COURSES IN PART IB OF THE MATHEMATICAL TRIPOS

This document contains a list of all the courses which are examinable in Part IB of the Mathematical Tripos together with an informal description of each course and suggestions for preliminary reading. A formal syllabus is given in the booklet Schedules for the Mathematical Tripos, which can be obtained from the Faculty Office, Centre for Mathematical Sciences, Wilberforce Road, Cambridge CB3 0WA (telephone: 01223 337968; e-mail: faculty@damtp.cam.ac.uk).

All the documentation (including Schedules for the Mathematical Tripos) is available on the WWW (http://www.maths.cam.ac.uk/).
Five changes have been implemented for 2004/05. They are as follows.

- There are two new courses,
  - Complex Analysis, which will be lectured in the Lent Term and examined in Part IB, May/June 2005. This will run in parallel to Complex Methods, and it is expected that students with mainly pure mathematical interests will take Complex Analysis and students with mainly applied mathematical interests will take Complex Methods. However, the courses are timetabled so that you could attend both courses. A total of four questions will be set in the examination on the two courses, two of which will be on material common to both courses.
  - The Geometry course has been replaced by a 16-lecture Geometry course given in the Lent term.
- Topological and Metric Spaces, which was lectured in the Easter term 2004, will be examined for the first time in Part IB, May/June 2005. This course contains material that is important for Complex Analysis.
- Further Analysis will no longer be lectured or examined, the material having been transferred to Complex Analysis and Metric and Topological Spaces.
- The schedules for Analysis II and Fluid Dynamics have been changed slightly. The main change to Analysis II is that some material that is useful for Complex Analysis has been transferred to Metric and Topological Spaces. The main changes to Fluid Dynamics are that Kelvin’s circulation theorem is starred and there is an additional topic on the lift on an an arbitrary 2D aerofoil.
- The allocation of quality marks in the examination has been altered. The new arrangement is that a beta will be available for each ‘short’ question (i.e. Section I question) and one quality mark — either an alpha or a beta — will be available for each ‘long’ question (i.e. each Section II) question.

Introduction

Contents

You will find here a list of all Part IB courses, together with non-technical summaries, a summary of the learning outcomes of the course and suggestions for vacation reading. The full learning outcome is that you should understand the material described in the formal syllabuses given in the Schedules of Lecture Courses for the Mathematical Tripos and be able to apply it to the sort of problems that can be found on previous Tripos papers.

Any mathematics that you manage to do over the summer vacation will be immensely helpful for next year. Although revision of the Part IA courses would be useful, it would probably be more helpful either to work on any of the Part IB courses which you attended this (your first) year or to do some preliminary reading for some of next year’s courses. Alternatively, you might like to read more general books on mathematics. The suggestions below are only intended to give an idea of the appropriate level and approach. They should all be in your college library. By browsing in the library, you will no doubt find other books which you find at least as useful as those listed here.

Choice of courses

You are not expected to take all the IB courses. You should choose the number of courses by comparison with Part IA, for which you were expected to attend two lectures per day for two terms (total 192 lectures). If you were comfortable with that, then this might be a realistic target for Part IB. However, many students prefer to take fewer courses and learn them more thoroughly; and some may wish to take more. The structure of the Part IB examination is such that you do not need to take as many lectures as this in order to obtain full marks.

You should consult your Director of Studies about your choice of courses, because it will have some impact on your choices in Part II.
Courses in Part IB

Analysis II

Michaelmas, 24 lectures

In the Analysis I course in Part IA, you encountered for the first time the rigorous mathematical study of the concepts of limit, continuity and derivative, applied to functions of a single real variable. This course extends that study in two different ways. First, it introduces the important notions of uniform convergence and uniform continuity, which help to explain various problematic aspects of limiting processes for functions of one variable. Then the fundamental ideas of analysis are extended from the real line $\mathbb{R}$, first to finite-dimensional Euclidean spaces $\mathbb{R}^n$ (thus providing the logical underpinnings for the results — such as symmetry of the mixed partial derivatives — which you met in Part IA Vector Calculus), and then to still more general ‘metric spaces’ whose ‘points’ may be things such as functions or sets. The advantages of this more general point of view are demonstrated using Banach’s Contraction Mapping Theorem, whose applications include a general existence theorem for solutions of differential equations.

If you wish to do some vacation reading, W.A. Sutherland’s *Introduction to Metric and Topological Spaces* (O.U.P., 1975) provides a good introduction to analysis on more general spaces. A.F. Beardon’s book *Limits* (Springer, 1997) provides a thought-provoking background to uniform convergence and continuity.

**Learning outcomes**

By the end of this course, you should:

- understand and be able to prove the basic results about convergence and the properties of continuous functions in $\mathbb{R}^n$;
- understand and be able to prove the basic results about differentiability of functions from $\mathbb{R}^n$ to $\mathbb{R}^m$ and be able to calculate derivatives in simple cases;
- understand the notion of uniform convergence of functions and appreciate its significance in the theory of integration;
- understand the basic theory of metric spaces, be able to prove the contraction mapping theorem and apply it to the solution of differential equations.

Metric and Topological Spaces

12 lectures, Easter term

This course may be taken in the Easter term of either the first year or the second year; however, if you are planning to take Complex Analysis (i.e. the course on complex variable theory which has a pure approach; Complex Methods covers roughly the same material with an applied approach), you will find the material in Metric and Topological Spaces very useful.

Continuity is one of the basic ideas developed in Analysis I, and this course shows the value of a very abstract formulation of that idea. It starts with the general notion of distance in the theory of metric spaces and uses that to motivate the definition of topological space. The key topological ideas of connectedness and compactness are introduced and their applications explained. In particular a fresh view emerges of the important result (from Analysis I) that a continuous function on a closed and bounded interval is bounded and attains its bounds.

By the end of this course you should:

**Learning outcomes**

By the end of this course, you should:

- appreciate the definitions of metric and topological space and be able to distinguish between standard topological and non-topological properties;
- understand the topological notion of connectedness and its relation to path-connectedness;
- understand the topological notion of compactness, know its significance in basic analysis and be able to apply it to identify standard quotients of topological spaces.
Methods
Michaelmas, 24 lectures

This course continues the development of mathematical methods which can be applied to physical systems. The material is fundamental to nearly all areas of applied mathematics and theoretical physics. The first section concentrates on Fourier series. The basic technique is used in solving partial differential equations such as the wave equation (governing vibrations of a violin string, for example), the Schrödinger equation (for a confined atomic particle) or the heat equation (for the temperature of a heated bar). The second section deals with linear ordinary differential equations. It introduces the famous Dirac δ, or spike, function and the Green’s function, which can be regarded as the inverse operator to a differential equation: it is used to express the solution in terms of an integral. Many courses later, it will reappear as a basic tool in quantum field theory. The third section tackles the Laplace equation, which is the basic equation of many physical theories including electrostatics. The fourth section is on extrema: of functions of many variables and also of integrals (a typical problem is to find the path of light in a medium with varying refractive index: the path will be the one which takes least time.) The last section introduces tensors, which are a generalisation of scalars and vectors. They carry information about physical systems which is independent of the axes used. Subjects such as General Relativity cannot be studied without the use of tensors.

It would be particularly worthwhile to get to grips with the major new ideas introduced here: Fourier series; Lagrange multipliers; the Euler-Lagrange equations; tensors. Reasonably friendly accounts can be found in Mathematical Methods in the Physical Sciences by Boas (Wiley, 1983); Mathematical Methods for Physicists by Arfken (Academic Press, 1985) and Mathematical Methods for Physicists and Engineers by Riley, Hobson and Bence (CUP, 98).

Learning outcomes
By the end of this course, you should:

- be able to solve wave problems using Fourier analysis and advanced/retarded coordinates;
- be able to apply the theory of Green’s functions to ordinary differential equations;
- understand the basic properties of Sturm-Liouville equations;
- be able to apply the method of separation of variables to partial differential equations;
- to be able to solve problems using the calculus of variations;
- understand the concept of, and be able to manipulate, cartesian tensors in \( \mathbb{R}^3 \).

Linear Algebra
Michaelmas, 24 lectures

The first year course Algebra and Geometry includes a concrete introduction to vector spaces. Here, vector spaces are investigated from an abstract axiomatic point of view. This has two purposes: firstly to provide an introduction to abstract algebra in an already familiar context and secondly to provide a foundation for the study of infinite dimensional vector spaces which are required for advanced courses in analysis and physics. One important application is to function spaces and differential and difference operators.

A striking result is the Cayley-Hamilton theorem which says (roughly) that any square matrix satisfies the same equation as its eigenvalues (the characteristic equation).

The spaces studied so far have nothing corresponding to length or angle. These are introduced by defining an inner product (i.e. a ‘dot’ product) on the vector space. This is generalised to the notion of a bilinear form (lengths do not have to be positive) and even further. There are direct applications to quantum mechanics and statistics.

The last part of the course covers the theory of bilinear and hermitian forms, and inner products on vector spaces. An important example is the quadratic form. The discussion of orthogonality of eigenvectors and properties of eigenvalues of Hermitian matrices has consequences in many areas of mathematics and physics, including quantum mechanics.

Learning outcomes
By the end of this course, you should:

- understand the concepts of, and be able to prove results in the theory of, real and complex vector spaces;
• understand the concepts of, and be able to prove results in the theory of, linear maps between and endomorphisms of real and complex vector spaces, including the role of eigenvectors and eigenvalues and Jordan canonical form;
• understand, and be able to prove and apply, the Cayley-Hamilton theorem;
• understand, and be able to prove results in the theory of, dual vector spaces.
• understand bilinear forms and their connection with the dual space, and be able to derive their basic properties;
• know the theory of canonical forms for symmetric, alternating and hermitian forms, and be able to find them in simple cases;
• understand the theory of hermitian endomorphisms of a complex inner product space, and know and be able to apply the Gram-Schmidt orthogonalisation process;

There are many suitable books on linear algebra: for example Finite-dimensional Vector Spaces by Halmos (Springer, 1974), Birkhoff and MacLane’s Algebra (Macmillan, 1979) and Strang’s Linear Algebra (Academic Press, 1980).

Fluid Dynamics

Fluid dynamics investigates the motion of liquids and gases, such as the motion that enables aircraft to stay up. Newton’s laws of motion apply – acceleration equals force per unit mass – but a subtlety arises because acceleration means the rate of change of velocity following a fluid particle. It does not mean the rate of change at a fixed point in space. A special mathematical operator, the convective derivative, expresses the required rate of change using vector calculus. The forces entering Newton’s laws can be external, such as gravity, or internal, arising from pressure or from viscosity (internal friction). This course neglects viscosity. Then the motion is often irrotational as well as incompressible; both the curl and divergence of velocity field vanish. Potential theory applies, and solutions of Laplace’s equation are relevant. The topics studied include jets, bubbles, waves, vortices, flow over weirs, and flow around aircraft wings. Suitable introductory reading material can found in Lighthill’s “An introduction to Theoretical Fluid Mechanics” (Oxford) or in Acheson’s “Elementary Fluid Dynamics” (Oxford). For background motivation, see also the visionary discussion in the Feynman Lectures on Physics, last two chapters of Volume II (Addison-Wesley).

Learning outcomes

By the end of this course, you should:
• understand the basic principles governing the dynamics of non-viscous fluids;
• be able to derive and deduce the consequences of the equation of conservation of mass;
• be able solve kinematic problems such as finding particle paths and streamlines;
• be able to apply Bernoulli’s theorem and the momentum integral to simple problems including river flows;
• understand the concept vorticity and the conditions in which it may be assumed to be zero;
• calculate velocity fields and forces on bodies for simple steady and unsteady flows derived from potentials;
• understand the theory of interfacial waves and be able to use it to investigate, for example, standing waves in a container.

Complex Methods

This material in this course is treated from a more sophisticated point of view, with more emphasis on rigorous proof, in the Complex Analysis course.

Complex variable theory was introduced briefly in Analysis I (for example, complex power series). Here, the subject is developed without the full machinery of a pure analysis course. Rigorous justification of the results used is given in the parallel course, Complex Analysis.
The course starts with a brief discussion of conformal mapping with applications to Laplace’s equation. Then a heuristic version of Cauchy’s theorem leads, via Cauchy’s integral formula, to the residue calculus. This is a technique for evaluating integrals in the complex plane, but it can also be used to calculate definite integrals on the real line. It allows the calculation of integrals which one would not have a hope of calculating by other means, as well as remarkably simple and elegant derivations of standard results such as \( \int_{-\infty}^{\infty} \exp(-x^2/2+ikx) \, dx = \sqrt{(2\pi)} \exp(-k^2/2) \) and \( \int_0^{\infty} (\sin x)/xdx = \pi/2. \)

An important application is to Fourier transform theory. This is the method of representing, for example, time dependent signal as a sum (in fact, an integral) over its frequency components. This is important because one often knows how a system responds to pure frequency signals rather than to an arbitrary input. In many situations, the use of a Fourier transform simplifies a physical problem by reducing a partial differential equation to an ordinary differential equation. This is a particularly important technique for numerous branches of physics, including acoustics, optics and quantum mechanics. For a fairly applied approach, look at chapters 6 and 7 of Mathematical Methods for Physicists by Arfken (Academic Press, 1985). This material is also sympathetically dealt with in: Mathematical Methods in the Physical Sciences by Boas (Wiley, 1983).

Learning outcomes

By the end of this course, you should:

- understand the concept of analyticity;
- be able to use conformal mappings to find solutions of Laplace’s equations;
- be able to use the theory of contour integration, including the residue theorem, to evaluate integrals;
- understand the theory of Fourier transforms and apply it to the solution of ordinary and partial differential equations.

Complex Analysis

This course covers about 2/3 of the material in Complex Methods, from a more rigorous point of view. The main omissions is applications of theory of Fourier Transforms and applications of conformal mappings to solutions of Laplace’s equations. The theory of complex variable is used in many branches of pure mathematics, including number theory. It also forms one of the guiding models for the modern development of geometry. A rigorous course not only provides a firm foundation for, and makes clear the underlying structure of, this material but also allows a deeper appreciation of the links with material in other analysis courses — in particular, IB Metric and Topological Spaces.

An excellent book both for the course and for preliminary reading is Hilary Priestley’s Introduction to Complex Analysis (OUP, paperback). The books by Stewart and Tall (Complex Analysis) and by Jameson (A First Course in Complex Functions) are also good.

Learning outcomes

By the end of this course, you should:

- understand the concept of analyticity;
- prove rigorously the main theorems in the course;
- be able to use the theory of contour integration, including the residue theorem, to evaluate integrals;
- understand the theory of Fourier transforms;

Groups, Rings and Modules

This course unites a number of useful and important algebraic and geometric concepts. The first third develops the notion of a group which you met in Part IA Algebra and Geometry proving a number of beautiful theorems. The next third deals with properties of polynomials in one and many variables and with some general algebraic ideas (Rings) which help us understand them. The last third deals with modules, which are generalised vector spaces. A ring is a set, like the integers or the real polynomials, which has two operations: addition and multiplication (compare with a group, which has only one operation). A module is a vector space for which the scalars which multiply the vectors come from a ring (instead of from a field). For example, every additive abelian group is a module with scalars from a ring of integers.
The course is complete in itself but also lays the foundations for most of the II algebra courses. In particular, it is essential for Galois theory, and highly desirable for areas such as Algebraic Curves, Number Fields and Representation Theory.

**Special Relativity**

**Easter and Lent, 8 lectures**

With the advent of Maxwell’s equations in the late nineteenth century came a comfortable feeling that all was well in the world of theoretical physics. This complacency was rudely shaken by Michelson’s attempt to measure the velocity of the Earth through the surrounding aether by comparing the speed of light measured in perpendicular directions. The surprising result was that it makes no difference whether one is travelling towards or away from the light source; the velocity of light is always the same. Various physicists suggested a rule of thumb (time dilation and length contraction) which would account for this phenomenon, but it was Einstein who deduced the underlying theory, special relativity, from his considerations of the Maxwell equations.

In this short introduction, there is time only to develop the framework in which the theory can be discussed (the amalgamation of space and time into Minkowski space-time) and tackle simple problems involving the kinematics and dynamics of particles.

An excellent discussion is given in chapters 15-17 of Feynman’s *Lectures on Physics, Volume I* (Addison-Wesley, 1964). You may also like to look at the first half of *Flat and Curved Space-times* by Ellis and Williams (Oxford University Press, 1988) or Turner’s *Relativity Physics* (Routledge Kegan Paul, 1984).

**Learning outcomes**

By the end of this course, you should:

- understand the basic theory of Special Relativity, and solve problems involving time dilation and length contraction;
- be able to solve problems using 4-vectors.

**Quantum Mechanics**

**Michaelmas and Lent, 16 lectures**

Quantum Mechanics is the theory which describes the behaviour of elementary particles. In fact, it supersedes Newton’s laws of motion for all bodies, but the difference is generally only significant on the atomic scale.

For a single particle, the basic equation is the Schrödinger equation, which expresses the conservation of total energy as a second order differential equation. The solution of this equation is the wave function of the particle. It carries all the available information about the motion of the particle, but this information comes in the form of a probability distribution; one cannot predict where exactly the particle will be, but one can give a probability that it will be found in any given volume.

Using the wave function, one can work out the expected position and momentum of the particle at any time but there is always an uncertainty in the result of any measurement. This uncertainty is enshrined as a basic principle of quantum mechanics.

This course sets up the mathematical framework required to discuss the theory of quantum mechanics. The Schrödinger equation is then solved in certain simple but important cases including the square well potential and the hydrogen atom.

For a very readable non-mathematical account with lots of pictures, which goes well beyond the IB course, see *The Quantum Universe* by Hey and Walters (CUP, 1987). A cheap and well-written text which covers the course is Davies’s *Quantum Mechanics* (Routledge, 1984). The first three chapters of Feynman’s *Lectures on Physics, Volume III* (Addison-Wesley, 1964) give a good physical discussion of the subject.

**Learning outcomes**

By the end of this course, you should:

- understand the basic theory of quantum mechanics, including the role of the Schrödinger equation, observables, operators and their eigenvectors and eigenvalues, and expectation values;
- be able to solve, and interpret the solution, of the Schrödinger equation in simple cases, including: 1-dimensional potential wells and steps; the harmonic oscillator; and the hydrogen atom.
Electromagnetism Lent, 16 lectures

Maxwell’s equations for electromagnetism were one of the great triumphs of nineteenth century physics; together with Newton’s equations of gravitation, they provided the solution to most of the known problems in fundamental physics. This course gives the first opportunity in the Tripos to study a modern physical field theory.

After a brief discussion of electric and magnetic forces, Maxwell’s equations are introduced. The treatment relies heavily on the vector calculus of Part IA. Then the equations are solved in special cases of physical interest. First, time independent situations are covered: point charges, bar magnets, currents in wires. Next, time varying situations are investigated: moving circuits, dynamo theory and electromagnetic theory.

Finally, it is shown how Maxwell’s equations imply the existence of potential functions which can be used instead of the field variables to describe the electric and magnetic fields.

Electromagnetism is important for all of the theoretical physics courses in Part II.

Statistics Lent, 16 lectures

The chief business of war (according to the Duke of Wellington) is finding out what we don’t know from what we do know. There are two quite separate approaches to statistical inference. This course will concentrate on classical methodology, although the alternative Bayesian approach will be considered.

The gap between the uncertainty of the real world and precise mathematics is bridged by assuming that the data come from manageable probabilistic distributions involving unknown parameters so that questions of statistical inference can be precisely posed.

Building on the Probability course (C7), this course presents the standard elementary statistical tool chest and explains how and why it works. It covers estimation, hypothesis testing, linear normal models and linear regression using least squares analysis.

For revision of probability Meyer’s Introductory Probability and Statistical Applications (Addison-Wesley, 1965) omitting chapters 11, 13, 14 and 15. For the course, read Lindgren’s Statistical Theory (Collier-Macmillan, 1976) without worrying too much about technical detail.

Learning outcomes

By the end of this course, you should:

- understand the concepts involved in estimation, including confidence intervals and Bayesian inference.
- understand and be able to apply the basic ideas of hypothesis testing, including the Neyman-Pearson lemma, likelihood ratio and goodness of fit tests;
- understand and be able to apply tests using \( \chi^2 \), \( t \) and \( F \) distributions;
- understand and be able to apply the basic theory of linear regression.

Markov Chains Michaelmas, 12 lectures

A Markov process is a probabilistic process for which the future (the next step) depends only on the present state; it has no memory of how the present state was reached. A typical example is a random walk (in two dimensions, the drunkard’s walk).

The course is concerned with Markov processes in discrete time, including periodicity and recurrence. For example, a random walk on a lattice of integers returns to the initial position with probability one in one or two dimensions, but in three or more dimensions the probability of recurrence in zero. Some Markov processes settle down to an equilibrium state and these are the next topic in the course. Then Poisson processes are studied, which provide a model for the arrival of calls at a telephone exchange or the rate of detection of radio-active particles by a geiger-counter.

The material in this course will be essential if you plan to take any of the applicable courses in Part II.

Geometry Lent, 16 lectures

Geometry here means the study of curved surfaces. In particular, the course concentrates on the sphere (which is a surface of constant positive curvature) and on the hyperbolic plane (which is the corresponding surface of constant negative curvature). This material is not only appealing in itself, but provides insight to more complicated geometries such as occur in General Relativity.
The mathematics of the last 50 years is marked by the increasing importance of geometry, both in pure mathematics and in theoretical physics. This course provides an introduction to some of the basic ideas. The initial lectures continue the material on the links between algebra (group theory) and geometry (symmetry) touched on in Part IA. The course then moves from the Euclidean plane to non-Euclidean geometries.

The starred book for the course provides a nice introduction to the material: *Notes on Geometry* by Rees (Springer, 1983).

**Learning outcomes**
By the end of this course, you should:

- understand, at a simple level, the connection between geometries and groups, and the influence of curvature on the nature of the geometry;
- know and be able to derive the basic properties of spherical geometry, and of the hyperbolic plane.
- understand and be able to calculate the Euler number in simple cases.
- understand what is meant by a Riemannian metric and a geodesic.

**Optimization**

**Easter, 12 lectures**

A typical problem in optimisation is to find the cheapest way of supplying a set of supermarkets from a set of warehouses: in more general terms, the problem is to find the minimum (or maximum) value of a quantity when the variables are subject to certain constraints. Many real-world problems are of this type and the theory discussed in the course are practically extremely important as well as being interesting applications of ideas introduced earlier in Discrete Mathematics (C3) and Algebra and Geometry (C1 and C2).

The theory of Lagrange multipliers, linear programming and network analysis is developed. Topics covered include the simplex algorithm, the theory of two-person games and some algorithms particularly well suited to solving the problem of minimising the cost of flow through a network. Whittle's *Optimisation under Constraints* (Wiley, 1971) gives a good idea of the scope and range of the subject but is a little advanced mathematically; Luenberger's *Introduction to Linear and Non-linear Programming* (Addison-Wesley, 1973) is at the right level but provides less motivation.

**Learning outcomes**
By the end of this course, you should:

- understand the nature and importance of convex optimisation;
- be able to apply Lagrangian methods to solve problems involving constraints;
- be able to solve problems in linear programming by methods including the simplex algorithm and duality;
- be able to solve network problems by methods using, for example, the Ford-Fulkerson algorithm and min-cut max-flow theorems.

**Numerical Analysis**

**Easter, 12 lectures**

An important aspect of the application of mathematics to problems in the real world is the ability to compute answers as accurately as possible subject to the errors inherent in the data presented and the limits on the accuracy of calculation. The course studies solution of linear problems, such as simultaneous linear equations, and the approximation of functions by polynomials. These ideas are essential for the solution by computer of problems involving integration and differentiation.

Gilbert Strang’s *Linear Algebra* (Academic Press, 1980) is an excellent text, setting the course clearly in the context of linear algebra.

**Learning outcomes**
By the end of this course, you should:

- understand the role of algorithms in numerical analysis;
- understand the theory of algorithms such as LU and QR factorisation, and be able to apply them, for example to least squares calculations;
- understand the role and basic theory (including orthogonal polynomials and the Peano kernel theorem) of polynomial approximation.
Computational Projects
This course consists mainly of practical computational projects carried out and written up for submission a week after the beginning of the Lent and Easter terms. For full credit, you do four projects. The first two are written up on pro-formas and submitted in the Lent term. The remaining two are chosen from a list of projects and are submitted in the Easter term.
The emphasis is on understanding the mathematical problems being modelled rather than on the details of computer programming. You will have been given the booklet of projects and if you have access to a suitable computer over the summer, it will be extremely helpful to get the first two projects out of the way: some students find the projects very time consuming, especially those who are not used to programming.
If you are wondering whether to take the Projects, you may like to know that over 95% of Part IB students submit projects (not necessarily complete); and the corresponding figure for the Part II Projects course is over 90%.
The amount of credit available for the Computational Projects course in Part IB examinations will 80 marks and 4 quality marks (alphas or betas).

Learning outcomes
By the end of this course, you should:

- be able to programme using a traditional programming language;
- understand the limitations of computers in relation to solving mathematical problems;
- be able to use a computers to solve problems in both pure and applied mathematics involving, for example, solution of ordinary differential equations and manipulation of matrices.