TCG CREST – Ph.D. Programme

Academic Session: August 2025

Research area-specific sample syllabus for the written Admission Test

Cryptology and Post-Quantum Cryptology

A. General Mathematics

1. **Basic Algebra:** Theory of Equations, Complex Numbers, Basic understanding of Group Theory.
2. **Elementary Linear Algebra:** Determinants and their properties, Cramer's Rule, Systems of linear equations, Rank, matrices and matrix algebra, Eigen values and Eigen vectors, orthogonal bases, vector spaces, inner products, Gram-Schmidt procedure.
3. **Basic Statistics:** Mean, median, mode, standard deviation, skewness and kurtosis, moment, correlation and regression.
4. **Discrete Mathematics:** Basics of set theory, functions and relations, basic combinatorics (basic counting, inclusion-exclusion principle, pigeonhole principle), permutation and combination, recurrence relations, generating functions.
5. **Elementary Probability:** Basic definitions, random variables, distributions, Standard discrete distributions (uniform, binomial, Poisson, geometric, hypergeometric); Expectation, Variance and moments; Conditional probability and Bayes' theorem.
6. **Basic Number Theory:** Divisibility, GCD, Modular arithmetic, Chinese Remainder Theorem.
7. **Elementary High School Level Calculus:** Limit, continuity, differentiation and integration.

B. Technical Topics in Computer Science

1. **Graph theory:** Paths and cycles, Connected components, Tree, Digraphs, Eulerian trails, Hamiltonian paths, Planar graphs, Graph coloring.
2. **Elements of computing:** Basics of programming (using pseudo-code and any one of the languages from C, C++, Java, Python), Procedure call and parameter passing.
3. **Data Structures:** Array, Linked list, Stack, Queue, Binary tree, Heap, AVL tree, B-tree.
4. **Design and Analysis of Algorithms:** Asymptotic notation, Searching, Sorting, Selection, Graph algorithms: Breadth First Search, Depth First Search, Shortest Path
5. **Circuits and systems:** Analysis of elementary high school level circuits involving resistance, capacitance and inductance; analog electronic circuits involving transistors, Boolean algebra, Minimization of Boolean functions, Gates and logic circuits, Combinational and sequential circuits; Signals and systems, Convolution, Fourier transform, and z-transform.
6. **Formal Languages and Automata Theory:** Finite automata and regular languages. Pushdown automata and context-free languages. Turing machines and recursively enumerable languages. Undecidability

C. Quantum Computation and Quantum Information

1. **Introduction:** Quantum dynamics, quantum measurements and collapse hypothesis, density operators, single qubit, multiqubits, pure and mixed states, quantum gates and circuits.
2. **Quantum Correlations:** Bell inequalities and entanglement, Schmidt decomposition, EPR paradox, quantum teleportation, theory of quantum entanglement, entanglement of pure bipartite states.
3. **Quantum Algorithms:** Introduction to quantum algorithms. Deutsch-Jozsa algorithm, Grover's search algorithm, Simon's algorithm. Shor's factorization algorithm.
4. **Quantum Information Theory:** Classical information theory, Shannon entropy, von Neumann entropy, no-cloning theorem, Quantum Key Distribution; BB84, Ekert, MDI QKD.

Artificial Intelligence and Machine Learning

A. Engineering Mathematics

1. **Linear Algebra:** Vector space, basis, linear dependence and independence, matrix algebra, Eigenvalues and eigenvectors, rank, solution of linear equations—existence and uniqueness.
2. **Probability and Statistics:** Mean, median, mode, standard deviation, combinatorial probability, probability distributions, binomial distribution, Poisson distribution, exponential distribution, normal distribution, joint and conditional probability.
3. **Calculus:** Differentiation and integration, partial derivatives, gradients, Jacobian and Hessian matrices, optimization techniques (gradient descent, stochastic gradient descent).

B. Topics in Computer Science / Information Technology

1. **Discrete Mathematics:** Propositional and first-order logic. Sets, relations, functions, partial orders, and lattices. Monoids, Groups. Combinatorics: counting, recurrence relations, generating functions.
2. **Graph Theory:** Graph: connectivity, matching, coloring. Paths and cycles, connected components, tree, digraphs, Eulerian trails, Hamiltonian paths, planar graphs.
3. **Elements of Computing:** Basics of programming (using pseudo-code and any one of the languages from C, C++, Java, Python), procedure call and parameter passing.
4. **Data Structures:** Array, linked list, stack, queue, binary tree, heap, AVL tree, B-tree.
5. **Design and Analysis of Algorithms:** Asymptotic notation, searching, sorting, selection. Algorithm design techniques: greedy, dynamic programming, and divide-and-conquer. Graph algorithms: Breadth First Search, Depth First Search, shortest path, minimum spanning trees.
6. **Formal Languages and Automata Theory:** Finite automata and regular languages. Pushdown automata and context-free languages. Turing machines and recursively enumerable languages. Undecidability.

C. Topics in Electronics & Communication Engg / Electrical Engg / Instrumentation Engg

1. **Continuous-time signals:** Fourier series and Fourier transform, sampling theorem and applications.
2. **Discrete-time signals:** DTFT, DFT, z-transform, discrete-time processing of continuous-time signals.
3. **LTI systems:** Definition and properties, causality, stability, impulse response, convolution, poles and zeros, frequency response, group delay, phase delay.
4. **Digital Signal Processing:** FIR and IIR structure, filter design, discrete Fourier transform, fast Fourier transform, wavelet.
5. **Random processes:** Autocorrelation and power spectral density, properties of white noise, filtering of random signals through LTI systems.
6. **Information theory:** Entropy, mutual information, and channel capacity theorem.

D. Topics in AI/ML/Data Science

1. **Discrete Mathematics:** Propositional and first-order logic. Sets, relations, functions, partial orders, and lattices. Monoids, Groups. Combinatorics: counting, recurrence relations, generating functions.
2. **Graph Theory: Graph:** connectivity, matching, coloring. Paths and cycles, connected components, tree, digraphs, Eulerian trails, Hamiltonian paths, planar graphs.
3. **Machine learning:** Unsupervised Learning: Clustering algorithms, Applications of dimension reduction techniques in machine learning problems. Supervised Learning: Learning from association, Support vector, Tree-based methods.

4. **Data Structures:** Searching and Sorting algorithms, Array, linked list, stack, queue, binary tree, heap, AVL tree, B-tree. Artificial Intelligence: Problem Solving and Searching Techniques: Breadth First Search, Depth First Search, Hill climbing, Heuristics Search Techniques: Best First Search, Constraint Satisfaction Problem. Game Playing: Minmax and game trees, refining minmax, Alpha – Beta pruning.
5. **Deep Learning:** Theory: Feed forward Neural Networks, Auto-encoders, Convolutional Neural Networks, Recurrent Neural Network. Applications: Computer Vision, speech analysis, and natural Language Processing.

Translational Research in Mathematics

Topics in Mathematics

1. **Basic Topology:** Topological spaces, Continuous functions, Connectedness, Compactness, Separation axioms. Product spaces. Complete metric spaces. Uniform continuity, Basic notions of homotopy, Fundamental Groups.
2. **Analysis:** Sequences and series, Continuity and differentiability of real valued functions of one and two real variables and applications, uniform convergence, Riemann integration, Ordinary differential equations, Basics of complex analysis.
3. **Linear Algebra:** Vector spaces, linear transformations, characteristic roots and characteristic vectors, systems of linear equations, inner product spaces, Gram-Schmidt procedure, diagonalization of symmetric and Hermitian matrices.
4. **Abstract Algebra:** Groups, homomorphisms, normal subgroups and quotients, isomorphism theorems, finite groups, symmetric and alternating groups, direct product, structure of finite Abelian groups, Sylow theorems. Rings and ideals, quotients, homomorphism and isomorphism theorems, maximal ideals, prime ideals, integral domains, field of fractions; Euclidean rings, principal ideal domains, unique factorisation domains, polynomial rings. Fields, characteristic of a field, algebraic extensions, roots of polynomials, separable and normal extensions, finite fields.
5. **Measure theory and Functional analysis:** Algebra, σ-algebra, measurable sets, measurable functions and their properties, measure space, Lebesgue measure, counting measure, Integration and convergence theorem, Normed linear spaces, equivalence of norms in finite dimensional spaces, Banach spaces, Bounded linear operators, Operator norm, Hahn-Banach theorem and its applications, Uniform bounded principle and its applications, Open mapping and closed graph theorem, Hilbert Spaces.

Quantum Computing, Information & Sensing

The test will consist of two sections. Section A will have limited or no choice. Section B will have a significant choice.

Section A

- **Quantum mechanics and linear algebra:** Basic linear algebra relevant to quantum mechanics (for example: vector spaces, direct sum, tensor product, hermitian and unitary operators, etc), postulates of quantum mechanics, Schrodinger equation and its applications, quantum harmonic oscillator, symmetries, angular momentum, variational principle, and approximation methods.
- **Quantum information and quantum computing:** Qubits, elementary gates and circuits, superposition, entanglement, partial trace, state vectors and density matrices.

Section B

- **Atomic and Molecular physics:** Hydrogen atom, helium atom, H2+ molecular ion, Zeeman effect, and Stark effect.
- **Thermodynamics and Statistical Mechanics:** Microcanonical, canonical, and grand canonical ensembles, partition function, laws of thermodynamics, Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics.
- **Electricity and Magnetism:** Electrostatics, magnetostatics, electrodynamics, Maxwell's equations, electromagnetic waves.
- **Analog and digital electronics:** Basic electronics, digital electronics, analog and digital modulation, microcontroller and process
- **Condensed matter:** Symmetry in solids, X-ray diffraction methods, free electron theory of metals, thermal conductivity of metals, theory of specific heat, lattice vibrations, dielectrics, magnetism, superconductors, energy bands in solids, semiconductors, defects in solids.
- **Embedded systems**
- **Digital signal processing**

Neuroscience – Translational Applications

The exam will test basic concepts in research methodology, physics, chemistry, and mathematics based on the NCERT CBSE curriculum for grades 11 and 12, with an emphasis on topics relevant to neuroscience research. It will also include advanced questions in biology, particularly in molecular biology, genetics, and physiology. Detailed subject-wise topics are as follows:

Physics (11th and 12th Grade, NCERT CBSE Syllabus):

- Mechanics: Laws of motion, gravitation, work, energy, and power.
- Waves and Optics: Wave motion, reflection, refraction, interference, and diffraction.
- Thermodynamics and Kinetic Theory.
- Electricity and Magnetism: Electrostatics, electric circuits, magnetic fields, and electromagnetism.
- Modern Physics: Atomic structure, nuclei, and semiconductor electronics.

Chemistry (11th and 12th Grade, NCERT CBSE Syllabus):

- Physical Chemistry: Atomic structure, thermodynamics, reaction kinetics.
- Organic Chemistry: Hydrocarbons, their structures and properties.
- Inorganic Chemistry: Periodic table, chemical bonding, p-block and d-block elements, coordination compounds.

Mathematics (11th and 12th Grade, NCERT CBSE Syllabus):

- Algebra: Matrix and determinants, quadratic equations, sequences and series. Calculus: Limits, derivatives, integrals, and applications.
- Trigonometry: Functions, identities, and equations.
- Geometry: Coordinate geometry, vectors, and 3D geometry.
- Probability and Statistics.
- Set theory

Biology (BSc Level):

- Biochemistry: Biomolecules (carbohydrates, proteins, lipids, nucleic acids), enzymes, metabolism (glycolysis, TCA cycle, oxidative phosphorylation).
- Genetics: Mendelian and non-Mendelian inheritance, DNA structure and replication, gene expression, mutations.
- Molecular Biology: Central Dogma, transcription, translation, gene regulation, recombinant DNA technology.
- Physiology: Cellular physiology, neurophysiology, cardiovascular, respiratory, and renal physiology.

Cancer Research – Neoantigen and Vaccine Development

This examination will assess foundational knowledge and applied understanding in cancer biology, immunology, neoantigen discovery, vaccine development, and bioinformatics. The program aims to recruit students passionate about translational cancer research with a focus on next-generation immunotherapy.

Section I: Fundamentals of Cancer Biology

Objective: Test understanding of cancer pathogenesis, molecular mechanisms, and the tumor microenvironment.

Key Topics:

- Hallmarks of Cancer (Hanahan and Hanahan & Weinberg)
- Tumor suppressor genes and oncogenes (e.g., p53, Rb, Ras)
- Genomic instability and epigenetic alterations
- Cell cycle regulation and checkpoints
- Apoptosis and mechanisms of cell death
- Tumor angiogenesis and metastasis
- Cancer metabolism and hypoxia
- Tumor microenvironment and stromal interactions

Suggested Reading:

- Weinberg, R.A. (2013). The Biology of Cancer (2nd ed.). W.W. Norton & Company. https://doi.org/10.1201/9780429258794
- Molecular biology of cancer: mechanisms, targets, and therapeutics
  L Pecorino – 2021

Section II: Immunology and Tumor Immunology

Objective: Evaluate understanding of host immunity and immune responses to tumors.

Key Topics:

- Innate vs. adaptive immunity
- T and B lymphocyte development
- Antigen presentation (MHC I and II)
- T cell activation and co-stimulation
- Immune checkpoints (PD-1/PD-L1, CTLA-4)
- Immune evasion mechanisms by tumors
- Tumor-associated and tumor-specific antigens
- Principles of immunotherapy: mAbs, CAR-T, checkpoint inhibitors

Suggested Reading:

- Murphy, K. M., & Weaver, C. (2017). Janeway's immunobiology. Garland Science.
- Butterfield, Lisa H., Howard L. Kaufman, and Francesco M. Marincola, eds. *Cancer Immunotherapy Principles and Practice*. New York: Demos Medical Publishing, 2017.

Section III: Neoantigen Discovery and Cancer Vaccine Development

Objective: Assess familiarity with techniques and concepts central to personalized cancer vaccine design.

Key Topics:

- Neoantigens: origin, types, and relevance
- Tumor exome and RNA sequencing pipelines
- Epitope prediction tools (NetMHCpan, MuPeXI, IEDB)
- mRNA and peptide vaccine platforms
- Adjuvants and delivery systems (LNPs, viral vectors)
- Preclinical validation in animal models

- Biomarker-based stratification and clinical trial design

Suggested Resources:

- Nature Reviews Cancer, Frontiers in Immunology (selected reviews)
- Online tutorials from IEDB and NetMHCpan
- Research articles on neoantigen vaccine trials (e.g., NCI, BioNTech)

Section IV: Experimental and Computational Tools

Objective: Examine familiarity with laboratory and bioinformatics tools used in immuno-oncology.

Key Topics:

- Experimental assays: ELISPOT, FACS, ICS, Tetramer staining
- CRISPR/Cas9 and gene editing
- Immunopeptidomics and mass spectrometry
- Variant calling and NGS data processing
- Tools: FastQC, GATK, VEP, STAR, Bowtie2
- Data visualization and analysis using R/Python

Suggested Resources:

- Choudhuri, Supratim, Kotewicz, Michael. (2014). *Bioinformatics for beginners: genes, genomes, molecular evolution, databases and analytical tools* . Amsterdam: Elsevier.
- Lesk, Arthur M. *Introduction to Bioinformatics*. Fifth edition. Oxford, United Kingdom: Oxford University Press, 2019.
- Online modules from Coursera, edX, and EMBL-EBI

Preparation Advice:

- Revise basics of cell and molecular biology, immunology, and oncology.
- Read recent review papers on cancer vaccines and immunotherapy.
- Practice using online epitope prediction and NGS tools.

Food Science and Technology

The topics include basic questions on Research Methodology, Food Technology, Biochemistry, Molecular Biology, and Industrial Biotechnology, especially from the topics that are relevant to Food Product Design. In addition, there are some advanced biology questions that include advanced Enzymology, Fermentation, protein Chemistry and Food Engineering topics. The detailed topics of each subject are given below.

Food Technology:

Reference: Textbook of Food Science and Technology, Sharma A

- Basic Concepts: Nutrition, balanced diet, energy, macronutrients and micronutrients.
- Principles of Food Science: Understanding the physical, chemical, and microbiological changes in food caused by various factors like heat, enzymes, and pH changes.
- Food Safety: HACCP (Hazard Analysis and Critical Control Points) and food safety management tools.
- Food Processing and Preservation: Understanding the significance of food processing, its impact on food quality, and different methods of preservation.
- Food Components:
  - Carbohydrates: Structure, function, and metabolism of carbohydrates in food, including monosaccharides, disaccharides, and polysaccharides.
  - Lipids: Chemistry and function of lipids in food, including fatty acids, fats, and oils.
  - Proteins: Structure, function, and metabolism of proteins in food, including amino acids and peptide sequencing.

- Nucleic Acids: Structure and biochemical roles of DNA and RNA in food.

Biochemistry:

Reference: Principles of Biochemistry, Lehninger.

- Quantitative Analysis: Quantitative analysis of food components.
- Enzyme Assays: Methods for determining enzyme activity.
- Microbial Analysis: Isolation, identification, and enumeration of microorganisms in food samples.
- Physical Chemistry: Atomic structure and reaction kinetics.

Molecular Biology:

Reference: Molecular Biology by Verma and Agarwal

- Enzymology: Structure of enzymes, their mechanisms, and role in biological processes.
- Bioinformatics: Deals with the analysis of biological data, including DNA and protein sequences, using computational tools.
- Molecular biology techniques: DNA extraction, PCR, gel electrophoresis, and other relevant methods.

Industrial Biotechnology:

Reference: Industrial Biotechnology: Current Progress and Novel Technologies, "Industrial Biotechnology: Principles and Applications" and "Industrial Biotechnology: Products and Processes (Advanced Biotechnology)"

- Enzyme Technology: Focuses on enzymes, their applications in industrial processes, and enzyme engineering.
- Bioprocess Technology and Downstream Processing: Covers the design, optimization, and scale-up of industrial bioprocesses, as well as techniques for product isolation and purification.
- Food Biotechnology: The role of biotechnology in food production, processing, and quality control.
- Fermentation Biology: Production of enzymes and other bioactive molecules, Bioreactors, Downstream processing, Inoculum preparation and Process optimization.

Research Methodology:

- Statistical techniques, Data collection and analysis, Ethics in research and Report generation will be the focus.

Sustainable Energy Solutions

Chemistry

- **Inorganic Chemistry:** Periodic Properties, Structure and Bonding, Acids & Bases, Main Group Elements and Transition metals, Co-ordination Chemistry, Organometallic Compounds, Bioinorganic Chemistry, Characterisation of Inorganic Compounds by Spectroscopic techniques, Basic Analytical Chemistry.
- **Physical Chemistry:** Basic Quantum Mechanics, Chemical Bonding Theory, Thermodynamics, Atomic structure & Term Symbols, Chemical Kinetics, Chemical Thermodynamics, Statistical Thermodynamics, Molecular spectroscopy, Electrochemistry, Solid state & Crystal structure, Colloids and Surfaces.
- **Organic Chemistry:** IUPAC nomenclature of organic molecules, Stereochemistry, Aromaticity, Organic reaction mechanisms, Common named reactions and rearrangements, Asymmetric synthesis, Pericyclic reactions, Organic transformations and reagents, Structure determination of organic compounds

Physics

- **Mathematical methods of Physics:** Dimensional analysis, Vector algebra and vector calculus, Linear algebra, matrices, Eigenvalues and eigenvectors, Fourier series, Fourier and Laplace transformations, ordinary differential equations.
- **Classical mechanics:** Phase space dynamics. Central force motions. Two-body collisions, Rigid body dynamics, Non-inertial frames, Variational principle. Generalized coordinates, Lagrangian and Hamiltonian formalism, Caley-Hamilton theorem
- **Electromagnetic theory:** Electrostatics, Maxwell's equations, Scalar and vector potentials, gauge invariance, Dielectrics and conductors.
- **Quantum Mechanics:** Wave-particle duality. Schrödinger equation. Tunnelling through a barrier. Heisenberg uncertainty principle. Hydrogen atom. Time-independent perturbation theory and applications. Pauli exclusion principle, Variational method. Spin-orbit coupling, fine structure.
- **Thermodynamic and Statistical Physics:** Laws of thermodynamics and their consequences. Thermodynamic potentials, Maxwell relations. Micro-canonical, canonical and grand-canonical ensembles and partition functions. Blackbody radiation and Planck's distribution law, Landau theory of first- and second-order phase transitions. Ising model.
- **Electronics and Experimental Methods:** Semiconductor devices, Operational amplifiers. Data interpretation and analysis. Precision and accuracy. Error analysis, propagation of errors. Least squares fitting, Linear and nonlinear curve fitting, chi-square test.
- **Atomic & Molecular Physics:** Quantum states of an electron. Spectrum of alkali atom, hyperfine structure and isotopic shift, LS & JJ couplings. Zeeman, Paschen-Bach & Stark effects.
- **Condensed Matter Physics:** Bravais lattices. Reciprocal lattice. Diffraction and the structure factor. Bonding of solids. Free electron theory and electronic specific heat, electron motion in a periodic potential, metal, insulators and semiconductors.
- **Nuclear and Particle Physics:** Basic nuclear properties, Binding energy, liquid drop model. Classification of fundamental forces. Elementary particles

**Research in this area is interdisciplinary, and we invite student applications from both Chemistry and Physics backgrounds. The Question paper for the admission test will have separate sections for Chemistry and Physics questions, and students are required to attempt questions from only one section, depending on their PG degree. There may also be a few questions from the general sciences of the XII standard.

Research Methodology

The examination will include questions designed to assess the candidate's research aptitude, reasoning ability, divergent thinking, and general awareness of research methodology.