium. Surface waves, e.g. Rayleigh and Love waves. Kinematical and dynamical conditions in relation to the motion of a surface of discontinuity. Poisson's and Kirchoff's solutions of the characteristic wave equation. Radial and rotatory vibration of a solid and hollow sphere. Radial and torsional vibration of a circular cylinder. Transverse vibration of plates, Basic differential equations. Vibration of a rectangular plate with simply supported edges. Free vibration of a circular plate.

Plasticity: Basic concepts and yield criteria. Prandtl-Reyss theory, Stress-strain relations of Von-Mises. Hencky's theory of small deformation. Torsion of cylindrical bars of circular andoval sections. Bending of a prismatic bar of narrow rectangular cross-section by terminal couple. Spherical and cylindrical shell under internal pressure. Plastic deformation of flat rings. Slip lines and plastic flow. Plastic mass pressed between two parallel planes.

Question Pattern for End Semester Examination (Course Code: PGMATHCE308)

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Part A (CONTINUUM MECHANICS-I, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10=40$

Course Outcomes (PGMATHCE308)

After completing the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Describe motion, deformation and forces in a continuum.	U	PO1	PSO1
CO2	Understand constitutive models for elastic and viscoelastic solids.	R, U	PO1	PSO1
CO3	Derive equations of motion and conservation laws for a continuum.	Ap	PO2, PO3	PSO2
CO4	Solve simple boundary value problems for solids.	Ap, E	PO2, PO3	PSO4

Recommended Books

1. Sokolnikoff I. S.: Mathematical Theory of Elasticity.
2. Love A.E. H.: A Treastise on the Mathematical Theory of Elasticity.
3. Fung Y.C.: Foundations of Solid Mechanics.
4. Timoshenko S. and Goodier N: Theory of Elasticity.
5. Ghosh. P.K.: Waves and Vibrations.
6. Prager, N and Hodge , P.G.: Theory of Perfectly Plastic Solids.
7. Southwell, R. V.: Theory of Elasticity.

SEMESTER – III	
Name of the Course: **Programming in Python & LaTex**	
Course Code: **PGMATHAE301**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHAE301)

The prime objectives of the course are:

- To develop Python and Latex programming for solving real world problems.
- Learn to use mathematical tools on Python.
- Develop codes for basic functions, animation, matplot, Rolle's and Mean value theorems.
- Learn to work on large projects using programming in Python and LaTex.

Course Content

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Programming in Python & LaTex

Python: Programming in Python

Unit I: Introduction to Python, Installation of Python, Basic elements of the language,Looping and Branching: If, select, for, break, continue, Functions, return, Contour plots, tiles,axes, legends.

Unit II: Matrices: Creating matrices, sum, product of matrices, inverse, rank determinant, comparing matrices, system of equations, High level linear algebra features, working with polynomials, plotting 2D and 3D graphs, defining a function and output arguments.

Mathematical tools in Python

Unit I: Python Demonstrations: Polynomials, discrete and continuous Random variables, Tcl/tk, spreadsheet, GUI: unicontrols, unicontrols with latex.

Unit II: Basic functions, animation, finite elements, Bezier curves and surfaces, matplot, complex elementary functions. Python help browser for mathematics. Parametric plots, Polar plots, Matrix Operations, Matrix inversions, Solving system of equations. Evaluation of definite integrals, Generating prime numbers, Illustration of Rolle's and Mean value theorems.

Course Outcomes (PGMATHAE301)

After the completion of this course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Understand the fundamentals of Python Language and the basics of LaTeX.	R, U	PO1	PSO1
CO 2	Acquire the basic skills required for Python programming.	U	PO1	PSO1
CO 3	Solve Mathematical problems using Python programs.	Ap	PO2, PO3	PSO2
CO 4	Learn to prepare a LaTeX document, article and a project report.	Ap, E	PO2, PO3	PSO4

Recommended Books

1. Introduction to computer and Programming Using Python: John V. Guttag

LaTex

LaTex Typesetting

Unit I: Introduction to LaTeX, Installation of LaTeX, Layout Design, LaTeX input files, Input file structure, document classes, packages, environments, pagestyles, Typesetting texts, Fancy Header, tables.

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Unit II: Inline math formulas and displayed equations, Math symbols and fonts,Deli meters, matrices, arrays, Typesetting Mathematical formulae: fractions, Integrals, sums, products, etc. Producing Mathematical Graphics.

Writing and Presentation Using LaTex

Unit I: Document classes for paper writing, thesis, books, etc. Table of contents, index, bibliography management, hypertext, pdf pages, geometry, fancy header and footer, Verbatim, itemize, enumerate, boxes, equation number.

Unit II: Beamer class, beamer theme, frames, slides, pause,overlay, transparent, handouts and presentation mode.

SEMESTER – IV		
Name of the Course: **Number Theory**		
Course Code: **PGMATHCC401**		
Full Marks: 50		Credits: 4
Theory	Credits: 4 Full Marks: 50	
Number of classes required: 60		
This course has been newly introduced vide BOS meeting dated 23/03/2018		

Course Objectives (PGMATHCC401)

The prime objectives of the course are:

- Understand the concept of Partitions and Compositions.
- Introduce the Euler's Generalization of Fermat's Theorem.
- Understand the primitive roots, indices and the quadratic reciprocity law
- Expose to the concept of the Arithmetic of *Zp,* pseudo prime, Carmichael Numbers, Quadratic residues and non quadratic residues.

Course Content

NUMBER THEORY

Unit I: Euler's Generalization of Fermat's Theorem: Sum and Number of divisors, The Mobius Inversion Formula, The greatest Integer function, Euler's Phi- Function, Euler's theorem, Properties of Phi function. [10]

Unit II: Primitive Roots, Indices and the Quadratic Reciprocity Law: The Order of an Integer Modulo n , Primitive Roots for Primes , Composite Numbers having primitive Roots, Theory of Indices, Euler's Criterion , The Legendre Symbol and its Properties , Quadratic Congruences with Composite Moduli. [10]

Unit-III: The Arithmetic of *Zp, p* a prime, pseudo prime and Carmichael Numbers, Fermat Numbers, Perfect Numbers, Mersenne Numbers. Primitive roots, the group of units *Zn**, the existence of primitive roots, applications of primitive roots, the algebraic structure of *Zn**. [20]

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Unit-IV: Quadratic residues and non quadratic residues, Legendre symbol, proof of the law of quadratic reciprocity, Jacobi symbols. Arithmetic functions, definitions and examples, perfect numbers, the M¨obius Inversion formula, properties of M¨obius function. Sum of two squares, the sum of three squares and the sum of four squares. [20]

Question Pattern for End Semester Examination (Course Code: PGMATHCC401)

Part A (NUMBER THEORY, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10=40$

Course Outcomes (PGMATHCC401)

Upon completion of the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Use congruence as a tool to reduce a hard labour of work in some calculations.	Ap	PO1	PSO1
CO2	Find primitive roots.	R	PO1	PSO1
CO3	Establish existing identities using Mobius inversion formula.	An	PO1, PO2	PSO3
CO4	Solve a Diophantine equation and system of Diophantine equations.	E, C	PO3, PO4	PSO5

Recommended Books

1. Gareth A Jones and J Mary Jones; Elementary Number Theory; Springer InternationalEdition.
2. Neal Koblitz; A course in number theory and cryptography; Springer-Verlag, 2ndedition.
3. D. M. Burton; Elementary Number Theory; Wm. C. Brown Publishers, Dulreque,Lowa, 1989.
4. Kenneth. H. Rosen; Elementary Number Theory & Its Applications; AT&T Bell Laboratories, Addition-Wesley Publishing Company, 3rd Edition.
5. Kenneth Ireland & Michael Rosen; A Classical Introduction to Modern NumberTheory, 2nd edition; Springer-verlag.
6. Saban Alaca, Kenneth S Williams; Introduction to Algebraic Number Theory;Cambridge University Press.
7. A Baker, A concise Introduction to the Theory of Numbers, Cambridge UniversityPress 1984
8. J.P. Serre, A course in arithmetic-. GTM Vol.7, Springer Verlag 1973
9. Tom M. Apostol. ,Introduction to Analytic number theory Narosa Publishing house1980
10. Niven and Zuckerman, An Introduction to the Theory of Numbers, 4th Ed Wiley, New York,1980,
11. Rosen K.H., Elementary Number Theory and its Applications Pearson AddisionWesely, 5th Edition.

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SEMESTER – IV		
Name of the Course: **Discrete Mathematics**		
Course Code: **PGMATHCC402**		
Full Marks: 50		Credits: 4
Theory	Credits: 4 Full Marks: 50	
Number of classes required: 60		
This course has been newly introduced vide BOS meeting dated 23/03/2018		

Course Objectives (PGMATHCC402)

The prime objectives of the course are:

- Prepare students to develop mathematical foundations to understand and create mathematical arguments require in learning many mathematics and computer sciences courses.
- To motivate students how to solve practical problems using discrete mathematics.
- Introduce the basic concepts of Graph theory such as Trees, Eulerian Graphs, Matching, Vertex colourings, Edge colourings, Planarity.

Course Content

DISCRETE MATHEMATICS

Discrete Mathematics -I

Unit-I: **Graph Theory:** Definition of an undirected graph, degree of a vertex, historical background of Graph Theory. Walks, paths, trails and cycles, subgraphs and induced subgraphs, connectivity, distance in a graph, complete and complete bipartite graphs. Eulerian graphs, Euler theorem on existence of Euler paths and circuits, Hamiltonian paths and cycles, Hamiltonian graphs. Definition and properties of trees, minimal spanning tree in aweighted graph, Kruskal algorithm and Primp's algorithm. Definition of planar graphs, Kuratowski's two graphs, the Euler polyhedron formula, Euler identity for connected planar graphs, detection of planarity, Kuratowski's theorem (proof not required). [15]

Discrete Mathematics -II

Unit-II: Graph Theory: Directed graphs (digraphs), digraphs and binary relations, strongly connected digraphs, Euler digraphs, vertex colouring of graphs, Chromatic number of graphs and its elementary properties, matrix representation of graphs, adjacency matrices of graphs and digraphs and their properties, path matrix, incidence matrices of graphs and digraphs and their properties. [10]

Unit-III: Ordered Sets: Partially ordered sets (posets), Hasse diagram of partially ordered sets, linear orders, linear extension of a partially ordered set, Realizer and dimension of a poset, lattices and their properties, complete lattice, sublattices, lattice as a partially ordered set, bounded lattice, distributive lattice, complements and completed lattices. The pigeonhole principle and its simple applications. [15]

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Unit-IV: Recurrence relations and Generating Functions: Introduction, recurrence relations, methods of solving recurrence relation with constant coefficients, solution of recurrence relations using Generating Functions. [10]

Question Pattern for End Semester Examination (Course Code: PGMATHCC402)

Part A (Discrete Mathematics -II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCC402)

After completing the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Understand the basic combinatorics, induction, inclusion exclusion, pigeon-hole principle.	U	PO1	PSO1
CO 2	Understand more advance topics in combinatorics: recurrence relations, generating functions.	R, U	PO1	PSO1
CO 3	Understand the basic logical concepts, analyzing arguments, quantification theory.	U	PO1	PSO1
CO 4	Apply the concepts to real life problems such as network theory, data structure, optimization etc.	Ap	PO2, PO3	PSO2
CO 5	Construct the method of deduction for validity of truth.	Ap	PO2, PO3	PSO2

Recommended Books

1. N. Deo; Graph Theory with Application to Engineering and Computer Science; PrenticeHall of India, New Delhi, 1990.
2. John Clark and Derek Allan Holton; A First Look at Graph Theory; World Scientific,New Jersey, 1991.
3. D. S. Malik and M. K. Sen; Discrete mathematical structures: theory and applications; Thomson, Australia, 2004.
4. Edward R. Scheinerman; Mathematics A Discrete Introduction; Thomson Asia Ltd., Singapore, 2001.
5. F. Harary; Graph Theory; Narosa Publishing House, New Delhi, 2001.
6. J. A. Bondy and U. S. R. Murty; Graph theory and related topics; Academic Press, NewYork, 1979.

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SEMESTER – IV	
Name of the Course: Advanced Real Analysis -II	
Course Code: PGMATHCE401	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE401)

The prime objectives of the course are:

- To consider theoretical foundations of concepts of mathematical analysis, viz. derivative, MVTs, functions of several variables, measure theory and integration.
- Learn to use the important applications of the subject in different branches of pure and applied mathematics.
- Enable students familiar with the concepts of real analysis and their fruitful applications.
- Understand the concept of measurable sets, non-measurable sets and Borel sets.

Course Content

ADVANCED REAL ANALYSIS -II

Unit-I: Derivative and Integrability: Properties of indefinite integral of a Lebesgue integrable function, Characterization of an absolutely continuous function in terms of indefinite integral. Fundamental theorem of Lebesgue integral. Lebesgue point of a Lebesgue integrable functions and its simple properties. [15]

Unit-II: Henstock integration on the real line: Concept of δ –time partition of the closed interval $[a,b]\subset\mathbb{R}$ where is δ a positive function on [a,b].Cousin's lemma, Definition of

Henstock integral of a function defined on [a,b] and its basic properties, Sacks-Henstock lemma and its consequence, Indefinite Henstock -9integral and its properties , Fundamental theorem, absolute Henstock integral, characterization of Lebesgue integral by absolute Henstock integral, Monotone convergence theorem, Dominated convergence theorem. [15]

Unit-III: Signed Measure and Integration: Definitions on a measurable space $(X,\mathcal{B})$ and elementary properties, positive and negative sets, Null sets, Hahn Decomposition Theorem, absolute continuity of measure, mutually singular measures, Jordan Decomposition theorem,

Integration with respect to signed measure, The Radon-Nikodym theorem, Lebesgue

Decomposition theorem, complex measures. [15]

Unit-IV: Distribution Theory: Test function, compact support, Distributions, operations on Distributions, local properties of distributions, convergence of distributions, Differentiation of

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distributions, Derivatives of locally integrable functions, Distribution of compact support, Direct product of distributions and convolution of distributions. [15]

Question Pattern for End Semester Examination (Course Code: PGMATHCE401)

Part A (ADVANCED REAL ANALYSIS -II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE401)

After completion of the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Solve problems relating to determinations of measures of finite, infinite sets.	Ap, E	PO2, PO3	PSO4
CO2	Constructing measurable, non-measurable sets and functions.	E, C	PO3, PO4	PSO5
CO3	Construct different Borel sets.	C	PO4	PSO6

Recommended Books

1. G. De. Berra: Introduction to measure theory, Van Nostrand Reinhold company, N.Y.1974.
2. S.K. Berberian: Measure and Integration, Chelsea, N.Y.1965.
3. A.M. Bruckner, J .B. Bruckner & B.S. Thomson: Real Analysis, Prentice-Hall, N.Y.1997.
4. G.B. Folland: Real Analysis-Modern techniques and their Applications, John Willeyand Sons, N.Y.1984.
5. R. L. Jeffery: The theory of functions of Real variables, Toronto University press,1953.
6. I.P. Natanson: Theory of Function of Real variables Vol-I & II, Frederic-Unger publishing,1953.
7. J.F. Randolph: Basic Real and Abstract Analysis –Academic Press, N.Y.1968.
8. W.F. Pfeffer: Integral and Measure, Marcel Dekker, Inc, N.Y,1977
9. H.L. Roydon: Real Analysis, Macmillan company N.Y.1988.
10. A.E. Taylor: General theory of functions and integration, Blains dell. pub. company, N.Y.1965
11. F.G. Friedlander: Introduction to the theory of Distributions, Cambridge university,press, 1982.
12. P.Y. Lee: Lanzhon Lectures on Henstock Integration, world scientific press,1989
13. W. Sierpinski: Cardinal and ordinal numbers.
14. Charles Swartz: Introduction to Gauge Integral, world scientific.
15. M.A. Al-Gwaiz: Theory of Distributions, Marcel-Dekker,N.Y.1992.

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SEMESTER – IV	
Name of the Course: **Advanced Complex Analysis-II**	
Course Code: **PGMATHCE402**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives(PGMATHCE402)

The prime objectives of the course are:

- Understand the concept of order and genus of entire functions.
- Learn to use the Poisson's integral formula and Meromorphic functions.
- Familiarise the univalent functions, Area theorem and Distortions theorem.

Course Content

ADVANCED COMPLEX ANALYSIS-II

Unit-I: Order and Genus of Entire Functions, Hadamard's Factorization Theorem, M(r, f), and its properties (statements only). Analytic Continuations: Direct analytic continuations, uniqueness of analytic continuation along a curve, Monodyomy theorem, Analyticcontinuation via Reflection. [20]

Unit-II: Poisson's integral formula, Meromorphic functions. Definition of the functions m(r, a), N(r, a) and T(r,f). Nevanlinna's first fundamental theorem. Cartan's identity theorem. Order of a meromorphic function. Comparative growth of $\log^+ M(r)$ and $T(r)$.

Nevanlinna's second fundamental theorem. Estimation of S(r) (Statement only). Someapplications. [22]

Unit-III: Univalent functions: Necessary and sufficient conditions for univalent, basicproperties of univalent functions, Area theorem, Distortions theorem. [18]

Question Pattern for End Semester Examination (Course Code: PGMATHCE402)

Part A (ADVANCED COMPLEX ANALYSIS-II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

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Course Outcomes (PGMATHCE402)

After completing the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO 1	Classify singularities, Integration of functions on C, applications to counting zeros and poles.	U	PO1	PSO1
CO 2	Evaluate definite real integrals.	E	PO2, PO3	PSO4
CO 3	Construct Mobius transformation between regions.	Ap, E	PO2, PO3	PSO4

Recommended Books

1. Functions of one complex variable – J. B. Conway, Springer International Studentedition, Narosa Publishing House, New Delhi, 2000.
2. Elementary Theory of Analytic Functions of one or several complex variables – H.Cartan, Courier Dover Publications, New York, 1995.
3. Complex Analysis (2nd Edition) – L. V. Ahlfors, McGraw-Hill Internationa l Student
4. Edition, 1990.
5. Complex Variables and applications – R. V. Churchil l, McGraw-Hill, 1996.
6. An Introduction to the Theory of functions of a complex Variable – E. T. Copson,Oxford university press, 1995.
7. An Introduction to Complex Analysis – A. R. Shastri, Macmillan India Ltd., 2003.
8. Complex Variables and Applications – S. Ponnusamy, and H. Silverman,Birhkäuser, 2006.
9. Complex Analysis: S. Lang , Springer-Verlag;1999

SEMESTER – IV	
Name of the Course: **Algebraic Topology – II**	
Course Code: **PGMATHCE403**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE403)

The prime objectives of the course are:

- Learn to prove and use the concepts of algebraic topology.
- Understand the cellular homology of a CW complex, Kunneth theorem and Eilenberg-Zilber Theorem.
- Perform mathematical reasoning with advanced knowledge of topology viz. higher homotopy groups, Whitehead's theorem, Cellular approximation and CW approximation.

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ALGEBRAIC TOPOLOGY – II

Unit-I: Cellular homology of a CW complex, Isomorphism between singular and cellular homology of a CW complex; Homology with arbitrary coefficient group and Universal coefficient theorem.

The product of CW-complexes and the tensor product of chain complexes; Singular chain complex of a product space; Homology of the tensor product of the product space (Kunneth theorem); Eilenberg-Zilber Theorem.

Cohomology groups – basic properties, Universal coefficient theorem for cohomology, geometric interpretation of co-cycles and co-chains; excision property and Mayer-Vietoris sequence. [30]

Unit-II: Cross product and Kunneth formula, Cup and cap product; Orientations, Poincare duality and other duality theorems.

The higher homotopy groups - basic constructions, properties and examples; Homotopy groups of spheres, Whitehead's theorem, classification of vector bundles and fibre bundles; Cellular approximation and CW approximation. Excision and homotopy groups, Hurewicz theorem, Eilenberg-MacLane space. Homotopy construction of cohomology, Fibrations. [30]

Question Pattern for End Semester Examination (Course Code: PGMATHCE403)

Part A (ALGEBRAIC TOPOLOGY – II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE403)

Upon successful completion, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Explain the fundamental concepts of algebraic topology and their role in modern mathematics and applied contexts.	R, U	PO1	PSO1
CO2	Apply problem-solving using algebraic topology techniques applied to diverse situations in physics, engineering and other mathematical contexts.	Ap	PO2, PO3	PSO2
CO3	Demonstrate accurate and efficient use of algebraic topology techniques.	Ap, An	PO1, PO2	PSO3
CO4	Demonstrate capacity for mathematical reasoning through analyzing, proving and explaining concepts from algebraic topology.	Ap, An	PO1, PO2	PSO3

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Recommended Books

1. G.E. Bredon; Topology and Geometry; Springer-Verlag GTM 139 (1993).
2. A. Dold; Lectures on Algebraic Topology; Springer-Verlag (1980).
3. W. Fulton; Algebraic Topology, A First Course; Springer-Verlag (1995).
4. M. J. Greenberg and J. R. Harper; Algebraic Topology: A first course; Perseus Books (Mathematical
5. Lecture Notes series) (1981).
6. A. Hatcher; Algebraic Topology; Cambridge University Press (2002).
7. William S. Massey; A Basic Course in Algebraic Topology; Springer-Verlag, New York Inc.(1993).
8. C.R.F. Maunder; Algebraic Topology; Dover Pub. N.Y. (1996).
9. J.J. Rotman; An Introduction to Algebraic Topology; Springer-Verlag, N.Y. (1988).
10. H. Schubert; Topology; Macdonald Technical and Scientific, London (1964).
11. James W. Vick; Homology Theory: An introduction to Algebraic Topology; Springer-Verlag, N. Y.(1994).

SEMESTER – IV	
Name of the Course: **Differential Manifold-II**	
Course Code: **PGMATHCE404**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Outcomes (PGMATHCE404)

The prime objectives of the course are:

- Introduce differentiable manifolds from an intrinsic point of view, leading to classical theorems such as the generalised Stokes theorem.
- Realise the subject matter of Lie algebra of vector fields on a manifold, Lie derivative of vector fields, Lie derivatives of differential forms, Frobenius theorem.
- Provides the necessary concepts to start studying more advanced areas of geometry, topology, analysis and mathematical physics.

Course Content

DIFFERENTIAL MANIFOLD-II

Topological manifolds – examples, differentiable manifolds – examples, smooth maps and diffeomorphisms, derivatives of smooth maps, local expression for the differential, curves ina manifold, immersion and submersion, rank, critical and regular points, submanifolds and regular submanifolds, Quotient manifold, examples of quotient manifolds.

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Tangent space and cotangent space, vector fields on a manifold, Lie algebra of vector fields on a manifold, integral curves of a vector field, local flows, *f*-related vector fields, Lie bracket, 1-parameter group of transformations, tangent bundles, manifold structure on tangent bundle, vector bundles.

Differential forms, local expression for a *k*-form, pull back of a *k*-form, wedge product, exterior differentiation, existence and uniqueness of exterior differentiation on manifold, exterior differentiation under pull-back.

Lie group, examples of Lie groups, action of a Lie group on a manifold, transformation group, action of a discrete group on manifold, invariant forms on a Lie group.

Lie derivative of vector fields, Lie derivatives of differential forms, Frobenius theorem.

Orientations on manifold, orientations and differential forms, manifolds with boundary.

Integration on manifolds – Stoke's theorem, line integral and Green's theorem.

Question Pattern for End Semester Examination (Course Code: PGMATHCE404)

Part A (DIFFERENTIAL MANIFOLD-II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Course Outcomes (PGMATHCE404)

After completing the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understand the normal curvature of a surface, its connection with the first and second fundamental form and Euler's theorem.	R, U	PO1	PSO1
CO2	Understand the concept of topological manifolds.	U	PO1	PSO1
CO3	Understand the concept of Lie group.	U	PO1	PSO1
CO4	Solve problems using Stoke's theorem, line integral and Green's theorem.	Ap	PO2, PO3	PSO2

Recommended Books

1. W. M. Boothby; An Introduction to Differentiable Manifolds and Riemanian Geometry; Academic Press, Revised, 2003.
2. L. Conlon; Differentiable Manifolds, A First Course; Birkhauser (Second Edition), 2008.
3. W. D. Curtis and F. R. Miller; Differential Manifolds and Theoretical Physics; AcademicPress, 1985.
4. S. Helgason; Differential Geometry, Lie Groups and Symmetric Spaces; Academic Press,1978.
5. N.J. Hicks; Notes on Differential Geometry; Notes.
6. Kobayashi & Nomizu; Foundations of Differential Geometry, Vol-I; IntersciencePublishers, 1963.
7. S. Kumaresan; A course in Differential Geometry and Lie-groups; Hindustan BookAgency.

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8. S. Lang; Differential and Riemannian manifolds; Springer-Verlag, 1995.
9. John M. Lee; Introduction to smooth manifolds; Springer.
10. S. Morita; Geometry of Differential forms; American Mathematical Society.
11. Bernard Schutz; Geometrical Methods of Mathematical Physics; Cambridge UniversityPress, 1980

SEMESTER – IV	
Name of the Course: Cosmology-II	
Course Code: **PGMATHCE405**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE405)

The prime objectives of the course are:

- Know the history of our universe from the Big Bang, through the formation of the cosmic microwave background; to the universe we see today, with all its large scale structures.
- Understand this whole evolution, perturbation theory, Einstein's General Theory of Relativity, statistical physics, thermodynamics, and a little bit of quantum field theory.
- Learn the theory, then implement and numerically solve the equations derived in order to obtain theoretical predictions.
- Learn to analyse the size, age, structure and motion of the universe overall.

Course Content

COSMOLOGY-II

Advanced Cosmology, The cosmic microwave background

The very early universe and inflation

Structure formation of the universe

Alternative cosmological models

Compact objects

Statistical simulation

Question Pattern for End Semester Examination (Course Code: PGMATHCE405)

Part A (COSMOLOGY-II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

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Course Outcomes (PGMATHCE405)

After completing the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understand the concept of advanced cosmology.	U	PO1	PSO1
CO2	Use an understanding of our galaxy to contrast and compare it with other galaxies as to type, contents, age, luminosity, motion, and size.	Ap	PO2, PO3	PSO2
CO3	Use cosmological models to analyze the size, age, structure, and motion of the universe overall.	R, An	PO1, PO2	PSO3

Recommended Books

1. Space-time and Geometry Sean M. Carroll
2. A Relativist's Toolkit: The Mathematics of Black-Hole Mechanics Eric Poisson
3. Modern Cosmology---Scott Dodelson
4. Introduction to Cosmology--- Barbara Ryden
5. Cosmology Steven Weinberg
6. Principles of Physical Cosmology P. J. E. Peebles
7. Introducing Einstein's Relativity Ray d'Inverno

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SEMESTER – IV	
Name of the Course: Mathematical Biology-II	
Course Code: PGMATHCE406	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCE406)

The prime objectives of the course are:

- Introduce students to the application of mathematical modeling in the analysis of biological systems including populations of molecules, cells and organisms.
- To show how mathematics, statistics and computing can be used in an integrated way to analyse biological systems.
- To develop students' skills in algebraic manipulation, the calculus of linear and non-linear differential equations, mathematical modelling, matrix algebra and statistical methods.
- To introduce students to the use of R for the analysis of biological processes and data, including simple computer programming.

Course Outcomes (PGMATHCE406)

After successful completion of the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Apply and extend classical models in mathematical biology.	Ap	PO2, PO3	PSO2
CO2	Construct mathematical models for biological systems like Continuous models for two, three or more interacting populations, Interaction of Ratio-dependent models.	Ap	PO2, PO3	PSO2
CO3	Use sophisticated mathematical techniques in the analysis of mathematical models in biology.	Ap, E	PO2, PO3	PSO4

Course Content

MATHEMATICAL BIOLOGY-II

Unit-I: Continuous models for two interacting populations: Lotka-Volterra model of predator -prey system, Kolmogorov model. Trophic function. Gauss's Model. Analysisof predator-prey model with in limit cycle behavior, parameter domains of stability.

Nonlinear oscillations in predator-prey system.

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Unit-II: Continuous models for three or more interacting populations: Food chainmodels. Stability of food chains. Species harvesting in competitive environment, Economic aspects of harvesting in predator-prey systems.

Unit-III: Interaction of Ratio-dependent models: Introduction, May's model, ratio-dependent models of two interacting species, two prey-one predator system with ratio-dependent predator influence- its stability and persistence.

Question Pattern for End Semester Examination (Course Code: PGMATHCE406)

Part A (MATHEMATICAL BIOLOGY-II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks $=4\times10 = 40$

Recommended Books

1. K. E. Watt: Ecology and Resource Management-A Quantitative Approach.
2. R. M. May: Stability and Complexity in Model Ecosystem.
3. Y. M. Svirezhev and D. O. Logofet: Stability of Biological Communities.
4. A. Segel: Modelling Dynamic Phenomena in Molecular Biology.
5. J. D. Murray: Mathematical Biology, Springer and Verlag.
6. N. T. J. Bailey: The Mathematical Approach to Biology and Medicine.
7. L. Perko (1991): Differential Equations and Dynamical Systems, SpringerVerlag.
8. F. Verhulust (1996): Nonlinear Differential Equations and Dynamical Systems, Springer Verlag.
9. H. I. Freedman - Deterministic Mathematical Models in Population Ecology.
10. Mark Kot (2001): Elements of Mathematical Ecology, Cambridge Univ. Press

SEMESTER – IV	
Name of the Course: **Operations Research-II**	
Course Code: **PGMATHCE407**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives(PGMATHCE407)

The prime objectives of the course are:

- Learn to formulate and solve problems as networks and graphs. Pravanjan Kr. Rana

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- Develop linear programming (LP) models for shortest path, maximum flow, minimal spanning tree, critical path, minimum cost flow, and transshipment problems.
- Learn to solve the problems using special solution algorithms.
- Explore the information theory, queuing theory and the theory of inventory control.

Course Outcomes (PGMATHCE407)

On completion of this course, students should be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Define and formulate linear programming problems and solve them using appropriate techniques and optimization solvers, interpret the results obtained and translate solutions into directives for action.	R, U	PO1	PSO1
CO2	Understand the concept of Queuing theory, simulation, Theory of Inventory Control, Information theory, Coding theory and Geometric Programming.	R, U	PO1	PSO1
CO3	Conduct and interpret post-optimal and sensitivity analysis and explain the primal-dual relationship.	U	PO1	PSO1
CO4	Develop mathematical skills to analyse and solve integer programming and network models arising from a wide range of applications.	Ap	PO2, PO3	PSO2
CO5	Effectively communicate ideas, explain procedures and interpret results and solutions in written and electronic forms to different audiences.	Ap, E	PO2, PO3	PSO4

Course Content

OPERATIONS RESEARCH-II

Network Analysis– Network definitions, Minimal Spanning Tree Algorithm, Shortest Route Algorithms, Max-flow Min-cut theorem, Genaralized Max-flow Min-cut theorem, linear programming interpretation of Max-flow Min-cut theorem, minimum cost flows. A brief introduction to PERT and CPM, Components of PERT/CPM Network and precedence relationships, Critical path analysis, PERT analysis in controlling project.

Queueing Theory: Basic features of Queueing Systems, Operating characteristics of a Queueing System, Arrival and Departure (birth and death) distributions, Inter-arrival and service times distributions, Transient steady-state conditions in queueing process.

Poisson queueing models: $(M / M / 1): (\infty / FIFO / \infty)$; $(M / M / 1): (N / FIFO / \infty)$; $(M / M / C): (\infty / FIFO / \infty)$; $(M / M / C): (N / FIFO / \infty), C \leq$; $(M / M / R): (K / GD / K), R < K$– machine servicing model;

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Simulation: A brief introduction to simulation, Advantages of simulations over traditional search methods, Limitations of simulation techniques, Computational aspects of simulating a system, random number generation in stochastic simulation, Monte-Carlo simulation and modelling aspects of a system, Simulation approaches to inventory and queueing systems.

Theory of Inventory Control: A brief introduction to Inventory Control, Single-item deterministic models without shortages and with shortages, models with price breaks. Dynamic Demand Inventory Models. Single-item stochastic models without Set-up cost and with Set-up cost Multi-item inventory models with the limitations on warehouse capacity, Average inventory capacity, Capital investment.

Information Theory: Information concept, expected information, bivariate information theory, economic relations involving conditional probabilities, Entropy and properties of entropy function.

Coding theory: Communication system, encoding and decoding, Shannon-Fano encoding procedure, Haffman encoding, noiseless coding theory, noisy coding, error detection and correction, minimum distance decoding, family of codes, Hammimg code, Golay code, BCH codes, Reed-Muller code, perfect code, codes and design, Linear codes and their dual, weight distribution.

Geometric Programming (GP):

Posynomial, Signomial, Degree of difficulty, Unconstrained minimization problems, Solution using Differential Calculus, Solution seeking Arithmetic-Geometric inequality, Primal dual relationship & sufficiency conditions in the unconstrained case, Constrained minimization, Solution of a constrained Geometric Programming problem, Geometric programming with mixed inequality constrains, Complementary Geometric programming.

Question Pattern for End Semester Examination (Course Code: PGMATHCE407)

Part A (OPERATIONS RESEARCH-II, 30 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$
2. Attempt 2 questions out of 3 questions and each question carries 10 marks $=2\times10=20$

Part B (OPERATIONS RESEARCH-II, 10 Marks)

3. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$

Part C (OPERATIONS RESEARCH-II, 10 Marks)

4. Attempt 2 questions out of 3 questions and each question carries 5 marks $=2\times5=10$

Recommended Books

1. Operations Research – K. Swarup, P. K. Gupta and Man Mohan.
2. Operations Research – H. A. Taha.

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3. Operations Research – S. D. Sharma.
4. Introduction to Operations Research – A. Frederick, F. S. Hillier and G. J. Lieberman.
5. Optimization Theory and Applications – S. S. Rao.
6. Engineering Optimization: Theory and Practice – S. S. Rao
7. Optimization Methods in Operation Research – K. V. Mital.
8. Inventory Control – J. Jonson and D. Montogomer.
9. Analysis of Inventory Systems – G. Haddly and T. M. Within.
10. Queuing Theory – J. A. Panico.
11. Introduction to Theory of Queues – L. Takacs.
12. Linear Programming in Single and Multiple Objective System – J. P. Ignizio.
13. Decisions with Multiple Objectives – R. L. Keeney and H. Raiffs.
14. Linear Goal Programming – M. J. Schniederjans.
15. Linear Multiobjective Programming – M. Zeleny.
16. Multi-objective Programming and Goal Programming: *Theory and Applications* – T. Tanino, T. Tanaka and M. Inuiguchi.
17. Mult-objective Programming and Goal Programming: *Theory and Applications* – M. Tamiz.
18. Goal Programming and Extensions – J. P. Ignizio.
19. Handbook of Critical Issues in Goal Programming – C. Romero.
20. Fuzzy Multiple Objective Decision Making – Y. J. Lai and C. L. Hwang.
21. Fuzzy Set Theory and its Applications – H. J. Zimmermann.
22. Genetic Algorithms in Search, Optimization and Machine Learning – D. E. Goldberg.
23. An Introduction to Genetic Algorithms – M. Mitchell.
24. Genetic Algorithms – K. F. Man, K. S. Tang and S. Kwong.
25. Genetic Algorithms + Data Structures = Evolution Programs – Z. Michalewicz.
26. Adaptation in Natural and Artificial Systems - J. H. Holland.
27. An Introduction to Information Theory – F. M. Reza.
28. Operations Research: *An Introduction* – P. K. Gupta and D.S. Hira.

SEMESTER – IV	
Name of the Course: **Continuum Mechanics-II**	
Course Code: **PGMATHCE408**	
Full Marks: 50	Credits: 4
Theory	Credits: 4 Full Marks: 50
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives(PGMATHCE408)

The prime objectives of the course are:

- To expose the students to the basic elements of continuum mechanics in a sufficiently rigorous manner.
- To appreciate a wide variety of advanced courses in fluid mechanics.
- Understanding the behaviour of viscous fluid dynamics.
- To analyze the problems related to basic incompressible viscous flows and non-dimension parameters for a given system.

Course Outcomes (PGMATHCE408)

After completing the course, students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Describe the physical properties of a fluid.	U	PO2, PO3	PSO2
CO2	Demonstrate the application point of hydrostatic forces on plane and curved surfaces.	R, U	PO2, PO3	PSO4
CO3	Calculate the pressure distribution for incompressible fluids.	E	PO2, PO3	PSO4
CO4	Calculate the hydrostatic pressure and force on plane and curved surfaces.	E, C	PO3, PO4	PSO5

Course Content

CONTINUUM MECHANICS-II

FLUID MECHANICS

Unit –I: Lagrangian and Eulerian methods of description; Governing equations of fluidmotion; stream line; velocity potential, path line, velocity and circulation; equations ofcontinuity in Lagrangian and Eulerian methods; equivalence of the two forms of equations ofcontinuity; Boundary surface; acceleration; Euler's equations of motion; integrals of Euler'sequations of motion, Lagrange's equations of motion; Cauchy's integrals; equation of energy. [15]

Unit- II: Motion in two dimensions; stream function; complex potential; source; sink and doublet; image, images in two dimensions, images of a source with regard to a plane, a circle and a sphere; image of a doublet; circle theorem; theorem of Blasius. [10]

Unit –III: Vortex Motion, Helmholtz properties of vortices, velocity in a vortex field, motion of a circular vortex, infinite rows of vortices, Ka'rma'n vortex street. [10]

Unit –IV: Viscous fluid, Stokes-Navier equations; diffusion of vorticity, dissipation of energy; steady motion of a viscous fluid between two parallel planes; steady flow through cylindrical pipes; Reynolds' number. [10]

Unit –V: Waves motion in a gas; speed of sound; equation of motion of a gas; subsonic, sonic and supersonic flows of a gas; isentropic gas flow; flow through a nozzle; shock formation; elementary analysis of normal and oblique shock waves. [15]

Question Pattern for End Semester Examination (Course Code: PGMATHCE408)

Part A (CONTINUUM MECHANICS-II, 50 Marks)

1. Attempt 2 questions out of 3 questions and each question carries 5 marks =$2\times5 = 10$
2. Attempt 4 questions out of 6 questions and each question carries 10 marks =$4\times10 = 40$

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Recommended Books

1. A treatise of Hydromechanics (3^{rd} edition) – W. H. Besant, A. S. Ramsey and G. Bell,1997.
2. Ideal and Incompressible Fluid Dynamics – M. E. O'Neill and F. Chorlton, John Wileypublications, 1986.
3. Theoretical Hydrodynamics – L. M. Milne-Thomson, Macmillan Publishing co., 1985. 2.Text Book of Fluid Dynamics – F. Chorlton, Van Nostr and Reinhold Co., London, 1990.

SEMESTER – IV	
Name of the Course: **Project Work**	
Course Code: **PGMATHCC403**	
Full Marks: 50	Credits: 4
Project Work	Credits: 4 ***Dissertation***: 35 ***Viva Voce: 15***
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHCC403)

The prime objectives of the course are:

- Learn to apply fundamental and disciplinary concepts and methods in ways appropriate to their principal areas of study.
- Demonstrate skill and knowledge of current information and technological tools and techniques specific to the professional field of study.
- Use effectively oral, written and visual communication.
- Learn to identify, analyze, and solve problems creatively through sustained critical investigation.
- Learn to integrate information from multiple sources.

Course Outcomes (PGMATHCC403)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Demonstrate a sound technical knowledge of their selected project topic.	U	PO1	PSO1
CO2	Design engineering solutions to complex problems utilising a systems approach.	Ap	PO2, PO3	PSO2
CO3	Undertake problem identification, formulation and solution.	An	PO1, PO2	PSO3
CO4	Conduct an engineering project.	Ap, E	PO2, PO3	PSO4

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SEMESTER – IV	
Name of the Course: **Seminar Presentation**	
Course Code: **PGMATHSS04**	
Full Marks: 25	Credits: 1
Seminar Presentation	Credits: 1 ***Full Marks: 25***
This course has been newly introduced vide BOS meeting dated 23/03/2018	

Course Objectives (PGMATHSS04)

The prime objectives of the course are:

- To show competence in identifying relevant information, defining and explaining topics under discussion.
- Learn to judge when to speak and how much to say, speak clearly and audibly in a manner appropriate to the subject, ask appropriate questions, use evidence to support claims, respond to a range of questions.
- Make the students able to take part in meaningful discussion to reach a shared understanding.
- Learn to show their depth of understanding and intellectual leadership and effective time management.

Course Outcomes (PGMATHSS04)

On successful completion of the course students will be able to:

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Show competence in identifying relevant information, defining and explaining topics under discussion.	R, U	PO1	PSO1
CO2	Demonstrate depth of understanding, use primary and secondary sources.	Ap	PO2, PO3	PSO2
CO3	Demonstrate complexity, insight, cogency, independent thought, relevance, and persuasiveness.	Ap	PO2, PO3	PSO2
CO4	Evaluate information and use and apply relevant theories.	Ap, E	PO2, PO3	PSO4

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