2.2.2 Description of Courses

MPS811 Defence Science
AUs: 3, Prerequisites: NIL, Special Term 2
This course fosters an appreciation of how fundamental sciences with its principles and approaches can be applied to the creation of advanced technologies and methodologies for national defence.

MPS901 Physical and Mathematical Sciences I
AUs: 3, Prerequisites: GCE 'A' level Mathematics or equivalent, Special Term 1
This course prepares students for degree courses in the physical and mathematical sciences by exposing them to key topics and concepts. Students will grasp the fundamental principles of chemistry and physics, and techniques in mathematics, and be able to apply them in problem solving.

MPS902 Physical and Mathematical Sciences II
AUs: 3, Prerequisites: GCE 'A' level Mathematics or equivalent, Special Term 2
This course prepares students for degree courses in the physical and mathematical sciences by exposing them to key topics and concepts. Students will grasp the fundamental principles of chemistry and physics, and techniques in mathematics, and be able to apply them in problem solving.

Note: The courses are still subject to minor revisions. Please check http://www.spms.ntu.edu.sg regularly for the latest updates.

Division of Chemistry and Biological Chemistry

CBC111 Principles of Modern Chemistry with Laboratory 1
AUs: 4, Prerequisites: GCE 'A' level Chemistry or equivalent or by permission, Semester 1
This course adopts a topical approach with a strong problem-solving orientation. A series of discussions covering modern day research as well as the impact of chemistry will be used to illustrate the various fundamental concepts. To be introduced are concepts of structures and properties of atoms and molecules, bonding, periodicity, isomerism and chemical reactions, and the fundamentals of spectroscopy. Laboratory work includes both qualitative and quantitative analysis.

CBC112 Principles of Modern Chemistry with Laboratory 2
AUs: 4, Prerequisites: CBC111 or by permission, Semester 2
A continuation of CBC111, this course covers thermodynamics, the rate of chemical reactions and reaction kinetics, chemical equilibria, electrochemistry and nuclear chemistry. Laboratory work includes chemical synthesis, separation and purification processes, and qualitative and quantitative analysis.

CBC113 Basic Organic Chemistry with Laboratory
AUs: 4, Prerequisites: GCE 'A' level Chemistry or equivalent or by permission, Semester 1
This course covers the chemistry, structures and reactions of the compounds of carbon and the concept of mechanism. It introduces the characteristic properties, synthesis and reactivity of alkanes, alkenes, alkynes, benzene, and other aromatic compounds, halides, alcohols, ethers, epoxides, phenols, aldehydes, ketones, carboxylic acids, amines, and their derivatives. Laboratory work involves techniques of separation and purification, organic reactions and preparation and systematic identification of compounds by the spectroscopy and physical properties.

CBC121 Biological Chemistry 1
AUs: 3, Prerequisites: GCE 'A' level Chemistry or equivalent or by permission, Semester 1
Biological Chemistry 1 provides a survey of significant biomolecules and their roles in living systems and relates both their structure and reactivity to the principles of organic chemistry.

CBC122 Biological Chemistry 2
AUs: 3, Prerequisites: GCE 'A' level Chemistry or equivalent or by permission, Semester 2
This course covers the reactivity of biomolecules, especially in enzymatic reactions, both qualitatively and quantitatively. The interaction of drug molecules with biological systems will be outlined based on chemical principles. The use of structural techniques for enzymology will be introduced.

CBC211 Analytical and Bioanalytical Chemistry
AUs: 3, Prerequisites: CBC111, CBC112 or by permission, Semester 2
The topics covered are sample treatment and extraction, sample preparation techniques, separation science, modern extraction techniques, chromatography, electrochemistry and electroanalytical methods. Examples from the biological systems will be used to illustrate the above concepts.

CBC212 Inorganic and Bioinorganic Chemistry
AUs: 3, Prerequisites: CBC111, CBC112 or by permission, Semester 1
This course covers coordination chemistry, nomenclature, structure and properties of transition metal complexes, stability constants and isomerism. It integrates chemical principles with biological applications with examples drawn from biochemistry, and molecular and cell biology.

CBC213 Organic and Bioorganic Chemistry
AUs: 3, Prerequisites: CBC113 or by permission, Semester 1
Topics covered include functional group transformations, disconnection approach to synthesis, synthesis and reactivity of polyfunctional organic molecules, heteroaromatic compounds, free radical reactions, pericyclic reactions, stereochemistry and reaction mechanisms. Examples from the biological systems will be used to illustrate the above concepts.

CBC214 Physical and Biophysical Chemistry 1
AUs: 3, Prerequisites: CBC111, CBC112, MAS182, PAP182 or by permission, Semester 2
This course covers properties of the Gibbs functions, chemical potential, fugacity, changes of states, phase equilibria, chemical equilibria, electrochemical equilibria, molecular reaction dynamics and potential energy surfaces, kinetics and principles of photochemistry. It integrates chemical principles with biological applications with examples drawn from biochemistry and molecular and cell biology.

CBC215 Chemistry and Biological Chemistry Laboratory 1
AUs: 2, Prerequisites: CBC111, CBC112, CBC113, CBC121, CBC122 or by permission, Semester 1
Laboratory work includes synthesis, qualitative and quantitative analysis of organic and inorganic compounds. Experiments are designed to illustrate topics covered in CBC212 and CBC213. They cover techniques of separation, organic and inorganic reactions, preparation and systematic identification of compounds by their spectroscopic and chemical properties. Examples from the biological systems will be used to illustrate the above concepts.

CBC216 Chemistry and Biological Chemistry Laboratory 2
AUs: 2, Prerequisites: CBC111, CBC112 or by permission, Semester 2
Experiments are designed to illustrate topics covered in CBC211 and CBC214. this module aims to integrate chemical principles with biological applications, with examples drawn from biochemistry and molecular and cell biology.

CBC311 Chemical Spectroscopy and Applications
AUs: 3, Prerequisites: CBC212, CBC213, CBC214 (only CBC214 for Physical Sciences students) or by permission, Semester 1
Covers structural and dynamic studies of inorganic and organic compounds by mass spectroscopy, electronic, vibrational and multi-nuclear magnetic resonance spectroscopic methods.

CBC312 Organometallic Chemistry
AUs: 3, Prerequisites: CBC212 or by permission, Semester 2
This course covers synthesis, bonding, structure, reactivity and applications of organometallic complexes.

CBC313 Organic Reaction Mechanisms and Synthesis
AUs: 3, Prerequisites: CBC213 or by permission, Semester 2
Topics covered include strategies in organic synthesis, reactivity, molecular rearrangements, reaction intermediates, enzymatic reactions and stereoelectronic effects.

CBC314 Physical and Biophysical Chemistry 2
AUs: 3, Prerequisites: CBC214 or by permission, Semester 1
This course covers the duality of matter and the Heisenberg principle, Schršdinger equation of simple systems, postulates of quantum mechanics, symmetry elements and operators, probability, order and disorder, statistical interpretation of entropy and the Boltzmann equation, Boltzmann distribution and the partition function for an ideal gas and thermodynamic functions for ideal gases. Examples from the biological systems will be used to illustrate the above concepts.

CBC315 Chemistry and Biological Chemistry Laboratory 3
AUs: 2, Prerequisites: CBC215 or by permission, Semester 2
Experiments are designed to illustrate topics covered in CBC312 and CBC313. This module aims to integrate chemical principles with biological applications, with examples drawn from biochemistry and molecular and cell biology.

CBC316 Chemistry and Biological Chemistry Laboratory 4
AUs: 2, Prerequisites: CBC216 or by permission, Semester 1
Experiments are designed to illustrate topics covered in CBC311 and CBC314. Examples from the biological systems will be used to illustrate the above concepts.

CBC801 Impact of Chemistry on Society
AUs: 3, Prerequisites: NIL, Semester 2
This course discusses Chemistry in the context of selected current or potential socio-technological problems. Chemistry is central to a better understanding of our world. The issues selected, the facts and principles presented, and the habits of mind developed serve as a guide on how to live responsibly into the future.

CBC423 Asymmetric Synthesis
AUs: 3, Prerequisites: CBC313 or by permission, Semester 1
This course introduces various methodologies for the control of the absolute stereochemistry of the desired product in organic syntheses. Topics include principles of asymmetric synthesis and asymmetric catalysis, and the application of chiral synthons in total synthesis.

CBC491 Honours Project I
AUs: 3, Prerequisites: CBC315, CBC316 (CBC112 and CBC113 for Physical Sciences students) or by permission, Semester 1
One semester of research activity in chemistry culminating in a presentation and a comprehensive written report (compulsory for students on track to a First Class Honours).

CBC811 Forensic Science
AUs: 3, Prerequisites: NIL, Semester 1
This course provides general knowledge of forensic science, the use of chemicals and chemical technology to commit and to detect criminal offences, and the modern development of crime detection. The course covers some aspects of crime scene physical evidence, such as fingerprinting, firearms and ammunition, hair, fibres, drug identification, serology and DNA methods. This module can be studied by those without a strong scientific background.

CBC921 Computational Chemistry
AUs: 3, Prerequisites: CBC113 or by permission, Semester 1
Introduces Computational Chemistry to synthetic Organic Chemists, who would like to understand why the product that they have obtained is not always the compound they wanted. Starting with conformational changes, and ending with ‘real’ reactions, the emphasis is on the transition state: how to construct it, characterise it, and compare it to other alternatives. Topics covered include building molecular structures in a modelling programme, identifying reaction coordinates, searching for transition states, and consideration of activation energies in different reaction pathways.

CBC922 Medicinal Chemistry
AUs: 3, Prerequisites: CBC213 or by permission, Semester 1
This course covers physicochemical principles of drug action, basic principles of drug design, the molecular basis of drug action and the structure-physicochemical activity relationship.

CBC923 Drug Discovery and Design
AUs: 3, Prerequisites: CBC212 or CBC213 or by permission, Semester 2
Basic principles of drug discovery and design, fundamental molecular basis of drug action, discussion of target discovery and “drugability”, structure-activity relationships, new design and high throughput screening methods to discover new drugs and classes of drugs are all covered in this course.

CBC931 Industrial Chemistry
AUs: 3, Prerequisites: CBC112, CBC113 or by permission, Semester 2
This course provides an overview of the interrelations between the different branches of the modern chemical commodities industry, and of abstract concepts that are important in the manufacture of its products. Topics covered include sources of raw materials and new materials, overviews of trends in major

chemical industries, principles and applications of chemical processes and unit operations in chemical industry and industrial catalysts.

CBC932 Polymer Chemistry
AUs: 3, Prerequisites: CBC113 or by permission, Semester 1
Classification of polymers, structure-property relationship, polymer technology and synthesis, stabilisation, composites, biocomposites and applications are covered under Polymer Chemistry

CBC934 Heterocyclic Chemistry
AUs: 3, Prerequisites: CBC113, CBC213 or by permission, Semester 1
This course outlines the role of heterocycles in organic, pharmaceutical and biological chemistry andexplains the methods for chemical synthesis, elaboration and use.

CBC951 Materials Chemistry
AUs: 3, Prerequisites: CBC111, CBC112 or by permission, Semester 2
Covered in this course are the fundamentals of solid state chemistry, crystalline solids, crystal structure, Bragg equation, Madelung constant, lattice energy, bonding, intermolecular forces, lattice planes and surfaces, defects, solid-solid phase transition, non-crystalline solids, local order and glasses.

CBC952 Metal Mediated Reactions
AUs: 3, Prerequisites: CBC212, CBC213 or by permission, Semester 2
Applications of organometallic and transition metal complexes in major homogenous and heterogeneous catalytic reactions, reaction mechanism, selectivity, stereochemistry and activation energy are covered in this course.

CBC953 Natural Product Chemistry
AUs: 3, Prerequisites: CBC213 or by permission, Semester 1
The diversity of natural products and their roles in biological systems, chemistry and biosynthesis of important natural product classes such as terpenoids and steroids, fatty acids, arachidonic acid derivatives, polyketides, shikimic acid and alkaloids is the focus of this course.

CBC941 Undergraduate Research Experience in Chemistry and Biological Chemistry I
AUs: 4, Prerequisites: By permission, Special Terms 1 and 2
This vacation-long module (40 hours per week for 10 weeks) provides an opportunity to carry out research with one or more faculty members in Chemistry and Biological Chemistry.

CBC942 Undergraduate Research Experience in Chemistry and Biological Chemistry II
AUs: 4, Prerequisites: By permission, Special Terms 1 and 2
This vacation-long module (40 hours per week for 10 weeks) provides an opportunity to carry out research with one or more faculty members in Chemistry.

CBC943 Undergraduate Research Experience in Chemistry and Biological Chemistry III
AUs: 4, Prerequisites: By permission, Special Terms 1 and 2
This vacation-long module (40 hours per week for 10 weeks) provides an opportunity to carry out research with one or more faculty members in Chemistry.

CBC962 Food Microbiology and Safety Control
AUs: 3, Prerequisites: NIL, Semester 1
Bacteria can be both good and bad for food. Some microorganisms cause food to turn bad and are a threat to health. On the other hand, some foods such as yoghurt can only be made by their action. This course looks at these aspects and how microorganism populations can be monitored and controlled. No previous knowledge of microbiology is required. This is one of three modules that will satisfy the requirement for the Concentration in Food Science and Technology.

CHEM1 Principles of Modern Chemistry
AUs: 4, Enrollment is limited to students who have gained entry into the scholar programme or by permission of the instructor, Semester 1
This course adopts a topical approach with a strong problem-solving orientation. A series of discussions covering modern day research as well as the impact of chemistry will be used to illustrate the various fundamental concepts. To be introduced are concepts of structures and properties of atoms and molecules, bonding, introductory thermodynamics, periodicity, isomerism and chemical reactions, the fundamentals of spectroscopy, electronic structure of atoms, periodic properties, ionic substances, covalent bonding, Lewis

representations of molecules and ions, shapes of molecules, Lewis acids and bases, Bronsted acids and bases, hybridisation and resonance, an introduction to organic chemistry, the chemistry of life and Biological Chemistry.

CHEM2A Fundamental Techniques of Experimental Chemistry and Biological Chemistry
AUs: 3, Prerequisites: NIL, Semester 1
This course introduces the basic principles and techniques of synthesis and analysis, such as extraction, TLC, distillation, recrystallisation, titration, acid-base work-up, and the synthesis of organic compounds. It develops the laboratory skills and precision that are fundamental to experimental chemistry and Biological Chemistry.

CHEM2B Undergraduate Research Experience in Chemistry and Biological Chemistry
AUs: 3, Prerequisites: NIL, Semester 2
This course provides an opportunity to carry out research during the semester with one or more faculty members in Chemistry and Biological Chemistry. Students will be required to write a proposal, submit a report and give a presentation of their research. Enrollment s limited to students who have gained entry to the scholar programme or by permission of the instructor.

CBC721 Graduate Analytical Chemistry
AUs: 4, Prerequisites: CBC421 - Advanced Analytical and Bioanalytical Techniques. CBC426 - Chemical Kinetics and Dynamics. Competence in mathematics (experience in solving partial differential equations and Laplace transforms) or Divisional approval, Semester 1
This course presents the latest analytical techniques and those that are just emerging. It provides graduate students with the background for research in the field. Emphasis is on experimental techniques and the theory of electroanalytical chemistry.

CBC722 Graduate Inorganic Chemistry
AUs: 4, Prerequisites: CBC312 Organometallic Chemistry or Division approval, Semester 1
A spectrum of essential topics in inorganic chemistry that will be useful for all entry level graduate students will be covered. They include physical inorganic chemistry, synthetic methodologies and characterisation techniques. These topics equip graduate students with basic knowledge and skills that will enable them to function more effectively in a modern inorganic research environment, and form the background knowledge for more specialised inorganic elective modules.

CBC723 Graduate Organic Chemistry
AUs: 4, Prerequisites: CBC313 Organic Reaction Mechanisms and Synthesis or Division approval, Semester 1
Covered in this course are advanced topics in organic synthesis, including major synthetically useful reactions, with an emphasis on asymmetric processes, metal-mediated organic transformations, protecting groups in organic synthesis, and selected mechanisms in organic synthesis.

CBC724 Graduate Physical Chemistry
AUs: 4, Prerequisites: CBC314 Physical and Biophysical Chemistry 2 or Division approval, Semester 2
This course provides a broad sweep of the molecular approach to physical chemistry required for research, and presents the core theories of physical chemistry in greater breadth and depth: quantum theory and spectroscopy, statistical and equilibrium thermodynamics, chemical kinetics and dynamics, and special advanced topics in modern physical chemistry.

CBC725 Contemporary Organometallic Chemistry
AUs: 4, Prerequisites: CBC312 Organometallic Chemistry or Division approval, Semester 2
This course covers the principles and applications of organometallic compounds: synthesis, reactivity and structural aspects.

CBC726 Advanced Organic Chemistry
AUs: 4, Prerequisites: CBC313 Organic Reaction Mechanisms and Synthesis or Division approval, Semester 2
Biomimetic reactions, the application of organometallics to organic synthesis, the synthesis of complex molecules, and other emerging areas in organic synthesis are covered in this course. Students will be required to write a proposal and a review of a topic related to organic synthesis.

CBC729 Graduate Seminar Module (1)
AUs: 4, Prerequisites: Division approval, Semester 1
Students are required, in this module, to:
- attend at least 14 seminars, of which at least six are given by visitors or staff members and at least six are from the CBC529 Graduate Student Symposium (e.g. 6+8, 7+7, etc)
- deliver a 30 to 40-minute talk in the Graduate Student Symposium
- answer questions on a specified topic (taken from papers published in the past 3 years either in organic, inorganic, bio-organic and bio-inorganic related journals)

CBC730 Graduate Seminar Module (2)
AUs: 4, Prerequisites: Division approval, Semester 2
Students are required, in this module, to:
- attend at least 14 seminars of which at least six are given by visitors or staff members and at least six are from the CBC530 Graduate Student Symposium (e.g. 6+8, 7+7, etc)
- deliver a 30 to 40 minute talk in the Graduate Student Symposium
- answer questions on a specified topic (taken from papers published in the past 3 years either in the area of physical, analytical, biophysical and bioanalytical related journals)

CBC732 Graduate Chemical Biology
AUs: 4, Prerequisites: Division approval, Semester 1
The course presents topics in modern chemical biology: proteins, nucleic acids, carbohydrate structure, enzyme catalysis and inhibition, metabolism, signal transduction, cancer and virus biology, molecular biology, transcription and translation, protein folding and selected topics of current interest.

CBC733 Advanced Computational Chemistry
AUs: 4, Prerequisites: Division approval, Semester 2
This course is concerned with the choice and use of computer programmes to study reaction mechanisms, catalysis, transport phenomena, organic and biorganic binding, device simulations and molecular conformation. It requires students to complete a computational project in discussion with their module lecturer and research advisor for hands-on experience.

Note: The courses are still subject to minor revisions. Please check http://www.spms.ntu.edu.sg regularly for the latest updates.

Division of Mathematical Sciences

MAS110 Introduction to Scientific Programming
AUs: 3, Prerequisites: GCE ‘A’ level Mathematics or equivalent, Semester 1
This introductory course on scientific programming using Fortran and C/C++ equips students with basic programming skills, including the use of existing libraries, useful in the study of physical and mathematical sciences. It covers:
- fundamental concepts of programming
- a brief overview of scientific programming languages (Fortran, C/C++)
- basic data types, functions, classes, templates, STL (container classes, algorithms), memory management
- compilation process, use of existing C/C++/Fortran libraries
- algorithmic problem solving and design process, programme development, coding and debugging, fundamental programming constructs, data structures, recursions, simple file processing, algorithmic complexity
- case studies in physical and mathematical sciences

MAS111 Foundations of Mathematics
AUs: 3, Prerequisites: GCE ‘A’ level Mathematics or equivalent, Semester 1
This course introduces fundamental ideas and techniques used in many different areas of mathematics.
- elementary logic, mathematical statements, quantified statements
- sets, operations on sets, Cartesian products, properties of sets
- natural numbers, integers, rational numbers, real numbers, complex numbers
- relations, equivalence relations, equivalence classes
- functions, injective and surjective functions, inverse functions, composition of functions
- mathematical proofs, mathematical induction

MAS112 Calculus I
AUs: 3, Prerequisites: GCE 'A' level Mathematics or equivalent (Preclusions: Students who read MAS112 are not allowed to read MAS181 and CPE103), Semester 1
This is the first course on calculus in a sequence of four modules. The objective is to introduce basic notions of calculus and analytic geometry, including differentiation.

- real numbers, functions, their inverses and graphs
- transcendental functions: trigonometric and inverse trigonometric, logarithm and exponential, hyperbolic
- limits of functions, continuity at a point, continuity on an interval
- differentiability, derivatives of functions, chain rule, implicit differentiation, derivatives of higher order
- local maxima and local minima, Rolle's Theorem and Mean Value Theorem, points of inflection, first-derivative and second-derivative tests, Netwon's Method
- antidifferentiation

MAS113 Calculus II
AUs: 3, Prerequisites: MAS112 (Preclusions: Students who read MAS113 are not allowed to read MAS181 and CPE103), Semester 2
This second course in the calculus sequence studies integration and related topics.

- indefinite and definite integrals, mean value theorem for integrals, fundamental theorems of calculus, area of plane regions
- parametric equations, polar coordinates
- volumes of solids, length of arcs, other applications of the definite integral
- techniques of integration
- elementary differential equations

MAS114 Linear Algebra I
AUs: 3, Prerequisites: GCE 'A' level Mathematics or equivalent (Preclusions: Students who read MAS114 are not allowed to read MAS183, EE2007 and CPE103), Semester 2
This first of two courses on linear algebra introduces basic notions in linear algebra that are often used in other areas of mathematics and applications.

- Systems of linear equations, Gaussian elimination
- Matrices, inverses, determinants
- Vectors, dot product, cross product
- Vector spaces, subspaces, linear independence, basis, dimension, row and column spaces, rank

MAS181 Calculus for the Sciences I
AUs: 3, Prerequisites: GCE 'A' level Mathematics or equivalent (Preclusions: Students who read MAS181 are not allowed to read MAS112, MAS113 and CPE103), Semester 1
This first of two courses on calculus equips students in the sciences with a basic working knowledge of calculus. Applications and computer-based learning are also included.

- functions and graphs, real numbers
- differentiation of functions of one variable, derivative as rate of change, chain rule, implicit functions, inverse functions
- local maxima and minima
- indefinite and definite integrals, applications of integration
- methods of integration
- fundamental theorem of calculus

MAS182 Calculus for the Sciences II
AUs: 3, Prerequisites: MAS181 or equivalent (Preclusions: Students who read MAS182 are not allowed to read MAS113, MAS211 and CPE103), Semester 2
This second course on calculus equips students in the sciences with knowledge of further topics in this useful tool for modern science and engineering.

- differential equations — first-order and second-order linear differential equations
- techniques of solving differential equations, applications
- series and power series
- Taylor's series
- Fourier series

MAS183 Linear Algebra and Multivariable Calculus
AUs: 3, Prerequisites: MAS181 or equivalent (Preclusions: Students who read MAS183 are not allowed to read MAS114, MAS212, MAS213 and CPE103), Semester 2
This course introduces techniques in linear algebra and multivariable calculus which are useful in applications. Applications and computer-based learning areincluded.

- systems of linear equations
- matrices, determinants
- vectors in 2- and 3-dimensional Euclidean spaces
- vector spaces, linear independence, basis, dimension
- linear transformations
- Eigenvectors and eigenvalues
- calculus of functions of several variables, aprtial derivatives, constrained and unconstrained optimisation, applications

MAS211 Calculus III
AUs: 3, Prerequisites: MAS113 (Preclusions: Students who read MAS211 are not allowed to read MAS182 and CPE103), Semester 1
This third course in the calculus sequence explores further topics in one-variable calculus such as sequences and series, as well as rudiments of multi-variable calculus.

- indeterminate forms, improper integrals
- Taylor's formula
- sequences, monotonic and bounded sequences
- infinite series, tests for convergence and divergence, alternating series, absolute and conditional convergence
- power series, differentiation and integration of power series, Taylor series, binomial series, Fourier series
- vector-valued functions and parametric equations, calculus of vector-valued functions, solid analytic geometry

MAS212 Calculus IV
AUs: 3, Prerequisites: MAS113 (Preclusions: Students who read MAS212 are not allowed to read MAS183), Semester 2
This last of four courses in the calculus sequence introduces multi-variable calculus.

- functions of more than one variable, limits, continuity, partial derivatives, differentiability and total differential, chain rule
- directional derivatives, gradients, Lagrange multipliers
- double integrals, area of a surface, triple integrals
- line integrals, Green's Theorem, surface integrals, Gauss' divergence theorem, Stokes' Theorem

MAS213 Linear Algebra II
AUs: 3, Prerequisites: MAS114 (Preclusions: Students who read MAS213 are not allowed to read MAS183), Semester 1
This second of two courses on linear algebra focuseson topics such as eigenvalues and canonical forms.

- linear transformations, kernels and images
- inner products, inner product spaces, orthonormal sets, Gram-Schmidt process
- Eigenvectors and eigenvalues, diagonalisation, applications
- symmetric and Hermitian matrices
- quadratic forms, bilinear forms
- Jordan Normal Form and other canonical forms

MAS214 Basic Discrete Mathematics and Number Theory
AUs: 3, Prerequisites: MAS111, Semester 2
This course introduces basic notions in discrete mathematics and number theory commonly used in mathematics and computer science.

- counting, permutations and combinations, binomial theorem
- inclusion-exclusion principle
- Boolean algebra
- recursion
- graphs, paths and circuits, isomorphisms, trees, spanning trees
- division algorithm, greatest common divisor, Euclidean algorithm, fundamental theorem of arithmetic, modulo arithmetic

- diophantine equations ax+by=c

MAS215 Probability and Statistics I
AUs: 4, Prerequisites: {MAS112 and MAS113} or {MAS181 and MAS182} (Preclusions: Students who read MAS215 are not allowed to read CPE103), Semester 1
This course focuses on probability theory, with the view of probability distributions as models for phenomena with statistical regularity.

- discrete distributions (binomial, hypergeometric and Poisson)
- continuous distributions (normal, exponential) and densities
- random variables, expectation, independence, conditional probability
- introduction to the law of large numbers and the central limit theorem

MAS216 Mathematical Exposition
AUs: 2, Prerequisites: MAS111, MAS112, MAS113, MAS114, Semester 2
This course focuses on techniques of effective presentation of mathematical materials, both in written and spoken forms. Topics covered include: selection and organisation of technical material, clarity of oral exposition and mathematical writing, planning, editing, formatting, and critique. Learning is done through written assignments and in-class presentations.

MAS281 Complex Methods for the Sciences
AUs: 3, Prerequisites: MAS182, MAS183 (Preclusions: Students who read MAS281 are not allowed to read MAS312), Semester 1
Some tools in complex methods and special functions that are commonly used in the sciences are introduced in this course.

- complex numbers, Argand diagrams, modulus and arguments, De Moivre's theorem
- functions of a complex variable, elementary examples, Cauchy-Riemann equations
- contour integrals, Cauchy's theorem and Cauchy's integral formula
- Taylor series, Laurent series, zeros, poles and essential singularities, residues
- Fourier transform, inversion, convolution, Parseval's theorem, delta function, applications
- elementary partial differential equations, methods of separation
- brief introduction to special functions, e.g., gamma function, beta function, Bessel's function, Legendre's function

MAS311 Real Analysis I
AUs: 4, Prerequisites: MAS112, MAS113, MAS211, Semester 1
This first course in real analysis – the rigorous investigation of calculus -- emphasisesrigour and proofs.

- basic properties of real numbers, supremum and infimum, completeness axiom
- limits and convergence of sequences, subsequences, Bolzano-Weierstrass theorem, Cauchy sequences
- limits of functions, continuity, intermediate value theorem, extreme-value theorem
- differentiability, derivatives, chain rule, Rolle's theorem, mean value theorem, inverse functions, Taylor's theorem, Lagrange's form of the remainder

MAS312 Complex Analysis
AUs: 4, Prerequisites: MAS211, MAS212 (Preclusions: Students who read MAS312 are not allowed to read MAS281), Semester 1
This course is an introduction to the theory of complex variables, whichis useful in many branches of pure and applied mathematics.

- Analytic functions of one complex variable, Cauchy-Riemann equations
- Contour integrals, Cauchy's theorem and Cauchy's integral formula, maximum modulus theorem, Liouville's theorem, fundamental theorem of algrebra, Morera's theorem
- Taylor series, Laurent series, singularities of analytic functions
- Residue theorem, calculus of residues
- Fourier transforms, inversion formula, convolution, Parseval's formula
- Applications

MAS313 Abstract Algebra I
AUs: 3, Prerequisites: MAS111, MAS213, MAS214, Semester 2
This first course on modern algebra introduces basic algebraic structures such as groups, rings and fields.

- Groups, subgroups, cyclic groups, groups of permutations, Cosets, Lagrange's Theorem, homomorphism, factor groups

- Rings and fields, ideals, integral domains, quotient fields, rings of polynomials, factorisation of polynomials over a field

MAS314 Numerical Analysis I
AUs: 3, Prerequisites: { MAS114 and MAS213 } or { MAS181 and MAS183 }, Semester 2
This first course on the theory and applications of numerical approximation techniques equips students with a number of commonly used numerical algorithms, knowledge, experience in writing a program from an algorithm, and skill in performing numerical computations using MATLAB.

- Basics on computational errors, basic numerical methods for solutions of systems of linear equations, iterative methods for systems of linear equations, polynomial interpolation, numerical integration, numerical solutions of nonlinear equations, implementation of algorithms using MATLAB

MAS315 Probability and Statistics II
AUs: 4, Prerequisites: MAS215 (Preclusions: Students who read MAS315 are not allowed to read CPE103), Semester 2
This course introduces modern statistical concepts and procedures derived from a mathematical framework.

- Statistical inference, decision theory, point and interval estimation, tests of hypotheses, Neyman-Pearson lemma
- Bayesian analysis, maximum likelihood, large sample theory

MAS316 Regression Analysis
AUs: 4, Prerequisites: MAS215, MAS315, Semester 1
The object of study in this course is regression analysis – one of the most widely used statistical techniques. The course also covers:

- multiple linear regression, nonlinear regression, analysis of residuals and model selection
- One-way and two-way factorial experiments, and random and fixed effects models

MAS317 Data Analysis with Computer
AUs: 3, Prerequisites: MAS215, Semester 2
This course on the use of statistical computer packages focuses on MINITAB, SAS and R. It covers pseudorandom number generation, generating discrete and continuous random variables, data access, transformations, estimation, testing hypotheses, ANOVA, resampling methods and simulations

MAS321 Ordinary Differential Equations
AUs: 4, Prerequisites: MAS212, Semester 1
This course provides methods and techniques to solve typical ordinary differential equations, introduces the fundamental theory of ODEs, and develops methods to analyze given equations.

- first-order equations, exact equations, integrating factors, separable equations, linear homogenous and non-homogenous equations, variation of parameters, Principle of superposition
- second-order equations, Wronskian, Abel's formula, variation of parameters, exact equations, adjoint and self-adjoint equations, Lagrange and Green's identities, Sturm's comparison and separation theorems
- first-order linear systems, Wronskian, Abel's formula, variation of parameters, systems with constant coefficients
- first-order nonlinear equations, initial value problem
- use of ODE in simple modelling problems

MAS323 Number Theory
AUs: 4, Prerequisites: MAS214, Semester 1
This course introduces basic number theory – a topic that epitomises the beauty and elegance of pure mathematics – and its modern applications. The course covers:

- A review of modular arithmetic, Chinese remainder theorem, Fermat's little theorem, Wilson's theorem
- number-theoretic functions: T, •, Euler's •-function, Mšbius inversion formula, applications to cryptography
- primitive roots, indices
- Legendre's symbols, quadratic reciprocity law
- continued fractions, Pell's equations
- primality tests and factorisation of integers, RSA cryptosystem

MAS324 Graph Theory
AUs: 4, Prerequisites: MAS214, MAS215, Semester 2
This course provides an introduction to working with the most accessible discrete structures, i.e., graphs.
- review of introductory graph theory from MAS214
- connectivity and matchings, Hall's theorem, Menger's theorem, Network flows
- paths and cycles, complete subgraphs and Turán's theorem, Erdšs-Stone theorem
- graph colouring, four-colour theorem
- Ramsey theory
- probabilistic methods in graph theory
- use of software to solve graph-theoretic problems

MAS326 Basic Optimisation
AUs: 4, Prerequisites: MAS213 or MAS183, Semester 2
This basic course in optimisation and operations research covers:
- introduction of Optimisation models: objective and constraints, convex sets and functions, polyhedron and extreme points
- introduction to LP: solving 2-variable LP via graphical methods; simplex method; dual LP and sensitivity analysis
- Karush-Kuhn-Tucker optimality conditions, optimal solution via optimality conditions, Duality theory
- Network Optimisation: Shortest path, maximum flow, minimum cost flow, assignment problem, transportation problem, network simplex method

MAS328 Stochastic Processes
AUs: 4, Prerequisites: MAS215, Semester 1
This course introduces modeling dependence and covers:
- Discrete-time Markov chains, examples of discrete-time Markov chains, classification of states, irreducibility, periodicity, first passage times, recurrence and transience, convergence theorems and stationary distributions
- Random walk, Poisson processes

MAS331 Undergraduate Research Experience in Mathematical Sciences I
AUs: 4, Prerequisites: Approval by Division, Special Terms 1 and 2
This research-based course will see students work on a specific topic under the supervision of a faculty member.

MAS332 Undergraduate Research Experience in Mathematical Sciences II
AUs: 4, Prerequisites: MAS331, Approval by Division, Special Terms 1 and 2
This research-based course will see students work on a specific topic under the supervision of a faculty member.

MAS421 Real Analysis II
AUs: 4, Prerequisites: MAS212, MAS311, Semester 2
A continuation of MAS311, this course investigatesfurther topics in real analysis with rigour.
- Riemann integral, integrability, fundamental theorem of calculus, improper integrals
- convergent series, absolute convergence, tests of convergence
- sequence and series of functions, uniform convergence
- power series, radius of convergence, local uniform convergence of power series

MAS422 Real Analysis III
AUs: 4, Prerequisites: MAS311 and MAS421, Semester 1
A continuation of MAS421, this course investigates further topics in real analysis with rigour.
- Normed space Rn, Lipschitz mappings, Bolzano-Weierstrass theorem in Rn, open and closed sets, sequences, Cauchy sequences, completeness, continuity of functions, compactness, Heine-Borel Theorem, Bolzano-Weierstrass Theorem, connectedness
- Introduction to metric spaces, limits, continuity, balls, neighbourhoods, open and closed sets, completeness, compactness, space of continuous functions, contraction mapping principle, Arzela-Ascoli Theorem, Weierstrass Approximation Theorem

MAS423 Partial Differential Equations
AUs: 4, Prerequisites: MAS311, MAS321 (MAS421 is useful but not essential), Semester 1
This introductory course on partial differential equations outlines their basic properties andthe techniques to solve the equations.

- first-order equations, Quasi-linear equations, general first-order equation for a function of two variables, Cauchy problem
- wave equation, wave equation in two independent variables, Cauchy problem for hyperbolic equations in two independent variables
- heat equation, the weak maximum principle for parabolic equations, Cauchy problem for heat equation, regularity of solutions to heat equation
- Laplace equation, Green's formulas, harmonic functions, maximum principle for Laplace equation, Dirichlet problem, Green's function and Poisson's formula

MAS425 Abstract Algebra II
AUs: 4, Prerequisites: MAS213 and MAS313, Semester 1
Further topics in groups, rings and fields are discussed in this course.

- Sylow's Theorems, Abelian groups
- Homomorphisms of rings, factor rings, prime and maximal ideals
- unique factorization domains, Euclidean domains, principal ideal domains
- modules, submodules, homomorphisms, quotient modules, modules over principal ideal domains

MAS426 Galois Theory
AUs: 4, Pre-requisites: MAS313 and MAS425, Semester 1
This course deals with the theory of fields, culminating in Galois theory, the most famous of whose application is the proof that the general quintic equation with rational coefficients cannot be solved by radicals.

- field extensions, algebraic extensions, geometric constructions
- finite fields
- automorphisms of fields, splitting fields, normal and separate extensions, Galois extensions, Galois groups
- Galois correspondence
- solution of equations by radicals, insolvability of the quintic equation
- fundamental theorem of algebra

MAS427Set Theory and Logic
AUs: 4, Pre-requisites:MAS111 and MAS214, Semester 2
This course introduces the notions of validity and provability in formal logic, the concepts of ordinals and cardinals as well as some formal set theory.

- partially-ordered sets, well orderings and order-types, induction and recursion on ordinals, ordinal arthmetric, cardinals, cardinal arithmetic
- Auxiom of choice and its equivalences, axiom of determination
- propositional calculus, truth tables, validity and contradictions
- predicate calculus with equality, completeness and compactness theorems, Lowenheim-Skolem theorem

MAS431 Combinatorics
AUs: 4, Prerequisites: MAS211, MAS213, and MAS214, Semester 1
This course studies some topics in combinatorics and their connections with other branches of mathematics and theoretical computer science.

- recursions and generating functions
- partitions and tableaux
- designs, Latin squares, combinatorial designs and projective geometries
- extremal combinatorics, asymptotic analysis

MAS432 Coding Theory
AUs: 4, Prerequisites: MAS213, MAS214, Semester 2
This course introduces basic notions in the theory of error-correcting codes, which is used in data storage and telecommunication.

- error detection, correction and decoding, Hamming distance
- basic facts on finite fields

- linear codes, Hamming weight, generator and parity-check matrices, encoding, decoding
- bounds, Hamming codes, Golay codes, perfect codes, MDS codes
- construction of codes, Reed-Muller codes
- Ccyclic codes, generator polynomials, BCH codes, Reed- Solomon codes
- computer implementation of efficient coding and decoding

MAS433 Cryptography
AUs: 4, Prerequisites: MAS214 and MAS313, Semester 2
This course introduces basic issues in cryptography, particularly underlying mathematical concepts.

- classical ciphers, cryptanalysis, linear complexity
- Data Encryption Standard
- RSA cryptosystem, primality testing and factorisation of integers
- discrete logarithms
- signatures, Digital Signature Standard

MAS434 Topics in Mathematics of Information and Communication
AUs: 4, Subject to approval by the Head of Division, Semester 2
This course introduces specialized advanced topics related to information theory, coding theory and cryptography. The choice of the topic depends on the instructor.

MAS436 Topology
AUs: 4, Prerequisites: MAS311 and MAS421, Semester 1
This course introduces the notions of metric and topological spaces.

- metric spaces, limits, continuity, balls, neighbourhoods, open and closed sets
- topology, metric topologies, convergence, Hausdorff spaces, homeomorphisms, topological and non-topological properties, subspace, quotient and product topologies
- connectedness, components, path-connectedness
- compactness, sequential compactness
- contraction mapping theorem

MAS437 Algebraic Topology
AUs: 4, Prerequisite: MAS313 and MAS421 (MAS436 is useful but not essential), Semester 2
Basic I\ideas in algebraic topology are introduced in this course, which covers:

- simplical complexes, subdivisions, simplicial approximation theorem, classification of surfaces
- fundamental groups, homotopy of continuous functions and homotopy equivalence, change of base point, van Kampen's theorem
- Euler characteristic, Lefschetz fixed point theorem
- covering spaces and covering maps

MAS438 Differential Geometry
AUs: 4, Prerequisite: MAS331 and MAS421 (MAS422 and MAS436 is useful but not essential)
This introduction to differential geometry, with curves and surfaces in the Euclidean 3 dimensional space as the focus, covers:

- metrics, lie brackets, connections, curvature and torsion of curves, the Frenet-Serret equations, Gaussian and mean curvature of surfaces, geodesics, isometries and Gauss's Theorem Egregium, tensors
- Gauss-Bonnet theorem

MAS441 Numerical Analysis II
AUs: 4, Prerequisites: MAS314, MAS321 (MAS431 is useful but not essential), Semester 2
This course seeks to provide numerical solutions of differential equations using finite difference methods andto understand the implementation of numerical computations using computer software packages such as MATLAB.

- Ffinite difference formulae, consistency of difference schemes, finite difference methods for ordinary differential equations, classification of second-order partial differential equations, first and second-order characteristics
- matrix method and von Neumann method for stability analysis, Lax's equivalence theorem for convergence, method of characteristics
- application to heat equation, wave equation and Poisson's equation

MAS442 Mathematical Tools of Image and Signal Processing
AUs: 4, Prerequisite: MAS311 and MAS441 (MAS421 and MAS422 is useful but not essential)
This course provides the necessary mathematical tools for image and signal processing

- Fourier transform, Window Fourier transform, Fourier series, discrete Fourier transform and discrete Window Fourier transform, orthonormal basis and tight frames
- Splines, approximation by splines
- Refinable functions, subdivision scheme
- Multiresolution analysis, orthonormal wavelets, spline tight frame wavelets, discrete wavelet transform, analysis and synthesis algorithms

MAS443 Topics in Scientific Computing
AUs: 4, Subject to approval by the Head of Division, Semester 2
This course introduces specialised advanced topics in scientific computation and continuous applied mathematics. The choice of the topic depends on the instructor.

MAS445 Deterministic Methods in OR
AUs: 4, Prerequisite: MAS212 and MAS326, Semester 2
This course introduces some deterministic methods commonly used in operations search and covers:

- unconstrained optimization: one dimensional search, gradient method, Newton-Raphson method
- constrained optimization: feasible direction methods, penalty/barrier function methods, modern interior point methods for convex programming
- discrete optimization: formulations, cutting plane methods, branch-and-bound methods, Lagrangian relaxation, dynamic programming approach

MAS446 Probabilistic Methods in OR
AUs: 4, Prerequisites: MAS215 and MAS326, Semester 1
This course introduces some useful probabilistic methods commonly used in operations research and statistics.

- Queuing: basic models, performance analysis, simulation of queuing systems
- Stochastic optimization: Stochastic programming, modelling and algorithms, Markov decision process, stochastic approximation

MAS447 Logistics and Supply Chain Management
AUs: 4, Prerequisite: MAS215 and MAS326, Semester 1
This course focuses on issues which arise in the integrated design and management of the entire logistics network and covers:

- overview of supply chain – components of a supply chain, material and information flow, supplier-retailer-customer interation, e-business
- inventory and materials management – Economic order quantity model, Lot sizing models, models with uncertain demands, MRP/JIT
- facility location and transportation – single sourced capacitated facility location, vehicle routing problem with equal, unequal demands and time-window constraints

MAS451 Time Series Analysis
AUs: 4, Prerequisite: MAS215, MAS315 and MAS316, Semester 2
This course introduces time series models used in economics, engineering and finance, and covers:

- trend fitting, autoregressive and moving average models, spectral analysis
- seasonality, forecasting and estimation
- use of computer package to analyze real data sets

MAS452 Multivariate Analysis
AUs: 4, Prerequisite: MAS215, MAS315 and MAS316, Semester 2
This course focuses on the standard methods of multivariate statistical analysis.

- Distribution theory: multivariate normal distribution, Hotelling's T2 and Wishart distributions, inference on the mean and covariance, principal components and canonical correlation, factor analysis, discrimination and classification

MAS453 Data Mining
AUs: 4, Prerequisite: MAS215, MAS315, MAS316 and MAS317, Semester 1
This course gives an overall view of modern statistical techniques for analyzing large data sets.

- neural networks, support vector machines, classification trees and boosting

MAS454 Sampling and Survey
AUs: 4, Prerequisite: MAS215 and MAS315, Semester 1
This course is an introduction to sampling and the design of sample surveys.

- ratio and regression estimators under simple random sampling, separate and combined estimators for stratified random sampling
- systematic sampling and its relationship with stratified and cluster sampling
- further aspects of stratified sampling, clustered sampling with clusters of unequal sizes
- subsampling; multi-stage sampling
- complex sample designs

MAS455 Clinical Trials
AUs: 4, Prerequisite: MAS215 and MAS315, Semester 1
This course provides an introduction to the design and analysis of clinical trials with an emphasis on the statistical aspects.

- Phases of clinical trials, objections and endpoints, the study cohort, controls, randomization and binding, sample size determination, treatment allocation, monitoring trial progress: complient effects. Ethical issues, quality of life assessment, data analysis involving multiple treatment groups and endpoints, stratification and subgroup analysis, intent to treat analysis, analysis of compliance data, surrogate endpoints, multi-centre trials and good practice versus misconduct.

MAS 456 Survival Analysis
AUs: 4, Prerequisites: MAS 215 and MAS 315, Semester 1
This course focuses on the standard methods of survival data analysis and covers:

- Examples of survival data analysis, types of censoring, parametric survival distributions (exponential, Weibull, lognormal), nonparametric methods, Kaplan-Meier estimator, tests of hypotheses, graphical methods of survival distribution fitting, goodness of fit tests.

MAS461 Special topics in Mathematics
AUs: 4, Subject to approval by the Head of Division
Some advanced topics in theoretical mathematics not normally covered in regular courses may be offered.

MAS462 Special topics in Applied Mathematics
AUs: 4, Subject to approval by the Head of Division, Semester 2
Some advanced topics in applied mathematics not normally covered in regular courses may be offered.

MAS463 Special topics in Statistics
AUs: 4, Subject to approval by the Head of Division
Some advanced topics in theoretical statistics not normally covered in regular courses may be offered.

MAS464 Supervised Independent Study I
AUs: 4, Subject to approval by the Head of Division
In this course, the student will do independent reading on a topic under the supervision of a faculty member.

MAS465 Supervised Independent Study II
AUs: 4, Prerequisite: MAS464, Subject to approval by the Head of Division
In this course, the student will do independent reading on a topic under the supervision of a faculty member.

MAS491 Honours project
AUs: 8, Prerequisite: Subject to approval by the Head of Division (Preclusions: Students who read MAS492 are not allowed to read MAS491)
This is a semester-long research course on an advanced topic leading to an Honours thesis under the supervision of a faculty member.

MAS492 Industrial internship (Pass/ Fail option only)
AUs: 8, Prerequisite: Subject to approval by the Head of Division (Preclusions: Students who read MAS491 are not allowed to read MAS492)
This course provides practical working experience and workplace exposure through a short-term job placement.

MAS801 It's a discreetly discrete world: Mathematics in real-life applications
AUs: 3, Prerequisites: GCE 'AO' level Mathematics or equivalent, Semester 1
Error-detecting and error-correcting codes – detecting and correcting errors in data: basic modular arithmetic used in the design of such codes, basic issues in theory and applications, well-known examples, real-life applications such as NRIC numbers, ISBN, CD, telecommunications, etc. Cryptography – ensuring security of information: basic issues and use in applications such as electronic transactions and communication, Euclidean algorithm, congruences, Chinese Remainder Theorem, the RSA cryptosystem. Travelling Salesman Problem – finding optimal routes: basic concepts in graph theory and linear programming, simplex algorithm, relationship to applications, e.g., wiring a chip, scheduling airline crews. P vs NP – understanding computational complexity: complexity classes, NP-complete problems and links with other applications such as the RSA cryptosystem and the Travelling Salesman Problem. Google – search for information on the Web: basic concepts in graph theory, probability and linear algebra, especially eigenvalues, underlying the Google search engine.

MAS802 Tackling the odds: Inside Statistics
AUs: 3, Prerequisites: GCE 'AO' level Mathematics or equivalent, Semester 2
This course provides an overview of statistics,its applications in other disciplines, and, in particular, an understanding of statistics methodology and the necessary skills to evaluate statistical studies..
Topics include an overview of statistics; measurement; visual displays; data descriptions; probability and risk; correlation and causality; statistical methodologies; and statistical modeling

MAS911 Advanced Investigations in Calculus I
AUs: 1, Approval by the Head of Division , may only be taken concurrently with MAS112, Semester 1
This course supplements MAS112, presenting challenging calculus problems to nurture the potential of students who wish to be stretched.

MAS912 Advanced Investigations in Calculus II
AUs: 1, Approval by Division of Mathematical Sciences, may only be read concurrently with MAS113, Semester 2
This course supplements MAS113, presenting challenging calculus problems to nurture the potential of students who wish to be stretched.

MAS913 Advanced Investigations in Linear Algebra I
AUs: 1, Approval by Division of Mathematical Sciences, may only be read concurrently with MAS114, Semester 2
This course supplements MAS114, presenting challenging problems in linear algebra to nurture the potential of students who wish to be stretched.

MAS921 Advanced Investigations in Calculus III
AUs: 1, Approval by the Head of Division, may only be taken concurrently with MAS211, Semester 1
This course supplements MAS211, presenting challenging calculus problems to nurture the potential of students who wish to be stretched.

MAS922 Advanced Investigations in Linear Algebra II
AUs: 1, Approval by the Head of Division, may only be taken concurrently with MAS213, Semester 1
This course supplements MAS213, presenting challenging problems in linear algebra to nurture the potential of students who wish to be stretched.

MAS923 Advanced Investigations in Discrete Mathematics and Number Theory
AUs: 1, Approval by Division of Mathematical Sciences, may only be read concurrently with MAS214, Semester 2
This course supplements MAS214, presenting challenging problems in elementary discrete mathematics and number theory to nurture the potential of students who wish to be stretched.

MAS931 Advanced Investigations in Real Analysis
AUs: 1, Approval by the Division of Mathematical Sciences, may only be read concurrently with MAS311, Semester 2
This course supplements MAS311, presenting challenging calculus problems to nurture the potential of students who wish to be stretched.

MAS932 Advanced Investigations in Abstract Algebra I
AUs: 1, Approval by the Division of Mathematical Sciences, may only be read concurrently with MAS313, Semester 2
This course, where students are given challenging problems in calculus to solve, serves as a supplement to MAS313 for the students who want to be challenged. The objective is to provide enrichment challenges to nurture the potential of these students.
This course supplements MAS313, presenting challenging calculus problems to nurture the potential of students who wish to be stretched.

MAS933 Advanced Investigations in Number Theory
AUs: 1, Approval by the Division of Mathematical Sciences, may only be read concurrently with MAS323, Semester 1
This course, where students are given challenging problems in calculus to solve, serves as a supplement to MAS323 for the students who want to be challenged. The objective is to provide enrichment challenges to nurture the potential of these students.
This course supplements MAS323, presenting challenging calculus problems to nurture the potential of students who wish to be stretched.

MAS941 Mathematical Problem-Solving
AUs: 2, Approval by the Division of Mathematical Sciences, may be required to sit for a qualifying test, Semester 2
Rather than studying theory or specialized techniques for solving specific mathematical problems, this seminar-style course leads students to think creatively, acquire exposition skills and develop their problem-solving skills through the solution of challenging mathematical problems from calculus, linear algebra, algebra, differential equations, probability and discrete mathematics.

MATH1A Calculus of One Variable
AUs: 4, Prerequisites: GCE ‘A’ level Mathematics or equivalent, Semester 1
This is an intensive introduction to calculus of one variable and (plane) analytic geometry for Science and Engineering scholars.

- Limits. Continutity of real valued functions, intermediate Value Theorem. Differentiability of functions from R to R, chain rule, critical points, Rolle’s Theorem and Mean Value Theorem. Inverse functions and derivatives of inverse functions. Integrability and integrals. Fundamental theorems of Calculus. Trigonometric, logarithm and exponential functions. Techniques of integration. Taylor’s formula. Infinite sequences. Infinite series. Power series and radius of convergence.

MATH1B Calculus of several variables
AUs: 4, Prerequisites: MATH1A, Semester 2
This is an intensive introduction to the calculus of several variables and first basics of PDEs for Science and Engineering scholars.

- Parametric equations and polar coordinates. Vectors in R2 and R3. Vector functions. Partial derivatives, limits and continuity, chain rule, directional derivatives, gradients, Lagrange multipliers. Double integrals, areas of a surface, triple integrals. Vector calculus, line integrals, Green’s Theorem, surface integrals, Gauss’s divergence theorem, Stokes’s Theorem. Partial differential equations (PDEs). Laplace’s equation in R2 and R3. Green’s (second) Theorem. Bounded regions and Dirichlet boundary condition, uniqueness and maximum principle.

MATH1C Linear Algebra and Differential Equations
AUs: 4, Prerequisite: GCE ‘A’ level Mathematics or equivalent, Semester 1
This is an intensive introduction to basics of sets, linear algebra and ODEs for Science and Engineering scholars.

- Sets, operations on sets, properties of sets. Systems of linear equations, Gaussian elimination. Matrices, inverses, determinants. Vector spaces, subspaces, linear independence, basis, dimension, row and column spaces, rank. Linear transformations, kernels and images. Eigenvectors and eigenvalues. First-order ordinary differential equations (ODEs). Second-order ODEs, oscillation and damping, series solutions of ODEs.

MAS710 Continuous Methods
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 2
This course covers abstract integration (basic topology, general Lebesgue-like integrals and measures), positive Borel measures (Riesz representation theorem for positive linear functionals), Lpspaces, integration on product spaces, abstract differentiation and holomorphic functions.

MAS 711 Discrete Methods
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 2
This course covers enumeration, graph and network algorithms, finite fields and applications, Boolean algebras, polyhedra and linear programming and algorithmic complexity.

MAS712 Algebraic Methods
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Groups, rings, fields, modules, basic techniques of Group Theory and Galois Theory are covered under this course.

MAS 713 Mathematical Statistics
AUs: 4, Approval by the Division of Mathematical Sciences , Semester 1
This course reviews probability, random variables and their distributions, moments and inequalities; point estimation in parametric setting; point estimation in nonparametric setting; interval estimation and hypothesis test.

MAS720 Topics in Discrete Mathematics I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
This course provides the necessary background knowledge e.g., topics from Combinatorics, Coding Theory, Cryptography, network algorithms and Bioinformatics to conduct independent research in Discrete Mathematics.,

MAS721 Topics in Scientific Computation I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
This course provides the necessary background knowledge e.g., topics from Functional Analysis, Partial Differential Equations, Computational Fluid Dynamics and Computational Biology to conduct independent research in Scientific Computation.

MAS722 Topics in Pure Mathematics I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
This course provides the necessary background knowledge e.g., topics from Commutative Algebra, Topology, Differential Geometry, Mathematical Logic and Functional Analysis to conduct independent research in Pure Mathematics.

MAS 723 Topics in Probability and Statistics I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
This course provides the necessary background knowledge e.g., topics from Survival Analysis Theory and Method, Computational Statistics, Time Series Analysis and Statistical Learning to conduct independent research in Probability and Statistics.

MAS 725 Topics in Discrete Mathematics II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics in Discrete Mathematics will be covered to provide background knowledge necessary to conduct independent research in the area, e.g. topics from Combinatorics, Coding Theory, Cryptography, Network Algorithms, Bioinformatics.
This course provides the necessary background knowledge e.g., topics from Combinatorics, Coding Theory, Cryptography, Network Algorithms and Bioinformatics to conduct independent research in Discrete Mathematics.

MAS 726 Topics in Scientific Computation II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics in Scientific Computation will be covered to provide background knowledge necessary to conduct independent research in the area, e.g. topics from Functional Analysis, Partial Differential Equations, Computational Fluid Dynamics, Computational Biology.

This course provides the necessary background knowledge e.g., topics from Functional Analysis, Partial Differential Equations, Computational Fluid Dynamics and Computational Biology to conduct independent research in Scientific Computation.

MAS 727 Topics in Pure Mathematics II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
This course provides the necessary background knowledge e.g., topics from Commutative Algebra, Topology, Differential Geometry, Mathematical Logic and Functional Analysis to conduct independent research in Pure Mathematics.

MAS 728 Topics in Probability and Statistics II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics in Statistics will be covered to provide background knowledge necessary to conduct independent research in the area, e.g. topics from Survival Analysis Theory and Method, Computational Statistics, Time Series Analysis, Statistical Learning etc.
This course provides the necessary background knowledge e.g., topics from Survival Analysis Theory and Method, Computational Statistics, Time Series Analysis and Statistical Learning to conduct independent research in Probability and Statistics.

MAS730 Special Topics – Image Analysis
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
- Differential Geometry of Curves and Surfaces
- Calculus of Variations
- Level Sets and Curve Evolutions
- Edge Preserving Smoothing of Curves and Surfaces
- Edge and Corner Detection
- Edge Integration and Segmentation
- Planar Shape Description and Analysis
- Invariant Recognition of Planar Shapes
- Shape from Shading and Photometric Stereo
- Depth from Stereo and Epipolar Geometry
- Optic Flow and Shape from Motion
- Grid Geometry and Numerics
- Fun Topics: Autostereograms, Space Fiducials, Visual Navigation

MAS790 Graduate Seminar – Discrete Mathematics I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics will be chosen to cover new developments in research in Discrete Mathematics, according to the interests of students.

MAS791 Graduate Seminar – Discrete Mathematics II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 2
Topics will be chosen to cover new developments in research in Discrete Mathematics, according to the interests of students.

MAS792 Graduate Seminar – Scientific Computation I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics will be chosen to cover new developments in research in Scientific Computation, according to the interests of students.

MAS793 Graduate Seminar – Scientific Computation II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 2
Topics will be chosen to cover new developments in research in Scientific Computation, according to the interests of students.

MAS794 Graduate Seminar – Pure Mathematics I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics will be chosen to cover new developments in research in Pure Mathematics, according to the interests of students.

MAS795 Graduate Seminar – Pure Mathematics II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 2
Topics will be chosen to cover new developments in research in Pure Mathematics, according to the interests of students.

MAS 796 Graduate Seminar – Statistics I
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 1
Topics will be chosen to cover new developments in research in Statistics, according to the interests of students.

MAS 797 Graduate Seminar – Statistics II
AUs: 4, Approval by the Division of Mathematical Sciences, Semester 2
Topics will be chosen to cover new developments in research in Statistics, according to the interests of students.

Note: The above courses are subject to revision. Please check http://www.spms.ntu.edu.sg regularly for the latest updates.

Division of Physics and Applied Physics

PAP111 Mechanics and Relativity
AUs: 3, Prerequisites: Physics and Mathematics at A or H2 level, or equivalent. Not available to students who have taken/are taking PAP181, Semester 1
This course introduces fundamental concepts of mechanics and relativity. Static mechanics - force and equilibrium, pressure, moments, work and potential Linear motions
- Newton's first and second laws, kinetic energy, linear momentum, frames of reference, rockets, collision Special relativity - Michelson-Morley experiment, Einstein's postulates, Lorentz transformation, time and causality, world-lines and space-time, Doppler effect, momentum and energy Force fields - gravity, concept of field, conservative fields, Gauss' law, superposition Rotational motion - centrifugal and Coriolis forces, angular speed and momentum, moment of inertia, parallel and perpendicular axes theorems, kinetic energy, gyroscope, orbits and Kepler's law

PAP112 Fields and Oscillations
AUs: 4, Prerequisites: Physics and Mathematics at A or H2 level, or equivalent. Not available to students who have taken/are taking PAP182, Semester 2
This course introduces basic notions of fields and oscillatory behaviour. Simple harmonic motion - time-dependence, angular frequency and phase, mass on a spring, relative phases, coupled oscillations and normal modes, phasor diagrams, representations in complex plane, damped oscillations and energy decay Electromagnetic field - Coulamb's law, electric field and potential, Gauss' law and capacitance, moving charges, magnetic flux density and Ampere's law, flux in circuits, Faraday's law and magnetostatic energy, JJ Thompson's experiment Electrical circuits - voltage, current and resistance, Kirchoff's laws, exponential decay in circuits Oscillations in circuits - LC circuits and relative phases, complex current and voltage, complex impedance, electrical resonance, filter and bandwidth, mechanical impedance.

PAP113 Optics and Waves
AUs: 4, Prerequisites: Physics and Mathematics at A or H2 level, or equivalent. Semester 2
This course studies the behaviour and properties of optical and particle waves. Waves, interference and optics - waves on a string, 1-D wave equation and solution; 3-D running waves and wave-vector; superposition; electromagnetic waves; phase and group velocity, boundary conditions, reflection and transmission coefficients, refractive index, Brewster angle, wave attenuation; Huygen's principle, Young's slit and diffraction grating; reflection and refraction; lens formulae; real and virtual images; telescope Wave-particle duality-photoelectric effect; photons, energy and momentum; Compton scattering; de Broglie waves; Davisson-Germer experiment; electron microscope, Schrodinger's equation.

PAP118 Physics Laboratory Ia
AUs: 2, Prerequisites: Physics at A or H2 level or equivalent. Semester 1
This course will train students in basic experimental physics that include topics in mechanics, basic optics and thermal physics. The laboratory sessions are designed to provide an active learning experience where key concepts can be better appreciated. Students will also learn about data acquisition, error analysis, error distribution and fitting procedures.

PAP119 Physics Laboratory Ib
AUs: 2, Prerequisites: Physics at A or H2 level or equivalent. Semester 2
This course will train students in basic experimental physics that include topics in electricity and magnetism, circuits, optics and wave phenomena. The laboratory sessions are designed to provide an active learning experience where key concepts can be better appreciated.

PAP181 Fundamentals of Physics 1
AUs: 3, Prerequisites: Mathematics at A or H2 level, or equivalent. Not available to students who have taken/are taking PAP111 and PAP113, Semester 1
Fundamentals of physics covering (a) mechanics, (b) wave motion, and (c) thermodynamics, with examples of practical applications to biomedical sciences, engineering sciences and other fields. Students learn about the principles of the physical world from which scientific and engineering applications are built upon. At a general level, students learn how to read scientific material effectively, identify fundamental concepts, reason through scientific questions, and solve quantitative problems.

PAP182 Fundamentals of Physics 2
AUs: 3, Prerequisites: PAP181. Not available to students who have taken/are taking PAP112 and PAP113, Semester 2
Fundamentals of physics covering (a) electricity and magnetism, (b) optics, and (c) modern physics, with examples of practical applications to biomedical sciences, engineering sciences and other fields. Students learn about the principles of the physical world from which scientifi c and engineering applications are built upon. At a general level, students learn how to read scientific material effectively, identify fundamental concepts, reason through scientific questions, and solve quantitative problems.

PAP211 Quantum Mechanics I
AUs: 4, Prerequisites: PAP113, Semester 1
This course introduces the basic ideas of quantisation in the physical world. Planck formula - black-body radiation and thermal equilibrium; ultraviolet catastrophe; quantisation and Planck spectrum; Stefan-Boltzmann law. Bohr atom - Balmer formula; postulates of Bohr's model in hydrogen atom; quantisation of angular momentum; quantum jumps; limitations of Bohr's model. Schrodinger wave equation - double slit experiment and Heisenberg's uncertainty; Schrodinger equation; stationary states; interpretation of wave function; solution for particle in 1-D infinite square well and general features of solutions; correspondence principle. Solutions to Schrodinger's equation - qualitative solutions; finite depth potential well; quantum mechanical tunnelling; radioactive a-decay; ammonia molecule; tunnel diode; scanning tunnelling microscope; angular momentum and rotational spectra of diatomic molecules; quantum harmonic oscillator and vibration of diatomic molecules.

PAP212 Electromagnetism
AUs: 4, Prerequisites: PAP112, MAS182, Semester 2
This course introduces key concepts in electromagnetism. Electric dipole moment, polarisation and displacement, multipole expansion. Laplace's and Poisson's equations; uniqueness theorem; method of images, electrostatic energy. Magnetic dipole moment, magnetic field and flux, magneticscalar and vector potentials; magnetisation and magneticmedia, permeability and susceptibility; properties of B and H; boundary conditions. Equation of continuity, Maxwell equations and relativistic invariance; Electromagnetic wave equation, electromagnetic spectrum, magnetic and electric energy densities, Poynting flux, momentum flux, radiation pressure, polarisation.

PAP213 Thermal Physics
AUs: 4, Prerequisites: PAP111, Semester 1
This course introduces the laws and key concepts of thermodynamics. Thermodynamic equilibrium, functions of state, equations of state. Zeroth law. Perfect gases and absolute zero. First law of thermodynamics. Work, heat and internal energy. Adiabatic, reversible and irreversible changes. Heat engines, efficiency and Carnot cycles. Clausius' theorem and Second law of thermodynamics. Fundamental equation of thermodynamics. Phase changes and latent heat. Enthalpy, Helmholtz free energy and Gibb's energy. Maxwell relations. Reciprocity theorem. Third law of thermodynamics. Kinetic theory - Maxwell distribution of velocities; pressure and effusion; mean free path; thermal conductivity and viscosity. Heat transport - conduction, radiation and convection as transport mechanisms; heat flux and heat diffusion equation; steady-state and initial-value problems; sinusoidally varying surface temperatures.

PAP218 Physics Lab IIa
AUs: 2, Prerequisites: PAP118, Semester 1
This course trains students in experimental physics and covers a wide variety of topics including quantum physics, physical optics and lasers, and electronics.

PAP219 Physics Lab IIb
AUs: 2, Prerequisites: PAP119, Semester 2
This course trains students in experimental physics and covers a wide variety of topics including electromagnetism, thermal physics, and solid state and materials physics.

PAP221 Classical Mechanics
AUs: 3, Prerequisites: PAP111 and MAS183, Semester 1
This course discusses the key ideas and principles in classical mechanics. Rigid body rotation: inertia tensor, principal axes of inertia, precession. Lagrangian mechanics: calculus of variations, action integral, Hamilton's principle of least action, generalised coordinates, momenta and forces, Hamilton's equations, canonical transformations, Liouville's theorem. Symmetries and conservation laws. Examples of applications: simple harmonic oscillator; planetary motion; charged particle in electromagnetic field; Lagrangian derivation of the fluid equations of motion.

PAP231 Physical Optics
AUs: 3, Prerequisites: PAP113, Semester 2
This course establishes the basic principles of physical optics which form the foundation for many modern sciences and technologies. Wave properties, refraction and dispersion, interference, Michelson interferometer, Fraunhofer and Fresnel diffraction, resolution limit, Fourier transformation, holography; polarisation, birefringence and wave plates, Fabry-Perot etalons, optical coatings, and zone plates.

PAP232 Introduction to Solids
AUs: 3, Prerequisites: PAP113, Semester 1
This course introduces the structure of solids and the quantisation of atomic and electronic motion in a periodic solid. Crystal symmetry - lattice, basis, unit cell, Miller indices, lattice planes and spacing; reciprocal lattice and Brillouin zones. Bragg and Laue diffraction, structure factor, atomic form factor; neutron and X-ray diffraction; powder and single crystal diffraction. Nomral mode dispersion for linear atomic chains; acoustic and optic modes; Born von Karman boundary conditions; density of states; lattice quantisation and phonons; Einstein and Debye models of heat capacity. Free electron theory, density of states, Fermi energy, Fermi surface.

PAP261 Introduction to Lasers
AUs: 3, Prerequisites: PAP113, Semester 2
This course serves as an introduction to lasers and their working principles. Quantum transitions in atoms, stimulated emission and amplification, rate equations, saturation, feedback, coherent optical oscillation, laser resonators, and various types of lasers.

PAP311 Quantum Mechanics II
AUs: 4, Prerequisites: PAP211, MAS281, Semester 2
This course introduces the framework and basic tenets of quantum mechanics.

- Wave mechanics - probability interpretation of interference; wave-functions, wave packets and momentum representation
- Schrodinger equation - operators; eigenfunctions and eigenvalues; solutions for free particle and barrier
- Bound states - zero-point energy; orthogonality and normalisation; expansion in basis states; expectation values; harmonic oscillator; 3D box and separation of variables
- Operator methods - Dirac notation; postulates of quantum mechanics; observables and operators; probability of measurement outcomes; orthogonality and completeness; degeneracy; discrete and continuous spectra; operator commutations and observables; generalised uncertainty relations; ladder operators; time-dependence; Ehrenfest's theorem; time evolution operator
- Angular momentum - operators, eigenvalues and eigenstates; parity, rotational invariance and conservation; hydrogen atom; quantum numbers
- Spin and identical particles - Stern-Gerlach experiment; symmetry and multiparticle states; fermions and bosons; exchange operator; Pauli exclusion; helium atom

PAP319 Physics Lab IIIa

AUs: 4, Prerequisites: PAP218, Semester 2

This course provides advanced training in experimental physics covering a wide variety of topics: quantum physics, electrodynamics, atomic physics and spectroscopy, solid state physics, fluid mechanics, semiconductor physics, photonics, biophysics and thin fi lm growth.

PAP321 Statistical Mechanics

AUs: 4, Prerequisites: PAP213, Semester 2

This course introduces the postulates and key ideas in statistical mechanics, with applications to classical and quantal gases.

- Basic postulates, macrostates and microstates, distinguishable and indistinguishable particles, distribution functions
- Temperature, entropy and the probability of system configuration occurring, Boltzmann relation, canonical ensemble and partition function
- Gibb's entropy; Third law of thermodynamics; information theory; irreversible processes and arrow of time
- Density of states; heat capacity in black body radiation
- Ideal classical gas, Maxwell-Boltzmann distribution, rotational and vibrational heat
- Free electron gas, Fermi energy and distribution function, Pauli paramagnetism
- Electronic contribution to heat capacity
- Phonons as normal modes, contribution to heat capacity, Debye approximation; phonon gas, thermal conductivity of insulators
- Mean description of phase transitions - Weiss model of ferromagnetism, order-disorder transition

PAP339 Physics Laboratory IIIb

AUs: 2, Prerequisites: PAP219, Semester 2

This course provides advanced training in experimental physics and covers a wide variety of topics: quantum physics, electrodynamics, atomic physics and spectroscopy, solid state physics, fluid mechanics, semiconductor physics, photonics, biophysics and thin film growth.

PAP341 Atomic Physics

AUs: 4, Prerequisites: PAP211, Semester 2

This course discusses the origins of atomic spectra and shows the application of quantum mechanics in describing the interaction between electron and nuclei in atoms.

- * Hydrogen atom - central potential approximation, radial wavefunction, quantum numbers, energy levels and degeneracy; electron spin and total angular momentum; spin-orbit coupling and fine structure; Zeeman splitting
- Helium atom - Coulomb repulsion and exchange; singlet-triplet splitting
- Electronic configuration and periodic table; alkali metals; residual electrostatic interaction; LS-coupling scheme; Hund's rules; hyperfine structure and isotope shift
- Selection rules for electric dipole interaction
- Zeeman and Stark effects
- Inner shell transitions and x-ray spectra
- Doppler broadening in laser spectroscopy

PAP342 Solid State Physics I

AUs: 4, Prerequisites: PAP211 and PAP232, Semester 2

This course discusses the electronic and magnetic properties of solids.

- Metals - conductivity and heat capacity; density of states at Fermi level; nearly free electron model and band gaps
- Distinction between metals, semiconductors, and insulators
- Semiconductors - direct and indirect band gap (Si, Ge, GeAS); optical absorption, effective mass and holes; carrier concentration, law of mass action; impurity donors and acceptors; mobility and Hall effect; band gap measurements
- Magnetic susceptibility, Larmor diamagnetism, paramagnetism, and Curie's law; Pauli paramagnetism; magnetic ordering (ferromagnetism and antiferromagnetism) and Weiss molecular field theory; Curie-Weiss susceptibility

PAP351 Electrodynamics
AUs: 4, Prerequisites: PAP212, Semester 2
This course introduces electrodynamics at a more advanced level.

- Four vectors, Lorentz transformations for electromagnetic fields, magnetic field required by relativity, magnetic vector potential, magnetic four-vector potential, Maxwell's equations in four-vector form
- Li¨|nard-Wiechert potentials, radiation by an accelerated charge, Bremsstrahlung, dipole radiation, antennas, Rayleigh scattering, Thomson scattering

PAP352 Chaotic Dynamical Systems
AUs: 4, Prerequisites: PAP221, Semester 2
This course introduces the ideas of determinism and randomness in the physical world.

- Introduction to phase plane, critical points and characterisation (hyperbolic/elliptic) - free and damped oscillators, prey-predator models
- Simple extensions to three-dimensional phase space and beyond, e.g. rotation of rigid bodis, the Lorenz system
- Integrable and non-integrable systems, Poincar¨
- return maps
- Discrete dynamics - 1D and 2D maps; fixed points and stability; period doubling - shift map, logistic map
- Breakdown of order and chaos; sensitivity to initial conditions ("butterfly effect") and Lyapunov exponents; limit to predictability; strange attractors and fractal dimension -Kepler problem, H¨•non-Heiles system
- Stable and unstable manifolds, homoclinic and heteroclinic tangle, lobes and turnstile transport, particle motion in 2D incompressible fluid

PAP353 Fluid Mechanics
AUs: 4, Prerequisites: PAP212 and PAP221, Semester 2
This course introduces the laws governing fl uid motion.

- Paschal's theorem, Bernoulli equation, Euler's equation, Navier-Stokes equation, vorticity and divergence
- Compressible and incompressible fluids, flow around objects, potential flow; viscosity, Reynolds number; laminar flow and turbulence; Kolmogorov scaling
- Sound waves, shock fronts, Rankine-Hugoniot relations
- Hydrostatic balance, shallow-water equations, surface waves; conservation of potential vorticity

PAP361 Semiconductor Processing
AUs: 3, Prerequisites: PAP232 or PAP233, Semester 1
This course discusses the basic principles underlying the fabrication of semiconductor devices and material processing techniques in semiconductor industry.

- Si based device fabrication - ion implantation, diffusion, oxidation, epitaxy, thin film deposition, material and device characterisation, lithography, etching and cleaning
- Processing and characterisation of photonic and nano-structured devices

PAP362 Photonics
AUs: 4, Prerequisites: PAP211, PAP231, Semester 1
This course introduces key concepts in optical, optoelectronics and optical communication technologies. Waveguides optics, fiber optics, crystal optics, interaction between photons and semiconductors, semiconductor light sources and detectors, liquid crystal optics, and flat panel displays

PAP363 Biophysics
AUs: 3, Prerequisites: PAP232, Semester 2
This course serves as an introduction to "How physics approaches living matter". Biophysics is an extremely rich but little structured field. This makes it impossible to introduce Biophysics as an entity. We therefore aim for a limited set of areas where physical concepts and instruments have been successfully employed to biology. During the course the student will become acquainted with experimental techniques to study biological processes and physical models to describe the dynamics at the relevant biological scales of mass, time, and velocity.

PAP441 Quantum Mechanics III
AUs: 4, Prerequisites: PAP311, Semester 1
This course discusses quantum interactions between matter and electromagnetic fields.
Time-independent perturbation theory - non-degenerate and degenerate. Variational method, ground state energy and eigenfunction. Born-Oppenheimer approximation.
Hamiltonian in an electromagnetic field, vector potential, phase and Aharanov-Bohm effect. Dirac equation, spin, gyromagnetic ratio and antiparticles. Zeeman and Landau levels.
Transitions - two-state system, Rabi oscillations, Larmor precession, magnetic resonance; time-dependent perturbation theory, Fermi's golden rule, scattering and Born approximation; radiative transition transitions; electric dipole approximation, quantised electromagnetic field.

Quantum information - quantum cryptography, entanglement and teleportation; quantum computing.

PAP442 Solid State Physics II
AUs: 4, Prerequisites: PAP342, Semester 1
This course introduces advanced concepts in solid state physics with particular attention to theoretical approaches.

- Theories and models; approaches to many-body problem; collective phenomena
- Structure and bonding - order and disordered; types of bonding and structure; electrons in periodic potential, Bloch theorem; tight-binding; 1D chain and polymer; band structure of real materials; optical transition and photoemission
- Interactions - effective medium approximation for electron-electron interaction; Hartree-Fock theory; exchange and correlation energy; electron fluid and screening; exclusion principle and quasiparticles
- Transport and scattering - crystal momentum; neutron scattering; electron-phonon scattering; optical conductivity; Drude theory, plasmons; transport in electric and magnetic fields; quantisation of orbits, cyclotron resonance; de Haas-van Alphen effect; Fermi surfaces; magnetoresistance oscillation; quantum Hall effect
- Semiconductors - thermal equilibrium of quasiparticles; field effect transistor; pn junctions, LED; exciton, heterostrutures, quantum well, semiconductor laser
- Magnetism - origin moments and interactions, ferromagnetism; itinerant magnetism, Stoner model; strongly interacting systems, Mott insulator

PAP443 Surfaces and Interfaces
AUs: 3, Prerequisites: PAP342, Semester 1
This course discusses the key concepts in surface and interface science with a special focus on electronic structure.Surface energy and thermodynamics; electronic structure; phase transition; elementary excitations; physisorption and chemisorption; energy transfer.Schottky barrier and band offsets in semiconductors; band engineering.Analytical techniques include scanning tunneling microscopy; electron diffraction methods; photoemission, ballistic electron emission microscopy

PAP444 Nanoscale Physics
AUs: 3, Prerequisites: PAP311, Semester 1
This course introduces the physical and transport properties in nanoscale systems.
Electron gas in 2D and multilayer systems.
Quantum transport in 1D; magnetotunneling; quantum capacitance and conductance.
Quantum dots and artificial atoms; eigenenergies and eigenstates; single particle conductance; Coulomb blockade; Kondo effect; Aharanov-Bohm effect.
Quantum computation – electrons and quasi-electrons as qubits; state preparation, manipulation, entanglement and measurement; Rabi oscillations and single-spin detection.
Some methods for quantum dot and nanostructure growth will be discussed.

PAP452 Atmospheric Physics
AUs: 4, Prerequisites: PAP 213 and PAP 353, Semester 2
This course introduces the atmosphere as a fluid system and discusses the physics that underlie weather and climate.
Basic properties of the atmosphere; temperature structure, potential temperature and entropy. Hydrostatic balance and geopotential. Pressure coordinates. Radiative balance of the Earth; radiative transfer; ozone-layer; greenhouse effect. Fluid dynamics on a rotating planet; geostrophic flow; cyclones & anticyclones; thermal-wind balance. Conservation of angular momentum, Hadley circulation. Global wind circulation. Static stability and Brunt-Vassala frequency; gravity waves; Rossby waves. Thermal convection; adiabatic

lapse rate; moist adiabat; radiative-convective equilibrium. Antarctic ozone hole; global warming and climate change.

PAP453 Quantum Theory
AUs: 4, Prerequisites: MAS 281, PAP 311, Semester 1
This course introduces the mathematical foundation of quantum mechanics and discusses the philosophical implications.
Vector spaces and basis vectors. Scalar products and norms. Hilbert spaces, Dirac notation. Linear operators, adjoint and Hermitian operators, projection operators. Eigenvectors, eigenvalues and the spectral theorem. Functions of an operator. General formalism of quantum theory. Density matrices and mixed states. Contrast with the state space of classical physics.
Compatible and incompatible quantities. Symmetries and conserved quantities. Unitary operators. Stones's theorem; Wigner's theorem. Canonical commutation relations. Uncertainty relations; the Schwarz lemma. Conceptual issues in quantum theory: probability, quantum entanglement, measurement. Schrodinger's cat. Kochen-Specher theorem. Quantum logic. Bell inequalities.

PAP451 Statistical Mechanics II
AUs: 3, Prerequisites: PAP321, Semester 1
This course introduces the theoretical framework of statistical mechanics and applications to novel physical systems. Principle of equal equilibrium probability; Boltzmann and Gibbs entropy; configurational entropy and defects. Microcanonical, canonical and grand canonical ensembles; harmonic oscillator and paramagnetic salt; negative temperature. Fluctuations in energy, particle number and volume; critical opalescence. Classical and quantum systems - indistinguishability; equipartition theorem; grand partition function, Fermi-Dirac and Bose-Einstein statistics; quantum to classical crossover; chemical equilibrium and Langmuir isotherm. Ideal Bose gas and Bose-Einstein condensation; quantum liquids; black-body radiation; phonons and Debye model; ideal fermi gas; normal modes and elementary excitations. Classical liquids - radial distribution function, internal energy and equation of state; virial expansion.

PAP454 Nuclear Physics
AUs: 3, Prerequisites: PAP311, Semester 1
This course provides a basic understanding of the structure of nuclei and their properties. Properties of nuclei: radii, masses, abundances, binding energies, spins and EM moments. Nuclear structure: deuteron, nucleon-nucleon scattering in terms of an exchange force. Nuclear models: the semi-empirical mass formula, the Fermi gas model, the shell model, liquid drop model with vibrational and rotational excitations, collective structure. Energy balances and spin/parity selection rules of alpha, beta and gamma decay processes. Measurement of nuclear lifetimes, applications of nuclear physics including fusion and fission processes Nucleosynthesis.

PAP455 Computational Physics
AUs: 3, Prerequisites: PAP311 and PAP342, Semester 1
This course introduces computational methods and tools to solving physical problems. Introduction to computational methods and tools. Programming Concepts. Errors and Uncertainties in Computations; Numerical solutions of differential equations in one variable. Approximation of functions. Variational Principle and Minimisation; spectral analysis, Monte Carlo simulations, Symbolic computing; High-performance computing. Applications to physical problems, molecular dynamics. Electronic structure of atoms, Hartree-Fock approximation and Density Functional Theory. Maxwell's Equations in Matter and ionised gases. Physics with MAPLE/MATLAB.

PAP462 Quantum Electronics
AUs: 4, Prerequisites: PAP311 and PAP362, Semester 1
This course aims to provide students with a solid foundation of photonics and optical technology. Gaussian beam optics, resonator optics, lasers, photon optics, statistical optics, semiclassical and quantum models on interaction between photons and atoms, electro-optics, nonlinear optics, and acousto-optics, generation of short and ultrafast laser pulses.

PAP802 Physics of Sports
AUs: 3, Prerequisites: Physics at GCE 'O' level, Semester 2
This course introduces the physical principles that govern human locomotion and sporting incidents.

- Human locomotion ¨C running, jumping, swimming. Biomechanics of skating ¨C jumping (projectile motion) and rotating (angular momentum), rink conditions and boot
- Soccer ¨C kicking, fl ight (air flow and resistance, Magnus effect)
- Baseball ¨C throwing (spin, curve and air flow), hitting (sweet spots)

- Miscellaneous ¨C golf and golf balls, sky diving

PAP929 Undergraduate Research Project I
AUs: 3, Prerequisites: Division approval, Special Terms 1 and 2
This course introduces research work in physics that is suitable for second-year undergraduate students. The content will be determined by project supervisors.

PAP939 Undergraduate Research Project II
AUs: 3, Prerequisites: Division approval, Special Terms 1 and 2
This course introduces research work in physics that is suitable for third year undergraduate students. The content will be determined by project supervisors.

PHYS1A Mechanics
AUs: 4, Prerequisites: Physics at A or H2 level or by approval, Semester 1
This course introduces fundamental concepts of Newtonian mechanics. Linear motion; vectors; trajectories; Newton's laws; forces; non-inertial frames; work and energy; energy conservation; momentum. Rotational motion: rigid rotations; angular momentum; gyroscopes. Harmonic motion. Resonance. Fluid mechanics. Gravity; Kepler's laws and orbits; law of ellipses.

PHYS1B Electromagnetism
AUs: 4, Prerequisites: Physics at A or H2 level or by approval, Semester 2
This course introduces the concepts of electricity and magnetism and couples electromagnetic theory with relativity. Principles of relativity; time dilation and length contraction; spacetime diagrams; Lorentz transformations; energy-momentum; force and mass; mass and energy. Electric fields; Gauss' law; electric potential; divergence and curl. Conductors; electric currents; conduction; dc circuits. Fields of moving charges; force on moving charges; general relativity. Magnetic field; vector potential; magnetostatics; fields in motion; Hall effect. Faraday's law; induction; ac circuits; complex impedance; applications of Faraday's law. Maxwell's equations; electromagnetic waves. Electric dipoles; dielectrics; electric fields in matter. Magnetic dipoles; magnetic materials; ferromagnetism; accelerating charges; superconductivity

PHYS1C Waves and Quantum Mechanics
AUs: 4, Prerequisites: Physics at A or H2 level or by approval, Semester 2
This course introduces the basic ideas of waves and quantisation in the physical world and provides the framework and basic tenets of quantum mechanics. Harmonic and coupled oscillators; normal modes. Wave equation; Fourier analysis; travelling waves; dispersion; impedance; reflection and transmission; diffraction and interference. De Broglie waves; Schrodinger equation; position and momentum; energy and time. Simple 1-D potentials; harmonic oscillator. Observables and operators; angular momentum. Hydrogen atom. Identical particles. Atoms.

PHYS1P Physics Laboratory 1
AUs: 3, Prerequisites: Physics at A or H2 level or by approval, Semester 1
Students will undertake basic experimental physics. The laboratory sessions are designed to provide an active learning experience where key concepts can be better appreciated. Students will also learn about data acquisition, error analysis, error distribution and fitting procedures. Experiments include topics in mechanics, basic optics, thermal physics, electricity and magnetism, circuits, optics, wave and quantum phenomena.

PHYS1Q Physics Laboratory II
AUs: 3, Prerequisites: Division approval, Semester 2
Students will undertake a project supervised by a faculty member of the Division. This module introduces research work in physics that is suitable for undergraduate students. The content will be determined by project supervisors.

PAP701 Graduate Seminar Module I
AUs: 4, Prerequisites: Division approval, Semester 1
Students will be trained in keeping updated with recent frontier research findings published in leading research journals, and in the ability to interact and communicate one-to-one or with a large group of people. In addition, they are expected to participate actively in discussions and address challenges/ questions with confidence. This module involves attending seminars organised by the Division and presented by experts in different fields. Students will also attend presentations by their peers. Students are required to give presentations as well as participate in discussions. They will also write critiques on the seminars they have attended.

PAP711 Graduate Solid State Physics
AUs: 4, Prerequisites: PAP442 Advanced Solid State Physics or Division approval, Semester 2
Crystal structure, reciprocal lattice, Brillouin zones; structure determination by diffraction methods; kinematic and dynamical scattering. Phonons - dispersion, anharmonicity, thermal properties, structural phase changes, soft modes. Electrons - periodic potential, band gaps, dispersion, effective mass, Fermi surfaces, semiconductors, transport properties in metals and semiconductors, Landau quantisation, low- dimensional structures. Optical properties - interband transitions, excitons, plasmons, infrared absorption/reflectivity, Raman scattering, nonlineareffects. Magnetism - crystal field theory, magnetic ordering and phase transition, low-dimensional magnetism, spin waves, magnetic resonance, critical phenomena, domains. Superconductivity, - conventional, organic, high Tc; thermodynamics, London and BCS theories, Josephson effects.

PAP712 Computer Simulations in Physical Sciences
AUs: 4, Prerequisites: PAP311 Quantum Mechanics and PAP321 Statistical Mechanics or Division approval, Semester 1
Basic Monte Carlo and molecular dynamics methods. Data and error analysis. Various advanced topics focusing on applications (First principle methods, advanced Monte Carlo and molecular dynamic topics, and modelling complex systems).

PAP713 Statistical Mechanic of Protein Folding
AUs: 4, Prerequisites: PAP 321 Statistical Mechanics or PAP 510 Concepts in Statistical mechanics, Semester 1
This module introduces an approach to protein folding from the point of view of kinetic theory. It includes standard topics such as thermodynamics, the Maxwell–Boltzmann distribution, and ensemble theory. Special discussions include the dynamics of phase transitions, and Brownian motion as an illustration of stochastic processes. Topics in molecular biology and protein structure, with a view to discovering mechanisms underlying protein folding are covered.

PAP714 Frontiers of Modern Physics
AUs: 4, Prerequisites: Division approval, Semester 1
This graduate module is designed as an introduction to the frontiers of modern physics, spanning from the nano to the cosmic. As physics has developed over many new fronts, and specialization sets in ever earlier in the life of a physicist, there is a need to develop the ability to look beyond the turf and appreciate the unity of physics. The course takes each topic and develops it using a basic knowledge of the physics principles involved.

PAP715 Materials Physics
AUs: 3, Prerequisites: PAP442 Solid State Physics II or Division approval, Semester 1
Students will learn the basic skills to establish the quantitative models based on modern thermodynamics; From the successful energy approaches, they will learn to understand many related experimental observations; They should also master the basic mathematical knowledge to solve the general nonlinear problems.

PAP719 Graduate Seminar Module II
AUs: 4, Prerequisites: Divisional approval, Semester 2
This course exposes students to recent frontier research findings published in leading research journals and enables them to study in depth some of this work while keeping abreast with current literature. Students will also be equipped with essential communication skills which enable them to express their idea clearly and to evaluate the research of other scientists critically. In addition, they are expected to be able to participate actively in discussions and address challenges with confidence. This module involves attending seminars organised by the Department and presented by experts in different fields. Students will also attend presentations by fellow graduate students. Students are required to give presentations as well as participate in discussions. They will also write critiques on the seminars they have attended. Towards the end of the module, a graduate student research congress will be organised for all graduate students to present their research work.

PAP721 Nonlinear Dynamics
AUs: 4, Prerequisites: PAP 352 Chaotic Dynamical Systems and PAP 441 Advanced Quantum Physics, or Division approval, Semester 2
This module provides students with the concepts and theories on nonlinear dynamical systems both in the classical and the quantum domains. Through this course, students will come to appreciate the beautiful

parallels between methods in nonlinear dynamics and thermodynamics; and gain a new perspective on quantum mechanics by studying quantum systems that correspond to classically chaotic systems.

PAP732 Nonlinear Optics
AUs: 4, Prerequisites: PAP362 Photonics and PAP462 Quantum Electronics, or Division approval, Semester 2
The course aims to provide a comprehensive understanding on the principles of nonlinear optics and is targeted at postgraduate students who have acquired a background in optics. The main content of the module introduces the principles of nonlinear optics and photonics devices used in modern optical communications, covered in four parts: Nonlinear optical susceptibility; Second-order nonlinear effects; Third-order nonlinear effects; Ultrafast laser optics.

PAP733 Elements of Modern Biophysics
AUs: 4, Prerequisites: PAP363 Biophysics or Division approval, Semester 1
Diffusion - random walk of colloids and biopolymers, diffusionin potential well, motor proteins, propulsion at low Reynoldsnumbers. Membranes - Langmuir monolayers, lipid bilayers, excitablemembranes, nerve signals. Fluorescence -fluorescence microscopy, Fluorescence Resonance Energy Transfer (FRET), labeling lipids andbiopolymers, applications to biomembranes. Optical particle tracking - basic theory, tracking colloids, fluorophores, motor proteins. Optical tweezers - basic theory, angular momentum, time-resolved and statistical methods, applications. Magnetic tweezers - basic theory, statistical methods, applications.

PAP739 Topics in Applied Physics
AUs: 4, Prerequisites: Divisional approval, Semester 2
This course introduces students to specialised topics in Applied Physics which are of current interest in research and development. Topics are chosen from various areas of Applied Physics including spectroscopy and modern devices. Students will be informed of the topic selected before the start of the semester.

Note: The above courses aresubject to revision. Please check http://www.spms.ntu.edu.sg regularly to read the latest updates.