University of Mumbai

SYLLABUS OF

T.Y.B.A/B.Sc. (Mathematics)

(Effective from June 2010)

T.Y.B. Sc. (Mathematics)

Single Major

Paper No.	No. of Lectures			Examination		
	Theory	Practical	Total	Theory	Practical	Total
I	90	90	180	100	50	150
II	90	90	180	100	50	150
III	90	90	180	100	50	150
IV	90	90	180	100	50	150
AC I	60	60	120	60	40	100
AC II	60	60	120	60	40	100
Total	**480**	**480**	**960**	**520**	**280**	**800**

Double Major

Paper No.	No. of Lectures			Examination		
	Theory	Practical	Total	Theory	Practical	Total
I	90	90	180	100	50	150
II	90	90	180	100	50	150
Total	**180**	**180**	**360**	**200**	**100**	**300**

T.Y.B. A. (Mathematics)

Single Major

Paper No.	No. of Lectures			Examination		
	Theory	Practical	Total	Theory	Practical	Total
I	90	90	180	100	50	150
II	90	90	180	100	50	150
III	90	90	180	100	50	150
IV	90	90	180	100	50	150
Total	**360**	**360**	**720**	**400**	**200**	**600**

Double Major

Paper No.	No. of Lectures			Examination		
	Theory	Practical	Total	Theory	Practical	Total
I	90	90	180	100	50	150
II	90	90	180	100	50	150
Total	**180**	**180**	**360**	**200**	**100**	**300**

Workload For T.Y.B.A./B.Sc. Mathematics (Without Applied Component)

Single Major

Paper No.	No. of Lectures Per Week		
	Theory	Practical	Total
I	3	3	6
II	3	3	6
III	3	3	6
IV	3	3	6
Total	**12**	**12**	**24**

Double Major

Paper No.	No. of Lectures Per Week		
	Theory	Practical	Total
I	3	3	6
II	3	3	6
Total	**6**	**6**	**12**

T.Y.B.A/B.Sc. Paper I

REAL ANALYSIS
and
MULTIVARIABLE CALCULUS

Note: This paper contains certain topics such as double and triple integrals, partial derivatives, direction derivatives, gradient of a scalar field, mixed partial derivatives, which have been covered in F.Y. and S.Y. B.A./B.Sc. syllabus. It is recommended that numerical examples based on these topics should not be asked in T.Y. Theory examination.

Term I

Unit 1. Riemann Integration, Double and Triple Integrals (23 Lectures)

(a) Uniform continuity of a real valued function on a subset of $\mathbb{R}$ (brief discussion)

- (i) Definition.
- (ii) a continuous function on a closed and bounded interval is uniformly continous (only statement).

(b) Riemann Integration.

- (i) Partition of a closed and bounded interval $[a, b]$, Upper sums and Lower sums of a bounded real valued function on $[a, b]$. Refinement of a partition, Definition of Riemann integrability of a function. A necessary and sufficient condition for a bounded function on $[a, b]$ to be Riemann integrable.(Riemann's Criterion)
- (ii) A monotone function on $[a, b]$ is Riemann integrable.
- (iii) A continuous function on $[a, b]$ is Riemann integrable.
  A function with only finitely many discontinuities on $[a, b]$ is Riemann integrable.
  Examples of Riemann integrable functions on $[a, b]$ which are discontinuous at all rational numbers in $[a, b]$

(c) Algebraic and order properties of Riemann integrable functions.

- (i) Riemann Integrability of sums, scalar multiples and products of integrable functions. The formulae for integrals of sums and scalar multiples of Riemann integrable functions.
- (ii) If $f : [a, b] \to \mathbb{R}$ is Riemann integrable and $f(x) \geq 0$ for all $x \in [a, b]$, then $\int_a^b f(x)dx \geq 0$.
- (iii) If f is Riemann integrable on $[a, b]$, and $a < c < b$, then f is Riemann integrable on $[a, c]$ and $[c, b]$, and $\displaystyle\int_a^b f(x)dx = \int_a^c f(x)dx + \int_c^b f(x)dx$.

(d) First and second Fundamental Theorem of Calculus.

(e) Integration by parts and change of variables formula.

(f) Mean Value Theorem for integrals.

(g) The integral as a limit of a sum, examples.

(h) Double and Triple Integrals

  (i) The definition of the Double (respectively Triple) integral of a bounded function on a rectangle (respectively box).
  (ii) Fubini's theorem over rectangles.
  (iii) Properties of Double and Triple Integrals:
    (1) Integrability of sums, scalar multiples, products of integrable functions, and formulae for integrals of sums and scalar multiples of integrable functions.
    (2) Domain additivity of the integrals.
    (3) Integrability of continuous functions and functions having only finitely (countably) many discontinuities.
    (4) Double and triple integrals over bounded domains.
    (5) Change of variables formula for double and triple integrals (statement only).

Reference for Unit 1:

1. **Real Analysis** Bartle *and* Sherbet.
2. **Calculus, Vol. 2**: T. Apostol, John Wiley.

Unit 2. Sequences and series of functions (22 Lectures)

(a) Pointwise and uniform convergence of sequences and series of real-valued functions. Weierstrass M-test. Examples.

(b) Continuity of the uniform limit (resp: uniform sum) of a sequence (resp: series) of real-valued functions. The integral and the derivative of the uniform limit (resp: uniform sum) of a sequence (resp: series) of real-valued functions on a closed and bounded interval. Examples.

(c) Power series in $\mathbb{R}$. Radius of convergence. Region of convergence. Uniform convergence. Term-by-term differentiation and integration of power series. Examples.

(d) Taylor and Maclaurin series. Classical functions defined by power series: exponential, trigonometric, logarithmic and hyperbolic functions, and the basic properties of these functions.

Reference for Unit 2: Methods of Real Analysis, R.R. Goldberg. Oxford and International Book House (IBH) Publishers, New Delhi.

Unit 3. Differential Calculus (23 Lectures)

(a) Limits and continuity of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$ (Vector fields)

Basic results on limits and continuity of sum, difference, scalar multiples of vector fields.

Continuity and components of vector fields.

(b) Differentiability of scalar functions:

  (i) Derivative of a scalar field with respect to a non-zero vector.
  (ii) Direction derivatives and partial derivatives of scalar fields.

(iii) Mean value theorem for derivatives of scalar fields.

(iv) Differentiability of a scalar field at a point (in terms of linear transformation).

Total derivative. Uniqueness of total derivative of a differentiable function at a point. (Simple examples of finding total derivative of functions such as $f(x,y) = x^2 + y^2$, $f(x,y,z) = x + y + z$, may be taken). Differentiability at a point implies continuity, and existence of direction derivative at the point. The existence of continous partial derivatives in a neighbourhood of a point implies differentiability at the point.

(v) Gradient of a scalar field. Geometric properties of gradient, level sets and tangent planes.

(vi) Chain rule for scalar fields.

(vii) Higher order partial derivatives, mixed partial derivatives.

Sufficient condition for equality of mixed partial derivative.

Second order Taylor formula for scalar fields.

(c) Differentiability of vector fields.

(i) Definition of differentiability of a vector field at a point.

Differentiability of a vector field at a point implies continuity.

(ii) The chain rule for derivative of vector fields.

Reference for Unit 3:

(1) **Calculus, Vol. 2**, T. Apostol, John Wiley.

(2) **Calculus**. J. Stewart. Brooke/Cole Publishing Co.

Unit 4. Surface integrals (22 Lectures)

(a) (i) Parametric representation of a surface.

(ii) The fundamental vector product, definition and it being normal to the surface.

(iii) Area of a parametrized surface.

(b) (i) Surface integrals of scalar and vector fields (definition).

(ii) Independence of value of surface integral under change of parametric representation of the surface.

(iii) Stokes' theorem, (assuming general form of Green's theorem) Divergence theorem for a solid in 3-space bounded by an orientable closed surface for continuously differentiable vector fields.

Reference for Unit 4:

(1) **Calculus. Vol. 2**, T. Apostol, John Wiley.

(2) **Calculus**. J. Stewart. Brooke/Cole Publishing Co.

Recommended books:

(1) Robert G. Bartle and Donald R. Sherbert. Introduction to Real Analysis, Second edition, John Wiley & Sons, INC.

(2) Richard G. Goldberg, Methods of Real Analysis, Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.

(3) Tom M. Apostol, Calculus Volume II, Second edition, John Wiley & Sons, New York.

(4) J. Stewart. Calculus. Third edition. Brooks/Cole Publishing Co.

(5) Berberian. Introduction to Real Analysis. Springer.

Additional Reference Books:

(1) J.E. Marsden and A.J. Tromba, Vector Calculus. Fifth Edition, http://bcs.whfreeman.com/marsdenvc5e/

(2) R. Courant and F. John, Introduction to Calculus and Analysis, Volume 2, Springer Verlag, New York.

(3) M.H. Protter and C.B. Morrey, Jr., Intermediate Calculus, Second edition, Springer Verlag, New York, 1996.

(4) D.V. Widder, Advanced Calculus, Second edition, Dover Pub., New York.

(5) Tom M. Apostol, Mathematical Analysis, Second edition, Narosa, New Delhi, 1974.

(6) J. Stewart. Multivariable Calculus. Sixth edition. Brooks/Cole Publishing Co.

(7) George Cain and James Herod, Multivariable Calculus. E-book available at http://people.math.gatech.edu/ cain/notes/calculus.html

Suggested Practicals for Paper I:

1. Riemann Integration.
2. Fundamental Theorem of Calculus.
3. Double and Triple Integrals; Fubini's theorem, Change of Variables Formula.
4. Pointwise and uniform convergence of sequences and series of functions.
5. Illustrations of continuity, differentiability, and integrability for pointwise and uniform convergence.
6. Power series in $\mathbb{R}$. Term by term differentiation and integration.
7. Limits and continuity of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$, Partial derivative, Directional derivatives.
8. Differentiability of scalar fields.
9. Differentiability of vector fields.
10. Parametrisation of surfaces, area of parametrised surfaces.
11. Surface integrals.
12. Stokes' Theorem and Gauss' Divergence Theorem.
13. Miscellaneous Theoretical questions based on Unit 1.
14. Miscellaneous Theoretical questions based on Unit 2.
15. Miscellaneous Theoretical questions based on Unit 3.
16. Miscellaneous Theoretical questions based on Unit 4.

Paper II

ALGEBRA

Unit 1. Linear Algebra (23 Lectures)

Review of vector spaces over $\mathbb{R}$:

(a) Quotient spaces:

   (i) For a real vector space V and a subspace W, the cosets $v + W$ and the quotient space V/W. First Isomorphism theorem of real vector spaces (Fundamental theorem of homomorphism of vector spaces.)

   (ii) Dimension and basis of the quotient space V/W, when V is finite dimensional.

(b) (i) Orthogonal transformations and isometries of a real finite dimensional inner product space. Translations and reflections with respect to a hyperplane. Orthogonal matrices over $\mathbb{R}$.

   (ii) Equivalence of orthogonal transformations and isometries fixing origin on a finite dimensional inner product space. Characterization of isometries as composites of orthogonal transformations and isometries.

   (iii) Orthogonal transformation of $\mathbb{R}^2$. Any orthogonal transformation in $\mathbb{R}^2$ is a reflection or a rotation.

(c) Characteristic polynomial of an $n \times n$ real matrix and a linear transformation of a finite dimensional real vector space to itself. Cayley Hamilton Theorem (Proof assuming the result $A \operatorname{adj}(A) = I_n$ for an $n \times n$ matrix over the polynomial ring $\mathbb{R}[t]$.)

(d) Diagonalizability.

   (i) Diagonalizability of an $n \times n$ real matrix and a linear transformation of a finite dimensional real vector space to itself.

   Definition: Geometric multiplicity and Algebraic multiplicity of eigenvalues of an $n \times n$ real matrix and of a linear transformation.

   (ii) An $n \times n$ matrix A is diagonalisable if and only if $\mathbb{R}^n$ has a basis of eigenvectors of A if and only if the sum of dimension of eigenspaces of A is n if and only if the algebraic and geometric multiplicities of eigenvalues of A coincide.

(e) Triangularization - Triangularization of an $n \times n$ real matrix having n real characteristic roots.

(f) Orthogonal diagonalization

   (i) Orthogonal diagonalization of $n \times n$ real symmetric matrices.

   (ii) Application to real quadratic forms. Positive definite, semidefinite matrices. Classification in terms of principal minors. Classification of conics in $\mathbb{R}^2$ and quadric surfaces in $\mathbb{R}^3$.

Reference for Unit 1:

(1) S. Kumaresan, Linear Algebra: A Geometric Approach.

(2) M. Artin. Algebra. Prentice Hall.

(3) T. Banchoff and J. Wermer, Linear Algebra through Geometry, Springer.

(4) L. Smith, Linear Algebra, Springer.

Unit 2. Groups and subgroups (22 Lectures)

(a) Definition and properties of a group. Abelian group. Order of a group, finite and infinite groups. Examples of groups including

(i) $\mathbb{Z}$, $\mathbb{Q}$, $\mathbb{R}$, $\mathbb{C}$ under addition.

(ii) $\mathbb{Q}^*(= \mathbb{Q} \setminus \{0\})$, $\mathbb{R}^*(= \mathbb{R} \setminus \{0\})$, $\mathbb{C}^*(= \mathbb{C} \setminus \{0\})$, $\mathbb{Q}^+$(= positive rational numbers) under multiplication.

(iii) $\mathbb{Z}_n$, the set of residue classes modulo n under addition.

(iv) $U(n)$, the group of prime residue classes modulo n under multiplication.

(v) The symmetric group S_n.

(vi) The group of symmetries of a plane figure. The Dihedral group D_n as the group of symmetrices of a regular polygon of n sides.

(vii) Quaternion group.

(viii) Matrix groups $\mathrm{M}_{m\times n}(\mathbb{R})$ under addition of matrices, $\mathrm{GL}_n(\mathbb{R})$, the set of invertible real matrices, under multiplication of matrices.

(b) Subgroups and Cyclic groups.

(i) Subgroups of $\mathrm{GL}_n(\mathbb{R})$ such as $\mathrm{SL}_n(\mathbb{R})$, $\mathrm{O}_n(\mathbb{R})$, $\mathrm{SO}_n(\mathbb{R})$, $\mathrm{SO}_2(\mathbb{R})$ as group of 2×2 real matrices representing rotations. S^1 as subgroup of $\mathbb{C}^*$, μ_n the subgroup of n-th roots of unity.

(ii) Cyclic groups (examples of $\mathbb{Z}$, $\mathbb{Z}_n$, and μ_n) and cyclic subgroups.

(iii) Groups generated by a finite set, generators and relations.
Examples such as Klein's four group V_4, Dihedral group, Quaternion group.

(iv) The Center $Z(G)$ of a group G, and the normalizer of an element of G as a subgroup of G.

(v) Cosets, Lagrange's theorem.

(c) Group homomorphisms and isomorphisms. Examples and properties. Automorphisms of a group, inner automorphisms.

Reference for Unit 2:

(1) I.N. Herstein, Algebra.

(2) P.B. Bhattacharya, S.K. Jain, S. Nagpaul. Abstract Algebra.

Unit 3. Normal subgroups (22 Lectures)

(a) (i) Normal subgroups of a group. Definition and exmaples including center of a group.

(ii) Quotient group.

(iii) Alternating group A_n, cycles. Listing normal subgroups of A_4, S_3.

(b) Isomorphisms theorems.

(i) First Isomorphism theorem (or Fundamental Theorem of homomorphisms of groups).

(ii) Second Isomorphism theorem.

(iii) Third Isomorphism theorem.

(c) Cayley's theorem.

(d) External direct product of a group. Properties of external direct products. Order of an element in a direct product, criterion for direct product to be cyclic. The groups $\mathbb{Z}_n$ and $U(n)$ as external direct product of groups.

(e) Classification of groups of order ≤ 7.

Reference for Unit 3:

(1) I.N. Herstein. Algebra.

(2) P.B. Bhattacharya, S.K. Jain, S. Nagpaul. Abstract Algebra.

Unit 4. Ring theory and factorization. (22 Lectures)

(a) (i) Definition of a ring. (The definition should include the existence of a unity element.)

(ii) Properties and examples of rings, including $\mathbb{Z}$, $\mathbb{Q}$, $\mathbb{R}$, $\mathbb{C}$, $M_n(\mathbb{R})$, $\mathbb{Q}[X]$, $\mathbb{R}[X]$, $\mathbb{C}[X]$, $\mathbb{Z}[i]$, $\mathbb{Z}[\sqrt{2}]$, $\mathbb{Z}[\sqrt{-5}]$, $\mathbb{Z}_n$.

(iii) Commutative rings.

(iv) Units in a ring. The multiplicative group of units of a ring.

(v) Characteristic of a ring.

(vi) Ring homomorphisms. First Isomorphism theorem of rings. Second Isomorphism theorem of rings.

(vii) Ideals in a ring, sum and product of ideals in a commutative ring.

(viii) Quotient rings.

(b) Integral domains and fields. Definition and examples.

(i) A finite integral domain is a field.

(ii) Characteristic of an integral domain, and of a finite field.

(c) (i) Construction of quotient field of an integral domain (Emphasis on $\mathbb{Z}$, $\mathbb{Q}$).

(ii) A field contains a subfield isomorphic to $\mathbb{Z}_p$ or $\mathbb{Q}$.

(d) Prime ideals and maximal ideals. Definition and examples. Characterization in terms of quotient rings.

(e) Polynomial rings. Irreducible polynomials over an integral domain. Unique Factorization Theorem for polynomials over a field.

(f) (i) Definition of a Euclidean domain (ED), Principal Ideal Domain (PID), Unique Factorization Domain (UFD). Examples of ED: $\mathbb{Z}$, $F[X]$, where F is a field, and $\mathbb{Z}[i]$.

(ii) An ED is a PID, a PID is a UFD.

(iii) Prime (irreducible) elements in $\mathbb{R}[X]$, $\mathbb{Q}[X]$, $\mathbb{Z}_p[X]$. Prime and maximal ideals in polynomial rings.

(iv) $\mathbb{Z}[X]$ is not a PID. $\mathbb{Z}[X]$ is a UFD (Statement only).

Reference for Unit 4:

(1) M. Artin. Algebra.

(2) N.S. Gopalkrishnan. University Algebra.

(3) P.B. Bhattacharya, S.K. Jain, S. Nagpaul. Abstract Algebra.

Recommended Books

1. S.Kumaresan. Linear Algebra: A Geometric Approach, Prentice Hall of India Pvt Ltd, New Delhi.
2. I.N. Herstein. Topics in Algebra, Wiley Eastern Limited, Second edition.
3. N.S. Gopalakrishnan, University Algebra, Wiley Eastern Limited.
4. M. Artin, Algebra, Prentice Hall of India, New Delhi.
5. T. Banchoff and J. Wermer, Linear Algebra through Geometry, Springer.
6. L. Smith, Linear Algebra, Springer.
7. Tom M. Apostol, Calculus Volume 2, Second edition, John Wiley, New York, 1969.
8. P.B. Bhattacharya, S.K. Jain, and S.R. Nagpaul, Abstract Algebra, Second edition, Foundation Books, New Delhi, 1995.
9. J.B. Fraleigh, A first course in Abstract Algebra, Third edition, Narosa, New Delhi.
10. J. Gallian. Contemporary Abstract Algebra. Narosa, New Delhi.

Additional Reference Books

1. S. Lang, Introduction to Linear Algebra, Second edition, Springer Verlag, New York.
2. K. Hoffman and S. Kunze, Linear Algebra, Prentice Hall of India, New Delhi.
3. S. Adhikari. An Introduction to Commutative Algebra and Number theory. Narosa Publishing House.
4. T.W. Hungerford. Algebra. Springer.
5. D. Dummit, R. Foote. Abstract Algebra. John Wiley & Sons, Inc.
6. I.S. Luthar, I.B.S. Passi. Algebra, Vol. I and II.

Suggested Practicals for Paper II:

1. Quotient spaces.
2. Orthogonal transformations,Isometries.
3. Diagonalization and Orthogonal diagonalization.
4. Groups – Definitions and properties.
5. Subgroups, Lagrange's Theorem and Cyclic groups.
6. Groups of Symmetry and the Symmetric group S_n.
7. Group homomorphisms, isomorphisms.
8. Normal subgroups and quotient groups.
9. Cayley's Theorem and external direct product of groups.
10. Rings, Integral domains and fields.
11. Ideals, prime ideals and maximal ideals. Ring homomorphism, isomorphism.
12. Euclidean Domain, Principal Ideal Domain and Unique Factorization Domain.
13. Miscellaneous Theoretical questions based on Unit 1.
14. Miscellaneous Theoretical questions based on Unit 2.
15. Miscellaneous Theoretical questions based on Unit 3.
16. Miscellaneous Theoretical questions based on Unit 4.

T.Y.B.A/B.Sc. Paper III

TOPOLOGY OF METRIC SPACES

Unit 1. Metric spaces (23 Lectures)

(a) (i) Metrics spaces: Definition, Examples, including $\mathbb{R}$ with usual distance, discrete metric space.

(ii) Normed linear spaces: Definition, the distance (metric) induced by the norm, translation invariance of the metric induced by the norm. Examples including

(1) $\mathbb{R}^n$ with sum norm $|| \ ||_1$, the Euclidean norm $|| \ ||_2$, and the sup norm $|| \ ||_\infty$.

(2) $C[a,b]$, the space of continuous real valued functions on $[a,b]$ with norms $|| \ ||_1$, $|| \ ||_2$, $|| \ ||_\infty$, where $||f||_1 = \int_a^b |f(t)|dt$, $||f||_2 = \left(\int_a^b |f(t)|^2 dt\right)^{\frac{1}{2}}$, $||f||_\infty = \sup\{|f(t)|, t \in [a,b]\}$.

(3) ℓ_1, ℓ_2, ℓ_∞, the spaces of real sequences with norms $|| \ ||_1$, $|| \ ||_2$, $|| \ |_\infty$, where $||x||_1 = \sum_{n=1}^{\infty} |x_n|$, $||x||_2 = (\sum_{n=1}^{\infty} |x_n|^2)^{\frac{1}{2}}$, $||x||_\infty = \sup\{|x_n|, n \in \mathbb{N}\}$, for $x = (x_n)$.

(iii) Subspaces, product of two metric spaces.

(b) (i) Open ball and open set in a metric space (normed linear space) and subspace Hausdorff property. Interior of a set.

(ii) Structure of an open set in $\mathbb{R}$, namely any open set is a union of a countable family of pairwise disjoint intervals.

(iii) Equivalent metrics, equivalent norms.

(c) (i) Closed set in a metric space (as complement of an open set), limit point of a set (A point which has a non-empty intersection with each deleted neighbourhood of the point), isolated point. A closed set contains all its limit points.

(ii) Closed balls, closure of a set, boundary of a set in a metric space.

(iii) Distance of a point from a set, distance between two sets, diameter of a set in a metric space.

(iv) Dense subsets in a metric space. Separability, $\mathbb{R}^n$ is separable.

(d) (i) Sequences in a metric space.

(ii) The characterization of limit points and closure points in terms of sequences.

(iii) Cauchy sequences and complete metric spaces. $\mathbb{R}^n$ with Euclidean metric is a complete metric space.

(e) Cantor's Intersection Theorem.

Reference for Unit 1:

1. S. Kumaresan, Topology of Metric spaces.

2. W. Rudin, Principles of Mathematical Analysis.

Unit 2. Continuity (22 Lectures)

(a) $\varepsilon - \delta$ definition of continuity at a point of a function from one metric space to another.

  (i) Characterization of continuity at a point in terms of sequences, open sets.

  (ii) Continuity of a function on a metric space. Characterization in terms of inverse image of open sets and closed sets.

  (iii) Urysohn's lemma.

  (iv) Uniform continuity in a metric space, definition and examples (emphasis on $\mathbb{R}$), open maps, closed maps.

Reference for Unit 2: S. Kumaresan, Topology of Metric spaces.

Unit 3. The function spaces (23 lectures)

(i) The function space $C(X, \mathbb{R})$ of real valued continuous functions on a metric space X. The space $C[a, b]$ with sup norm, Weierstrass approximation Theorem.

(ii) Fourier series of functions on $C[-\pi, \pi]$, Dirichlet kernel, Fejer kernel, Cesaro summability of Fourier series of functions on $C[-\pi, \pi]$, Bessel's inequality and Pareseval's identity, convergence of the Fourier series in L^2 norm.

Reference for Unit 3:

1. R. Goldberg. Methods of Real Analysis.

2. S. Kumaresan, Topology of Metric spaces.

Unit 4. Compactness and connectedness. (22 lectures)

(a) Definition of a compact set in a metric space (as a set for which every open cover has a finite subcover). Examples, properties such as

  (i) continuous image of a compact set is compact.
  (ii) compact subsets are closed.
  (iii) a continuous function on a compact set is uniformly continuous.

(b) Characterization of compact sets in $\mathbb{R}^n$: The equivalent statements for a subset of $\mathbb{R}^n$ to be compact:

  (i) Heine-Borel property.
  (ii) Closed and boundedness property.
  (iii) Bolzano-Weierstrass property.
  (iv) Sequentially compactness property.

(c) (i) Connected metric spaces. Definition and examples.
  (ii) Characterization of a connected space, namely a metric space X is connected if and only if every continuous function from X to $\{1, -1\}$ is a constant function.
  (iii) Connected subsets of a metric space, connected subsets of $\mathbb{R}$.
  (iv) A continous image of a connected set is connected.

(d) (i) Path connectedness in $\mathbb{R}^n$, definitions and examples.

(ii) A path connected subset of $\mathbb{R}^n$ is connected.

(iii) An example of a connected subset of $\mathbb{R}^n$ which is not path connected.

Reference for Unit 4:

1. S. Kumaresan, Topology of Metric spaces.
2. W. Rudin, Principles of Mathematical Analysis.

Recommended Books

1. S. Kumaresan. Topology of Metric spaces.
2. R.G. Goldberg Methods of Real Analysis, Oxford and IBH Publishing House, New Delhi.
3. W. Rudin. Principles of Mathematical Analysis. McGraw Hill, Auckland, 1976.
4. P.K. Jain, K. Ahmed. Metric spaces. Narosa, New Delhi, 1996.
5. G.F. Simmons. Introduction to Topology and Modern Analysis. McGraw Hill, New York, 1963.

Additional Reference Books

1. T. Apostol. Mathematical Analysis, Second edition, Narosa, New Delhi, 1974.
2. E.T. Copson. Metric spaces. Universal Book Stall, New Delhi, 1996.
3. Sutherland. Topology.
4. D. Somasundaram, B. Choudhary. A first course in Mathematical Analysis. Narosa, New Delhi.
5. R. Bhatia. Fourier series. Texts and readings in Mathematics (TRIM series), HBA, India.

Suggested Practicals for Paper III:

1. Metric spaces and normed linear spaces. Examples.
2. Open balls, open sets in metric spaces, subspaces and normed linear spaces.
3. Limit points: (Limit points and closure points, closed balls, closed sets, closure of a set, boundary of a set, distance between two sets).
4. Continuity.
5. Uniform continuity in a metric space.
6. The function spaces $C(X, \mathbb{R})$ and $C[a, b]$.
7. Fourier series; Parseval's identity.
8. Compact sets in a metric space.
9. Compactness in $\mathbb{R}^n$ (emphasis on $\mathbb{R}$, $\mathbb{R}^2$). Properties.
10. Connectedness.
11. Path connectedness.
12. Continuous image of compact and connected sets.
13. Miscellaneous Theoretical Questions based on Unit 1.
14. Miscellaneous Theoretical Questions based on Unit 2.
15. Miscellaneous Theoretical Questions based on Unit 3.
16. Miscellaneous Theoretical Questions based on Unit 4.

T.Y.B.Sc. Paper IV (Elective A)

Numerical Methods

Unit 1. Transcendental and Polynomial equations (23 Lectures)

(a) Iteration methods based on first and second degree equation

  (i) The Newton-Raphson method
  (ii) Secant method
  (iii) Muller method
  (iv) Chebyshev method
  (v) Multi point iteration methods

(b) Rate of convergence and error analysis

  (i) Secant method
  (ii) The Newton-Raphson method
  (iii) Methods of multiple roots

(c) Polynomial equations

  (i) Birge-vieta method
  (ii) Bairstow method
  (iii) Graeffe's roots squaring method

Reference of Unit 1: Chapter 2 of M.K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, New age International publishers, Fourth Edition, 2003

Unit 2. System of linear algebraic equations and eigenvalue problems.(23 Lectures)

(a) Linear systems of equations

  (i) Direct methods - Triangularization method, Cholesky method, Partition method.
  (ii) Error analysis for direct methods, Iteration methods-convergence analysis of iterative methods.

(b) Eigenvalue problems

  (i) Eigenvalues and eigenvectors - Jacobi methods for symmetric matrices, Given's methods for symmetric matrices, House holder's method of symmetric matrices, Rutihauser method for arbitrary matrices, Power method.

Reference of Unit 2: Chapter 3 of M.K. Jain, S.R.K.Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, New age International publishers, Fourth Edition, 2003.

Unit 3. Interpolation and approximation (23 Lectures)

(a) Higher order Interpolation

(b) Finite difference operators

(c) Interpolating polynomial using finite differences

(d) Hermite interpolation

(e) Piecewise and spline interpolation

(f) Bivariate interpolation - Lagrange bivariate interpolation, Newton's bivariate interpolation for equispaced points

(g) Least square approximation

Reference of Unit 3: Chapter 4 of M.K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, New age International publishers, Fourth Edition, 2003

Unit 4. Differentiation and Integration (23 Lectures)

(a) Numerical differentiation

  (i) Methods based on Interpolation
  (ii) Optimum choice of step length-Extrapolation method
  (iii) Partial differentiation

(b) Numerical integration

  (i) Methods based on interpolation
  (ii) Method based on undermined coefficients - Gauss Legendre integration method, Gauss Chebyshev integration method, Radau integration methods
  (iii) Composite integration methods - Trapezoidal rule, Simpson's rule
  (iv) Double integration - Trapezoidal method, simpson's method.

Reference of Unit 4: Chapter 5 of M.K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, New age International publishers, Fourth Edition, 2003.

References:

(1) M.K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, New age International publishers, Fourth Edition, 2003.

(2) S.D. Comte and Carl de Boor, *Elementary Numerical analysis - An Algorithmic approach*, 3rd Edition., McGraw Hill, International Book Company, 1980.

(3) James B. Scarboraugh, *Numerical Mathematical Analysis*, Oxford and IBH Publishing Company, New Delhi.

(4) F.B. Hildebrand, *Introduction to Numerical Analysis*, McGraw Hill, New York, 1956.

Additional References:

(1) Kendall E. Atkinson, *An Introduction to Numerical Analysis*, John Wisely and Sons..

(2) Anthony Ralston, Philip Rabinowitz, *A First Course in Numerical Analysis*

Practicals:

(1) Iteration methods based on second degree equation - The Newton-Raphson method, Secant method.

(2) Iteration methods based on second degree equation - Muller method, Chebyshev method, Multi point iteration methods.

(3) Polynomial equations.

(4) Linear systems of equations.

(5) Eigenvalues and eigenvectors - Jacobi methods for symmetric matrices, Given's methods for symmetric matrices, House holder's method of symmetric matrices.

(6) Eigenvalues and eigenvectors - Rutihauser method for arbitrary matrices, Power method.

(7) Higher order Interpolation/Finite difference operators.

(8) Interpolating polynomial using finite. differences/Hermite interpolation.

(9) Piecewise and spline interpolation/Bivariate interpolation.

(10) Numerical differentiation.

(11) Numerical integration.

(12) Double integration.

(13) Miscellaneous Theoretical questions based on Unit 1.

(14) Miscellaneous Theoretical questions based on Unit 2.

(15) Miscellaneous Theoretical questions based on Unit 3.

(16) Miscellaneous Theoretical questions based on Unit 4.

The Practicals should be performed using non-programmable scientific calculator. (The use of programming language like C or Mathematical Software like Mathematica, MatLab, MuPAD may be encouraged).

T.Y.B.Sc. Paper IV (Elective B)

Number Theory and its applications

Unit 1. Prime numbers and congruences (23 Lectures)

(a) (i) Review of divisibility.
(ii) Primes: Definition, The fundamental theorem of Arithmetic Distribution of primes (There are arbitrarily large gaps between consecutive primes), The Prime number Theorem - $\pi(x) \sim \frac{x}{\log x}$ (statement only).

(b) Congruences

(i) Definition and elementary properties, complete residue system modulo m. Reduced residue system modulo m, Euler's function ϕ.
(ii) Euler's generalisation of Fermat's little Theorem, Fermat's little Theorem, Wilson's Theorem. The Chinese remainder Theorem.
(iii) Congruences of higher order (emphasis on degree 2).
(iv) Prime power moduli.

(c) Diophantine equations and their solutions

(i) The linear equations $ax + by = c$.
(ii) The equations $x^2 + y^2 = p$, where p is a prime and $x^2 + y^2 = n$ where n is a positive integer.
(iii) The equation $x^2 + y^2 = z^2$, Pythagorean triples, primitive solutions.
(iv) The equations $x^4 + y^4 = z^2$ and $x^4 + y^4 = z^4$ have no solutions (x, y, z) with $xyz \neq 0$.
(v) Every positive integer n can be expressed as sum of squares of four integers.
Universal quadratic forms $x^2 + y^2 + z^2 + t^2$.

Unit 2. Quadratic Reciprocity (22 Lectures)

(a) (i) Quadratic residues and Legendre Symbol. The Gaussian quadratic reciprocity law.
(ii) The Jacobi Symbol and law of reciprocity for Jacobi Symbol.
(iii) Arithmetic functions of number theory: $d(n)$ (or $\tau(n)$), $\sigma(n)$, $\sigma_k(n)$, $\omega(n)$, $\Omega(n)$ and their properties.
$\mu(n)$ and the Möbius inversion formula.
(iv) Special numbers; Fermat numbers; Mersene numbers; Perfect numbers, Amicable numbers.

Unit 3. Continued Fractions (23 Lectures)

(a) Finite continued fractions

(b) (i) Infinite continued fractions and representatio of an irrational number by an infinite simple continued fraction.
(ii) Rational approximations to irrational numbers.
Order of convergence.
Best possible approximations.

(iii) Periodic continued fractions.

(iv) Algebraic numbers and Transcendental numbers.
The existence of the transcendental numbers.

(c) Pell's equation $x^2 - dy^2 = n$, where d is not a square of an integer. Solutions of Pell's equation. (The proofs of convergence theorems to be omitted).

(d) The ring $\mathbb{Z}[\sqrt{d}]$, $\mathbb{Z}[\sqrt{-d}]$, where d is a positive integer which is not a perfect square.
Units and primes in $\mathbb{Z}[i]$ and units in $\mathbb{Z}[\sqrt{-d}]$, the ring $\mathbb{Z}[\sqrt{d}]$ has infinitely many units.

Unit 4. Cryptography (23 Lectures)

(a) Basic notions such as encryption (enciphering) and decryption (deciphering).
Cryptosystems, symmetric key cryptography. Simple examples such as shift cipher, affine cipher, hill's cipher.

(b) Concept of Public Key Cryptosystem; RSA Algorithm.

(c) Primality and factoring:

(i) pseudo primes, Carmichael numbers.

(ii) Fermat Factorization and Factor base.

(iii) Continued fraction, factoring algorithm.

Recommended Books

1. I. Niven, H. Zuckerman and H. Montogomery. *An Introduction to the Theory of Numbers.* John Wiley & Sons. Inc.

2. G. H. Hardy, and E.M. Wright. *An Introduction to the Theory of Numbers.* Low priced edition. The English Language Book Society and Oxford University Press, 1981.

3. Neville Robins. *Beginning Number Theory.* Narosa Publications.

4. S.D. Adhikari. *An introduction to Commutative Algebra and Number Theory.* Narosa Publishing House.

5. N. Koblitz. *A course in Number theory and Crytopgraphy.* Springer.

6. M. Artin.*Algebra.* Prentice Hall.

7. K. Ireland, M. Rosen. *A classical introduction to Modern Number Theory.* Second edition, Springer Verlag.

8. William Stalling. *Cryptology and network security.*

Suggested Practicals:

1. Primes, Fundamental theorem of Airthmetic.
2. Congruences.
3. Diophantine equations and their solutions.
4. The Gaussian quadratic reciprocity law.
5. Jacobi symbols and law of reciprocity for Jacobi symbols.
6. Airthmetic functions of Number Theory. Special Numbers.
7. Finite continued fractions.
8. Infinite continued fractions. Algebraic Numbers, Transcendental Numbers.
9. Pell's equations, Units in $\mathbb{Z}[\sqrt{d}]$ and $\mathbb{Z}[\sqrt{-d}]$. Primes in $\mathbb{Z}[i]$.
10. Cryptosytems (Private key).
11. Public Key Cryptosystems. RSA Algorithm.
12. Primality and factoring.
13. Miscellaneous Theoretical problems on unit I.
14. Miscellaneous Theoretical problems on unit II.
15. Miscellaneous Theoretical problems on unit III.
16. Miscellaneous Theoretical problems on unit IV.

Paper IV (Elective C)

Graph Theory and Combinatorics

Unit 1. Basics (22 lectures)

Review: Definitions and basic properties of

(i) Simple, multiple and directed graphs.

(ii) Degree of a vertex, walk, path, tree, cycle, complement of a graph, etc.

(a) Connected Graphs:

Subgraphs, induced subgraphs - Definition and simple examples. Connected graphs, connected components, adjacency and incidence matrix of a graph. Results such as:

- (i) If $G(p, q)$ is self complementary graph, then $p \equiv 0, 1 (\text{mod } 4)$.
- (ii) For any graph G, either G or G^c is connected.
- (iii) Degree sequence-$Havel - Hakimi$ theorem.

(b) Trees– Definition of Tree, Spanning tree. Properties of trees

- (i) Any two vertices are connected by a unique path.
- (ii) The number of edges is one less than the number of vertices in a tree.
- (iii) There are at least two vertices of degree 1 and there are at least two vertices that are not cut vertices in a tree.

(c)
- (i) Let G be a graph on p vertices and q edges. Then the following are equivalent
  - (1) G is connected.
  - (2) G is acyclic.
  - (3) G is tree.
- (ii) In a graph, an edge is a cut edge if and only if it is acyclic.
- (iii) A connected graph is a tree if and only if every edge is a cut edge.
- (iv) Any connected graph on p vertices has at least $p - 1$ edges.
- (v) If T is a spanning tree in a connected graph G and e is an edge of G that is not in T, then $T + e$ contains a unique cycle that contains the edge e.
- (vi) A vertex v of a tree is a cut-vertex if and only if $d(v) > 1$.

(d) A rooted tree, binary tree, Huffman code (or prefix-free code), Huffman's Algorithm.

Unit 2. Hamiltonian Graphs (23 lectures)

(a) Counting the number of spanning trees. Definitions of the operations $G - e$ and $G.e$ where e is any edge of G.

If $\tau(G)$ denotes the number of spanning trees in a connected graph G, then, $\tau(G) = \tau(G - e) + \tau(G.e)$. Small examples.

(b) Hamiltonian graphs - Basic definitions and Introduction.

- (i) If G is Hamiltonian graph, then $\omega(G - S) \leq | S |$ where S is any subset of vertex set V of G.

(ii) Hamilton cycles in a cube graph.

Unit 3. Colouring in a graph and Chromatic number (22 lectures)

(a) Introduction to vertex and edge colouring, Chromatic number of a graph. Computation of edge chromatic number of graphs.

(b) Chromatic polynomials.

(i) Let $\pi_k(G)$ denotes the chromatic polynomial of graph G. If G is simple graph then $\pi_k(G) = \pi_k(G - e) - \pi_k(G.e)$ for any edge e of G.

(ii) The chromatic polynomial $\pi_k(G)$ for a graph G with n vertices is a monic polynomial of degree n with integer coefficient having constant term 0. Further non-zero coefficient of $\pi_k(G)$ alternate in sign.

(iii) Evaluation of chromatic polynomial $\pi_k(G)$ when G is Tree, cycle, complete graphs.

Unit 4. Combinatorics (23 lectures)

(a) Inclusion-Exclusion principle. Applications to counting $\phi(n)$, Derangements, restricted position problems, Rook Polynomial.

(b) Stirling numbers of second kind.

(c) Introduction to generating fuctions. Counting problem and generating functions. Solving recurrence relation using generating functions.

REFERENCES

1. Biggs Norman, Algebraic Graph Theory,Cambridge University Press.
2. Bondy J A, Murty U S R. Graph Theory with Applications,Macmillan Press.
3. Brualdi R A, Introductory Combinatorics, North Holland Cambridge Company.
4. Cohen D A, Basic Tecniques of Combinatorial Theory,John Wiley and sons.
5. Tucker Allan, Applied Combinatoricds, John Wiley and sons.
6. Robin J. Wilson, “Introduction to Graph Theory”, Longman Scientific & Technical.
7. Joan M. Aldous and Robin J. Wilson, “Graphs and Applications”, Springer (indian Ed)
8. West D B, Introduction to Graph Theory, Prentice Hall of India.

Suggested Practicals

1 Degree sequence and matrix representation of graphs.
2 Tree, Spanning tree.
3 Vertex and edge connectivity.
4 Huffman code.
5 Hamiltonian graphs.
6 Hamilton cycles in a cube graph
7 Vertex colouring.
8 Edge colouring.
9 Chromatic polynomial.
10 Recurrence relation, Generating function.
11 Stirling numbers.
12 Rook Polynomial.
13 Miscellaneous Theoretical problems on unit I.
14 Miscellaneous Theoretical problems on unit II.
15 Miscellaneous Theoretical problems on unit III.
16 Miscellaneous Theoretical problems on unit IV.

T.Y.B.Sc. Paper IV (Elective D)

Probability and Application to Financial Mathematics

Pre-requisites: Countable set, uncountable set, power set of a set, Cartesian product, symmetric difference of sets, supremum and infimum of a set, a function from a set A to B, indicator function, limit of a sequence, sum of a series, limit of a function, indefinite integral of a function.

Unit 1. Probability as a Measure - Basics (22 Lectures)

(a) Modeling random experiments.

(b) Uniform probability measure.

(c) Fields and finitely additive probability measure.

(d) Sigma fields.

  (i) σ field generated by a family of subsets of Ω.
  (ii) σ field of Borel sets.
  (iii) Upper limit (limit superior), lower limit(limit inferior) of a sequence of events.
  (iv) Countably additive probability measure (extending notion of probability measure from fields to σ fields).

(e) Borel Cantelli lemma

Reference of Unit 1: Chapter 1 - 5, Chapter 6 - Definition 6.1,Theorem 6.1 of Marek Capinski and Tomasz Zastawniak, *Probability through Problems* , Springer, Indian Reprint 2008.

Unit 2. Conditional Probability and conditional Expectation(23 Lectures)

(Brief treatment of (a) and (b) below)

(a) Lebesgue measure and Lebesgue integral (definition and statement of properties only)

(b) Density function, Using density function to define a probability measure on the real line, Absolutely continuous probability measure

(c) Conditional probability and independence, Total probability theorem and Baye's theorem.

(d) (i) Given a probability space Ω with σ field $\mathcal{F}$ and probability measure P, define a function from Ω to $\mathbb{R}$ to be a random variable.
  (ii) Distribution of a random variable X as a probability measure on Borel sets in $\mathbb{R}$.
  (iii) Discrete and continuous random variable.
  (iv) Joint distribution of random variables X and Y as a probability measure on $\mathbb{R}^2$.
  (v) Expectation and variance of discrete and continuous random variables.
  (vi) Jensen's inequality.

(vii) Conditional Expectation.

Reference of Unit 2: Chapter 6 - Sections 6.2 to 6.7, Chapter 7 - 10 of Marek Capinski and Tomasz Zastawniak, *Probability through Problems* , Springer, Indian Reprint 2008.

Unit 3. Financial Mathematics (Part I)(23 Lectures)

(a) Limit theorems :Statement, Applications

(i) Chebyshev inequality
(ii) Weak law of large numbers
(iii) Strong law of large numbers
(iv) Central limit theorem

(b) Geometric Brownian Motion GBM(Brief Treatment):

(i) Definition of a Brownian Motion.
(ii) Geometric Brownian Motion as a Limit of Random walks.

(c) Interest Rates and Present Value Analysis:

(i) Present Value Analysis.
(ii) Rate of return.
(iii) Continuously varying Interest Rates.

(d) Options:

(i) Call and Put Options.
(ii) European Options.
(iii) American Options.
(iv) Asian Options.
(v) Options Pricing.

(e) Arbitrage Theory.

(i) Pricing contracts using Arbitrage.
(ii) Multi-period Binomial Model.
(iii) Arbitrage theorem.
(iv) Limitations of Arbitrage Pricing.

Reference of Unit 3: Chapter 12 of Marek Capinski and Tomasz Zastawniak, *Probability through Problems* , Springer, Indian Reprint 2008 and Chapter 3 - 6 of Sheldon Ross, *An elementary introduction to Mathematical Finance*, Cambridge University Press second edition 2005.

Unit 4. Financial Mathematics (Part II)(22 Lectures)

(a) Pricing and Return: Brief Treatment:

(i) Black Scholes Formula.

(ii) Rates of Return: Single period and Geometric Brownian Motion.
(iii) Pricing American Put Option.
(iv) Portfolio Selection Problem.
(v) Capital Asset Pricing Models.
(vi) Mean Variance Analysis of Risk Neutral Priced Call Options.

Reference of Unit 4: Chapter 7, Chapter 8 - Section 8.3, Chapter 9 - Sections 9.1, 9.3 - 9.8 of Sheldon Ross, *An elementary introduction to Mathematical Finance*, Cambridge University Press second edition 2005.

References:

(1) Marek Capinski and Tomasz Zastawniak, *Probability through Problems*, Springer, Indian Reprint 2008.

(2) Sheldon Ross, *An elementary introduction to Mathematical Finance*, Cambridge University Press second edition 2005.

(3) Sheldon Ross, *A first Course in Probability*, Pearson Education, Low Priced edition, 2002.

(4) John C Hull, *Options, Futures and other derivatives*, Pearson, sixth edition.

(5) David Luenberger, *Investment science*, Oxford University press.

(6) Paul Wilmott, *Paul Wilmott introduces Quantitative Finance*, Wiley.

Practicals:

(1) Modeling random experiments, uniform probability measure ,fields.

(2) σ field and countably additive probability, Bayes theorem

(3) Random variable, expectation, variance.

(4) Normal random variable, Joint distribution of random variables.

(5) Conditional expectation.

(6) Central limit theorem, GBM as a limit of random walk.

(7) Present value analysis, forward price using arbitrage.

(8) Options: Payoff, Put Call parity

(9) Multi-period Binomial model

(10) Black Scholes option pricing formula

(11) Portfolio selection problem, CAPM

(12) Mean variance analysis of risk neutral call options, rates of return in case of single period and GBM.

(13) Miscellaneous Theoretical questions based on Unit 1.

(14) Miscellaneous Theoretical questions based on Unit 2.

(15) Miscellaneous Theoretical questions based on Unit 3.

(16) Miscellaneous Theoretical questions based on Unit 4.

Evaluation scheme and Paper pattern for T.Y.B.A./B.Sc. (Single Major):

Examination	Maximum marks	Total
Theory	100 per paper	400
Practicals	40 per paper	160
Project **OR** Practicals with Theoretical questions	40 (one project) 10 per paper	40
Total		**600**

Paper Pattern for Theory examination for Paper I, II, III, IV

		Maximum marks	Maximum Options
Q1.	Based on Unit 1,2,3,4	20	30
Q2.	Based on Unit 1	20	30
Q3.	Based on Unit 2	20	30
Q4.	Based on Unit 3	20	30
Q5.	Based on Unit 4	20	30
		100	

All questions are **compulsory**. Each questions will have 3 subquestions of 10 marks and students has to attend any two.

Evaluation scheme and Paper pattern for T.Y.B.A./B.Sc. (Double Major):

Examination	Maximum marks	Total
Theory	100 per paper	200
Practicals	40 per paper	80
Practicals with Theoretical questions	10 per paper	20
Total		**300**

Practicals: Conduct and evaluation (T.Y. B.A./B.Sc.)

The purpose of Practicals in Mathematics is to motivate the students in problem solving activity and to strengthen their theoretical concepts.

There are three practical periods per week in each paper.

The practicals should be conducted as a group activity under the teacher's guidance and not as a test.

There are 12 practicals (computation type) in each paper, and each practical of this type has objective and descriptive type questions. In addition, there are 4 practicals having theoretical questions.

The student should maintain a Practical Journal for each paper.

The student has to write atleast 8 objective and 4 descriptive type questions in each practical of computational type and further complete at least 9 practicals in each paper. The student has to also write all 4 practicals based on theoretical questions in each paper.

A student opting for Case study/Project will only have to do Computational type practicals in each paper and write atleast 9 of these practicals in the journal for each paper.

The Journal should be certified by the teacher and the Head of the Department.

Practical Examination: Duration for examination: 3 hours.

Duration for Practical paper: 2 hours.

Duration for assessment of journal: 1 hour.

Paper pattern for Paper I, II, III, IV

	Paper pattern	Maximum marks
Section I	Objective questions	15
Section II	Descriptive questions	20
	Journal	05
		40 per paper
	Total	160

Project/Practicals with Theoretical Questions - **40 marks**

Total – 200 marks

Case study/Project work: Case study/project work wll be optional.
Conduct and Evaluation: The student can submit a project/case study report in Mathematics of about 10 typed pages (the number of pages should not exceed 20). The topic of the project/case study should be selected in consultation with the teacher.

The topic can be of expository / historical survey / interdisciplinary nature and the material covered in the project/case study should go beyond the scope of the syllabus. The student should clearly mention the sources (book/on-line) used for the project/case study.

The use of Computer Algebra System (CAS) such as Mathematical softwares should be encouraged. The project/case study may be done under the supervision of a faculty member in a College / Institution / University of Mumbai.

The following marking scheme is suggested for the evaluation of projects:

30 percent marks: exposition
20 percent marks: literature
20 percent marks: scope
10 percent marks: originality
20 percent marks: oral presentation

A student opting for Case study/Project will only have to do Computational type practicals in each paper and write atleast 9 of these practicals in the journal for each paper.