RAMAKRISHNA MISSION VIVEKANANDA CENTENARY COLLEGE

RAHARA, KOLKATA-700118

DEPARTMENT OF MATHEMATICS

SESSION 2019-20

Coursework Syllabus for Ph.D. in Mathematics

The coursework syllabus of Ph. D. in Mathematics is introduced vide BOS resolution dated 26.02.2019 with 100% modification

PROGRAM OUTCOMES

After completion of the Ph.D. Degree program, the students will be able to

PO No.	Program Outcomes	Cognitive Level
PO 1	Understands and apply theories, methodologies, and knowledge to address fundamental questions in their primary area of study.	U, Ap
PO 2	Demonstrate the gained knowledge and skills in oral and written and hence communicate them to publish and present work in their field.	E, C
PO 3	Develop a mastery of analysing skills and knowledge at a level required for college and university undergraduate teaching in their discipline and assessment of student learning.	An
PO 4	Develop the intellectual independence that epitomizes true scholarship and Pursue research of significance in the discipline under the guidance of an advisor.	C

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

PROGRAMME SPECIFIC OUTCOMES

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

PSO No.	Program Specific Outcomes	Cognitive Level
PSO1	Mastery of fundamental knowledge in Mathematics (Algebra, Analysis, Geometry).	U, Ap
PSO2	Ability to solve problems, and communicate solutions in rigorous mathematical language.	E, C
PSO3	Ability to communicate mathematical concepts effectively.	An, C
PSO4	Ability to conduct independent research.	C

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Course Structure

Course Code	Course Title	Credit
PHDMATH01	Research Methodology	4
PHDMATH02	Computer Applications	4
PHDMATH03	Literature review	4
	Special Paper	
PHDMATH04	Algebraic Topology	4
PHDMATH05	Complex Analysis	4
PHDMATH06	Cosmology	4
Total Credits		16

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SEMESTER – I	
Name of the Course: **Research Methodology**	
Course Code: **PHDMATH01**	
Full Marks: 100	Credit: 4
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 26/02/2019	

Course Objectives (PHDMATH01)

The prime objectives of the course are:

- Develop the ability to choose methods appropriate to research aims and objectives.
- Understand the advantages and disadvantages of particular research method.
- Develop skill of critical thinking and the skill of qualitative and quantitative data analysis and presentation.
- Prepare students for organizing and conducting research in a more appropriate manner

Course Content

Unit 1: Research Formulation: Objectives and motivation of Research –Research Methodology *vs* methods. Types of research– Descriptive, Analytical, Applied, Fundamental, Quantitative, Qualitative, Conceptual, Empirical etc.; Approaches to Research: Preparation of Schedule, Case study approach, Comparison approach, Definition approach, Descriptive approach, Evaluative approach, Exploratory approach, Interpretive approach, Narrative approach, Persuasive approach, Policy memorandum approach. Definition and formulation of the research problem – Selection of the problem - Necessity of defining the problem - Importance of literature review in defining a problem–Literature review–Primary and secondary sources–reviews, treatise, monographs-patents–webasasource–searching the web-Critical literature review–Development of working hypothesis. [12]

Unit- II: Data Collection and analysis: Execution of the research-Observation and Collection of data - Methods of data collection –Sampling Methods- Data Processing and Analysis strategies – Data Analysis with Statistical Packages-Hypothesis-testing-Generalization and Interpretation. [12]

Unit III: Reporting and thesis writing: Structure and components of scientific reports - Types of report – Technical reports and thesis –Significance – Different steps in the preparation – Layout, structure and Language of typical reports–Illustrations and tables–Bibliography, referencing and footnotes. [12]

Unit IV: Application of results and ethics: Environmental impacts – Ethical issues - ethical committees. Intellectual property rights (IPR): kinds of property, nature of IP, basic principle, major IP, moral rights &economic rights; Copy right, patent, industrial design,

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trade mark, geographical indication, farmers' right, IPR licensing & technology transfer; Reproduction of published material- plagiarism, citation and acknowledgement. Reproducibility of IP and accountability. [12]

Unit V: Presentation of Results: Poster presentation, Oral presentation, Software related to presentation, layout and structure. Oral presentation–Planning–Preparation–Practice–Makingpresentation–Useofvisualaids-Importanceofeffective.Communication. Writing an Abstract: Importance, Types: Critical Abstract; Descriptive Abstract; Informative Abstract; Highlight Abstract; Writing Style. Writing Introduction: Background Information, Research Questions, Theoretical Framework. Writing a Case Study: Identifying a Case, Structure and writing style, Limitations. Writing a Field Report: Objects to observe, Obtaining consent, Field Notes, Techniques to Record Observation. Writing an Executive Summary; Policy Memo Writing a Book Review: Descriptive; Critical. Proof Reading: Strategies to identify errors; use of computer checking, common grammatical errors. Group Projects: Goals, Planning, Preparation and Implementation. [12]

Course Outcomes (PHDMATH01)

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

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Understand the objectives, motivation and types of research	U	PO1	PSO1
CO2	Define and formulate a research problem	R, C	PO4	PSO2
CO3	Collect data (primary or secondary) based on the formulated problem and analyse the data.	An	PO2	PSO3
CO4	Analyse the data with hypothesis testing, generalization and interpretation.	An, C	PO3	PSO3
CO5	Discuss the application of results and write the thesis.	Ap, E	PO3	PSO4

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SEMESTER – I	
Name of the Course: **Computer Applications**	
Course Code: **PHDMATH02**	
Full Marks: 100	Credit: 4
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 26/02/2019	

Course Objectives (PHDMATH02)

The prime objectives of the course are:

- To develop competency in technical writing.
- To master the fundamentals of writing LaTeX and Python scripts.
- To acquire Object Oriented Skills in Python.

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- To develop the skill of designing Graphical user Interfaces in Python and LaTeX.
- To develop the ability to write database applications in Python.

Course Content

Unit-I LaTex: Introduction to LaTeX, Installation of LaTeX, Layout Design, LaTeX input files, Input file structure, document classes, packages, environments, page styles, Type setting texts, Fancy Header, tables. In line math formulas and displayed equations, Math symbol sand fonts, Delimeters, matrices, arrays, Typesetting Mathematical formulae: fractions, Integrals, sums, products, etc. Producing Mathematical Graphics. 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. Beamer class, beamer theme, frames, sljdes, pause, overlay, transparent, hand outsand presentation mode. [30]

Unit-II Python: 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. 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. Python Demonstrations: Polynomials, discrete and continuous Random variables, Tcl/tk, spreadsheet, GUI: unicontrols, with latex.
Basic functions, animation, finite elements, Bezier curve sand surfaces, matplot, complex elementary functions. Python help browser for mathematics. Parametricplots, Polarplots, Matrix Operations, Matrix inversions, Solving system of equations. Evaluation of definite integrals, Generating prime numbers, Illustration of Rolle's and Mean value theorems. [30]

Course Outcomes (PHDMATH02)

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

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Explain and use TeX and LaTeX.	An	PO2	PSO2
CO2	Understand the advantages of LaTeX over other more traditional software's.	U	PO1	PSO1
CO3	Prepare handouts and presentations using LaTeX.	C	PO4	PSO3
CO4	Understand the core Python scripting elements such as variables and flow control structures.	U, Ap	PO1	PSO1
CO5	Use Python to read, write, demonstrations files.	E, C	PO3	PSO3

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SEMESTER – I	
Name of the Course: **Literature review**	
Course Code: **PHDMATH03**	
Full Marks: 100	Credit: 4
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 26/02/2019	

Course Objectives (PHDMATH03)

The prime objectives of the course are:

- To learn to review and assess scientific literature critically.
- To write and present an overview of the relevant literature for a specific research topic.
- To develop knowledge, insight, and academic skills.
- To develop transferable skills & interpersonal skills.

Course Content

Unit 1: Searching of Literature **5 hours**

- Formulation of key questions for a literature review.
- Identification of literature through generating a definite search string using relevant keywords.
- How to use Publication Databases: Web of Science, Scopus, PubMed, Google Scholar

Unit 2: Quantitative Evaluation of Literature **5 hours**

- Quantification of the research performance and research trends analysis.
- Identification of important bibliometric parameters namely Countries, Organizations, Authors, Research areas, funding agencies.
- Identification of important Journals for designing and communicating the research.

Unit3: Qualitative Evaluation of Literature **5 hours**

- Citation analysis: Average citation, h-index, G-index, i-10 index, self-citation, citation half-life.
- Mapping of science: Collaboration, Co-citation, co-occurrence network map analysis.
- Journal's impact: Impact factor, 5-year impact factor, Ranking, JCR and SNIP.
- Patent citation analysis.

Unit 4: Content Analysis **7 hours**

- Identification of "Trending Issues" of a particular research topic.
- Analysis of thematic evolving trends of a particular research field to identify "Emerging themes".
- Applications of various bibliometric software: Sci2, SciMat, Bibliometrix, VOSviewer.
- Basic introduction about meta data analysis.

Unit 5: How to Write a Review Literature **8 hours**

- Types of literature review: Critical Review, Systematic Review and Computational Review.
- Identification of the most important works, trends and debates within a certain field.
- Evaluation and presentation of the important research findings in a systematic way.

Unit 6: Assignments **30 hours**

- Independently defining, designing and writing of a literature review.

Course Outcomes

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

CO. No.	Course Outcome	Cognitive Level	POs Addressed	PSOs Addressed
CO1	Identify and retrieve relevant publications within a field of research and write a literature review by searching the literature systematically.	An, E	PO2	PSO4
CO2	Select representative scientific sources from several perspectives relevant to the assignment.	E	PO2	PSO3
CO3	Write a research proposal for obtaining Financial assistance from national funding agencies.	C	PO4	PSO4
CO4	Draw conclusions related to the research problem and give recommendations towards new research opportunities.	C	PO4	PSO4
CO 5	Represent and systematically structure a discussion on the theories and experimental results and define, design and write a literature review independently	An, C	PO3	PSO2

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SEMESTER – I	
Name of the Course: **ALGEBRAIC TOPOLOGY**	
Course Code: **PHDMATH04**	
Full Marks: 100	Credit: 4
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 26/02/2019	

Course Objectives (PHDMATH04)

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.

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- 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

Unit I: The Fundamental Group: Homotopy of Paths- The Fundamental Group- Covering spaces – The Fundamental Group of the circle-Retraction and Fixed points. [12]

Unit II: The Fundamental theorem of Algebra – The Borsuk – Ulamtheorem-Deformation Retracts and Homotopy Type – The Fundamental Group of S^n- Fundamental Group of some surfaces. [12]

Unit III: Separation Theorem in the plane: The Jordan Separation Theorem –invariance of domain-The Jordan curve Theorem-imbedding Graphs in the plane. [12]

Unit IV: The Selfert – van Kampen Theorem: Direct sums of abelian groups-Free product of groups- Free groups – The Selfert –van kampen Theorem– The Fundamental Group of a Wedgeofcircles. [12]

Unit V: Classification of surfaces: Fundamental Groups of surfaces –Homology of surfaces– Cutting and pasting – The Classification theorem– Constructing compact surfaces. [12]

Course Outcomes(PHDMATH04)

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	PSO2
CO4	Apply problem-solving using algebraic topology techniques and theorems including the Fundamental theorem of Algebra, Separation Theorem in the plane, Selfert – van Kampen Theorem.	Ap	PO1	PSO1

References:

1. A.Dold; Lectureson AlgebraicTopology;Springer-Verlag(1972).
2. W.Fulton;Algebraic Topology:AFirst Course;Springer-Verlag(1995).
3. M.Greenberg; Lectureson AlgebraicTopology; W.D.Benjamin,N.Y. (1967).
4. AllenHatcher;AlgebraicTopology;CambridgeUniv.Press(2002).

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5. C.Kosniowski;A FirstCoursein AlgebraicTopology; CambridgeUniversityPress (1980).
6. Dugundiji,Topology, Allynand Bacon,Boston,1966.
7. JamesR.Munkres;Topology(2ndEdit.);Pearson EducationInc.(2004).
8. E.H.Spanier;AlgebraicTopology;McGrawHillBookCo.N.Y.(1966).
9. C.T.C.Wall;A Geometric IntroductiontoTopology;Addison-WesleyPubl.Co.Inc(1972).
10. G.E.Bredon;TopologyandGeometry;Springer-VerlagGTM139(1993).
11. WilliamS.Massey;ABasicCourseinAlgebraicTopology;Springer-Verlag,NewYorkInc.(1993).
12. C.R.F.Maunder;AlgebraicTopology;Dover Pub.N.Y.(1996).
13. J.J.Rotman;AnIntroductiontoAlgebraicTopology;Springer-Verlag, N.Y.(1988).
14. H.Schubert;Topology;MacdonaldTechnicalandScientific,London(1964).
15. James W.Vick;HomologyTheory:An introductiontoAlgebraic Topology;Springer-Verlag,N.Y.(1994).

SEMESTER – I	
Name of the Course: **COMPLEX ANALYSIS**	
Course Code: **PHDMATH05**	
Full Marks: 100	Credit: 4
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 26/02/2019	

Course Objectives (PHDMATH05)

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.
- Learn to use the Poisson's integral formula and Meromorphic functions.
- Familiarise the univalent functions, Area theorem and Distortions theorem.

Course Content

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. [12]

Unit II: 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, Analytic continuation via Reflection. [10]

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Unit III: Open Mapping Theorem, Hurwitz's Theorem, Inverse Function Theorem, The Riemann Mapping Theorem. [10]

Unit IV: Spherical metrics, Normal Convergence, Montel's Theorem, Marty's Theorem, Picard's Little Theorem, Picard's Great Theorem. [10]

Unit V: 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 ameromorphic function. Comparative growth of $\log^+ M(r)$ and T(r). Nevanlinna'ssecondfundamentaltheorem.EstimationofS(r)(Statementonly). Some applications. Univalent functions: Necessary and sufficient conditions for univalent, basic properties of univalent functions, Area theorem, Distortions theorem. [18]

Course Outcomes(PHDMATH04)

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
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	PO1	PSO1
CO 4	Classify singularities, Integration of functions on C, applications to counting zeros and poles.	U	PO1	PSO1
CO 5	Evaluate definite real integrals.	E	PO2	PSO2
CO 6	Construct Mobius transformation between regions.	Ap, E	PO2	PSO2

References:

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

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SEMESTER – I	
Name of the Course: **COSMOLOGY**	
Course Code: **PHDMATH06**	
Full Marks: 100	Credit: 4
Number of classes required: 60	
This course has been newly introduced vide BOS meeting dated 26/02/2019	

Course Objectives (PHDMATH06)

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

Unit I: Advanced General theory of Relativity: Lagrangian and Hamiltonian formulations of General Relativity: Action integral, Lie derivative, Killing vectors, Field theory, First fundamental form, Second fundamental form, Variation of Hilbert term, Variation of boundary term,Variation of matteraction, Bianchi identity. Application of General Relativity to Astrophysics: Schwarzschildexterior solution, Birkhoff's theorem, Kruskal coordinate, Singularity, Idea of Blackhole, Staticblackhole (Schwarzschildblackhole), Rotatingblack hole(Kerrblackhole).

Unit II: Geodesiccongruence: Energy conditions: Weak energyconditions, Strongenergy conditions, Null energy conditions, Dominant energy conditions.

Kinematics of a deformable medium: Expansion, Shear, Rotation,Congruenceoftime like geodesic, Congruence of null geodesic, Frobenius theorem, Raychaudhuri's equation, Focusing theorem.

Unit III: Cosmology: Cosmological Principle, Weyl postulates, Robertson-Walkermetric, Cosmological Observations, Cosmological parameters, Friedmanncosmological models, Einstein's static Universe, de Sitter Universe, Expanding Universe, Cosmological Constant, Cosmologicalred shift, Hubble's Law. Dark Energy, Inflation, Horizon problem, Flatness problem, Steady state theory.

Unit IV: Non-linear Dynamicalsystems: System of ODE sinR^n,Autonomous systems, Flows, Vector field in Phase space, Attractor, Periodic orbit, limit cycles. Critical points, Hyperbolic andnon-hyperboliccritical points, Linear Stability theory, Hartman-Grobman theorem, Centre manifold theorem, Lyapunov functions, Poincare Bendixon theorem, Poicaresphere and behaviour at infinity.

Course Outcomes(PHDMATH06)

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

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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	PO3	PSO3
CO3	Using cosmological models to analyze the size, age, structure, and motion of the universe overall.	An	PO3	PSO3

References:

1. General Relativity–R.M.Wald
2. Gravitationand Cosmology—S.Weinberg
3. General Relativity, Astrophysics and Cosmology—Raychaudhury, Banerji and Banerjee
4. A Relativist's Toolkit—Eric Poisson
5. Introducing Einstein's Relativity—Rayd' Inverno
6. Differential Equations and Dynamical Systems—LawrencePerko
7. Nonlinear Dynamics and Chaos—S.H.Strogatz
8. Dynamical systems and Cosmology—A.A.Coley

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