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Course Regulations for Year 4

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4)

Note: The modules below are for the current academic year only, it is not guaranteed that they will run next year, or in future years, due to their highly specialised nature.

MASTER OF MATHEMATICS MMATH G103 4th Years

Normal Load = 120 CATS. Maximum Load = 150 CATS.

Students are required to take at least 90 CATS from the Core plus Lists A, C and D and, in their third and fourth years combined, at least 105 CATS from the Core plus Lists C and D.

[For example, a typical MMath student might satisfy this last requirement by including two **List C** modules in their offering for Year 3, and then including MA4K8/9 Project and three other **List C** modules in their offering for Year 4.]

4th Year MMath students will not be allowed to take second year modules, except as unusual options and even then only with a valid reason for doing so.

Direct link to MA4K8/9 Projects here.

Many **List A** Year 3 Mathematics modules have a support class timetabled in weeks 2 to 10. This is your opportunity to bring the examples you have been working on, to compare progress with fellow students, and where several people are stuck or confused by the same thing, to get guidance from the graduate student in charge. **List C** and **D** modules tend to have fewer students and support classes are less common; in these cases you are more than usually encouraged to discuss problems or concerns directly with the lecturer, either during or after lectures, or in office hours.
For a full list of available modules see the relevant course regulation page.

Maths Modules

Optional Modules - List A
As the Third year option List A for G103 Mathematics (not including MA385 Third Year Essay nor MA397 Consolidation) with the exception of second year modules (coded MA2xx for example).

Optional Modules - List B
As the Third Year option List B for G103 Mathematics with the exception of second year modules (coded MA2xx for example).

Optional Modules - List C and D:

Term	Code	Module	CATS	List
Term 1	MA424	Dynamical Systems	15	List C
	MA433	Fourier Analysis	15	List C
	MA482	Stochastic Analysis	15	List C
	MA4A2	Advanced PDEs	15	List C
	MA4A5	Algebraic Geometry	15	List C
	MA4C0	Differential Geometry	15	List C
	MA4E0	Lie Groups	15	List C
	MA4G5	Analytical Fluid Dynamics	15	List C
	MA4H0	Applied Dynamical Systems	15	List C
	MA4H8	Ring Theory	15	List C
	MA4J3	Graph Theory	15	List C
	MA4K3	Complex Function Theory	15	List C
	MA4L1	Mathematical Modelling in Biology and Medicine	15	List C

	MA4L3	Large Deviation Theory	15	List C
	PX408	Relativistic Quantum Mechanics	7.5	List C
	PX425	High Performance Computing in Physics	7.5	List C
	PX430	Gauge Theories for Particle Physics	7.5	List C
	PX436	General Relativity	15	List C
	ST411	Dynamic Stochastic Control	15	List C
Terms 1 & 2	MA4K8 MA4K9	Projects (Research/Maths in Action)	30	Core
	MA472	Reading Module	15	List C
Term 2	MA426	Elliptic Curves	15	List C
	MA427	Ergodic Theory	15	List C
	MA442	Group Theory	15	List C
	MA474	Representation Theory	15	List C
	MA475	Riemann Surfaces	15	List C
	MA4A7	Quantum Mechanics: Basic Principles and Probabilistic Methods	15	List C
	MA4E7	Population Dynamics: Ecology and Epidemiology	15	List C
	MA4F7	Brownian Motion (also has code ST403)	15	List C
	MA4H4	Geometric Group Theory	15	List C
	MA4H7	Atmospheric Dynamics	15	List C
	MA4J0	Advanced Real Analysis	15	List C
	MA4J7	Cohomology and Poincare Duality	15	List C
	MA4L2	Statistical Mechanics	15	List C
	MA4L4	Mathematical Accoustics	15	List C
	MA4L6	Analytic Number Theory	15	List C
	MA5Q3	Topics in Complexity Science	18	List D
	ST417	Topics in Applied Probability	15	List C

Common Unusual Options

Term	Code	Module	CATS	List
Terms 1/2	STxxx	ST4 modules offered by the Statistics Department (note ST401, ST402 and ST404 are **only** available to Statistics Students and ST407 is List B).	15 or 18	Unusual Option

Note: some modules coded CO9 or BS9 may be classed as List D and so count towards the List C and List D combined CATS total in the regulations. Please check with the Undergraduate Office.

Interdisciplinary Modules (IATL)

Second, third and fourth-year undergraduates from across the University faculties are now able to work together on one of IATL's 12-15 CAT interdisciplinary modules. These modules are designed to help students grasp abstract and complex ideas from a range of subjects, to synthesise these into a rounded intellectual and creative response, to understand the symbiotic potential of traditionally distinct disciplines, and to stimulate collaboration through group work and embodied learning.

Maths students can enrol on these modules as an Unusual Option, you can register for a maximum of TWO IATL modules but also be aware that on many numbers are limited and you need to register an interest before the end of the previous academic year. Contrary to this is IL006 Challenges of Climate Change which replaces a module that used to be PX272 Global Warming and is recommended by the department, form filling is not required for this option, register in the regular way on MRM.

Please see the IATL page for the full list of modules that you can choose from, for more information and how to be accepted onto them, but some suggestions are in the table below:

hide

Term	Code	Module	CATS	List

Term 1	IL005	Applied Imagination	12/15	Unusual
	IL006	Challenges of Climate Change	7.5/12/15	Unusual
Term 2	IL016	The Science of Music	7.5/12/15	Unusual
	IL026	Genetics: Science and Society	12/15	Unusual

Languages

The Language Centre offers academic modules in Arabic, Chinese, French, German, Japanese, Russian and Spanish at a wide range of levels. These modules are available for exam credit as unusual options to mathematicians in all years. Pick up a leaflet listing the modules from the Language Centre, on the ground floor of the Humanities Building by the Central Library. Full descriptions are available on request. Note that you may only take one language module (whether as an Unusual Option or from List B) for credit in each year. Language modules are available as whole year modules, or smaller term long modules; both options are available to maths students. These modules may carry 24 (12) or 30 (15) CATS and that is the credit you get. But, where a language module is offered at a choice of 24 (12) or 30 (15) CATS, you MUST choose the 24 (12) CATS version.

Note: 3rd and 4th year students cannot take beginners level (level 1) Language modules.

There is also an extensive and very popular programme of lifelong learning language classes provided by the centre to the local community, with discounted fees for Warwick students. Enrolment is from 9am on Wednesday of week 1. These classes do not count as credit towards your degree.

The Language Centre also offers audiovisual and computer self-access facilities, with appropriate material for individual study at various levels in Arabic, Chinese, Dutch, English, French, German, Greek, Italian, Portuguese, Russian and Spanish. (This kind of study may improve your mind, but it does not count for exam credit.)

A full module listing with descriptions is available on the Language Centre web pages.

Important note for students who pre-register for Language Centre modules

It is essential that you confirm your module pre-registration by coming to the Language Centre as soon as you can during week one of the new academic year. If you do not confirm your registration, your place on the module cannot be guaranteed. If you decide, during the summer, NOT to study a language module and to change your registration details, please have the courtesy to inform the Language Centre of the amendment.

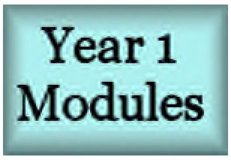
Information on modules can be found at

http://www2.warwick.ac.uk/fac/arts/languagecentre/academic/

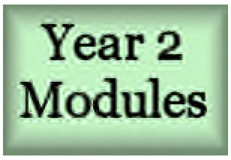
Objectives

After completing the fourth year of the MMath degree the students will have

- covered advanced mathematics in greater depth and/or breadth, and be in a position to decide whether they wish to undertake research in mathematics, and to ascertain whether they have the ability to do so
- achieved a level of mathematical maturity which has progressed from the skills expected in school mathematics to the understanding of abstract ideas and their applications
- developed
  - investigative and analytical skills,
  - the ability to formulate and solve concrete and abstract problems in a precise way, and
  - the ability to present precise logical arguments
- been given the opportunity to develop other interests by taking options outside the Mathematics Department in all the years of their degree course.



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC

MA474 Representation Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma474)
Lecturer: Dmitriy Rumynin

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: Three hour examination

Prerequisites: MA3E1 Groups and Representations

Leads to: Postgraduate work in Algebra, Combinatorics, Geometry and Number Theory

Content:

This is a second course on ordinary representations of finite groups, which only assumes the basics covered in Groups and Representations. Representation Theory studies ways in which a group can act on vector spaces by linear transformations. This has important applications in algebra, in number theory, in geometry, in topology, in physics, and in many other areas of pure and applied mathematics. We will begin by reviewing the basics of representation and character theory, covered in MA3E1. Then, we will introduce new powerful representation theoretic techniques, including:

* Symmetric and alternating powers, Frobenius-Schur indicators, and definability over R. For example, we will be able to study the following questions:

Given an element g in a finite group G, count the number of elements x in G whose square is g.Given a complex representation of G, is there a change of basis after which all matrices are defined over the reals?

* Representations of the symmetric groups following Vershik-Okounkov approach.

* Schur-Weyl duality and representations of the general linear groups.

* If time permits: induction theorems, Brauer induction and Artin induction.

Aims:

To introduce some techniques in the theory of ordinary representations of finite groups that go beyond the basics and that are important in other areas of mathematics.

Objectives:

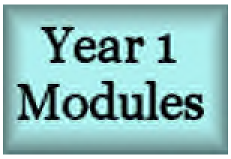
By the end of the module the student should be able to:

- quickly compute the full character table of some important groups
- investigate real, complex and quaternionic fields representations
- understand characters of symmetric and general linear groups

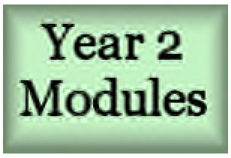
Books:
Isaacs, *Character Theory of Finite Groups*
Curtis and Reiner, *Methods of Representation Theory, with Applications to Finite Groups and Orders,* Vols. 1 and 2

Fulton, Harris, *Representation Theory: a first course*
Ceccherini-Silberstein, Scaraborti, Tolli, *Representation Theory of the Symmetric Groups:* the Okounkov–Vershik Approach, Character Formulas, and Partition Algebras

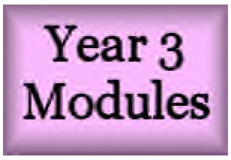
Additional Resources



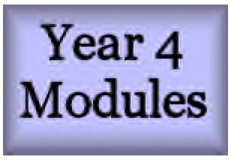
Year 1 regs and modules
G100 G103 GL11 G1NC



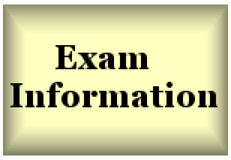
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA4E3 Asymptotic Methods

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4e3)

Not running in 2017/18.

Lecturer: Claude Baesens

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: 3 hour examination

Prerequisites: All the core Analysis modules of Years 1 and 2; MA3B8 Complex Analysis is desirable but may be taken in parallel.

Content:
The classical analysis mainly deals with convergent series in spite of the fact that an attempt to solve a problem using series often leads to divergence. If treated in a consistent way, a divergent solution may provide even more information about the original problem than a convergent one. Asymptotic series has been a very successful tool to understand the structure of solutions of ordinary and partial differential equations.

Divergent series: summation of divergent series, divergent power series, analytic continuation of a convergent series outside the disk of convergence, asymptotic series, an application to ODEs.
Laplace transform: basic properties, Borel transform, Gevrey-type series, Borel sums, Watson theorem.
Stokes phenomenon: examples, asymptotics in sectors of a complex plane, an application - asymptotic of Airy function.
Multivalued analytic functions: analytic continuation, multivalued functions, introduction to Riemann surfaces.
Formal convergence: space of formal series, formal convergence, an application to ODEs.
Rapidly oscillating integrals: asymptotics of rapidly oscillating integrals, method of stationary phase, examples.

Aims:
To introduce a systematic approach to analysis of divergent series, their interpretation as asymptotic series, and application of these methods to study of ordinary differential equations and integrals.

Objectives:
At the end of the module the student should be familiar with the methods involving analysis of asymptotic series and to acquire basic techniques in studying asymptotic problems. The student should be able to perform analysis of divergent series and to be able to correctly interpret them as asymptotic series.

Books:
We will not follow any particular book, but most of the material can be found in:
C.F. Carrier, M. Krook and C.E. Pearson, *Functions of a Complex Variable: theory and technique*, Hodbooks.
N.G. De Bruijn, *Asymptotic Methods in Analysis*, North-Holland Publishing co. (3d ed.) (1970).
P.P.G. Dyke, *An Introduction to Laplace Transforms and Fourier Series*, Springer Undergraduate Mathematics Series (2000).
G. Hardy, *Divergent Series*, Clarendon Press, 1963/American Mathematical Society, 2000.
R.B. Dingle, *Asymptotic Expansions: Their Derivation and Interpretation*, Academic Press (1973).

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA4G5 Analytical Fluid Dynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4g5)

Lecturer: Ben Pooley

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: 100% Exam (3 hours)

Prerequisites: MA3G7 Functional Analysis I is required.
A few selected results from MA359 Measure Theory, MA3G1 Theory of PDEs and MA3G8 Functional Analysis II may be reviewed briefly, as required. MA433 Fourier Analysis, MA4A2 Advanced PDEs, and MA4J0 Advanced Real Analysis may make good companion courses.

Content:
Topics include:

- The equations (brief derivation and key properties) 1
- The vorticity formulation and Biot–Savart law
- Local-in-time existence and uniqueness results in Rn, n = 2, 3, via energy estimates
- An alternative approach to local well-posedness for Euler, using particle trajectory methods
- Global-in-time existence results in 2D and comparisons to 3D
- Criteria for blowup of solutions e.g. the celebrated Beale-Kato-Majda theorem
- An introduction to weak solutions of the Navier–Stokes equations
- A global existence result for weak solutions of the Navier–Stokes equations (time permitting)
- Other selected topics, according to student interest (time permitting)

Aims:
This course aims to give an introduction to the rigorous analytical theory of the PDEs of fluid mechanics. In particular we will focus on the incom-pressible Euler and Navier-Stokes equations in R2 and R3, which are widely used models for inviscid and viscous flow, respectively. The questions of global existence and uniqueness of solutions to these systems form the basis for a great deal of current research. In this course we will study a few of the fundamental results in this field, which will give students a chance to apply knowledge from Functional Analysis and PDE modules to these highly-relevant non-linear systems.

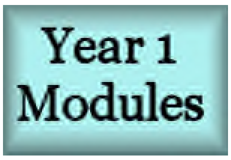
Objectives:
By the end of the module, students will:

- Be familiar with the Euler and Navier–Stokes and the physical meaning of the terms therein, for classical and vorticity-stream formulations.
- Have explored, in these particular cases, some of the typical issues arising in the study of PDEs (local vs global existence, uniqueness, blowup criteria, 2D vs 3D behaviour etc.)
- Have learnt two approaches to proving local existence and uniqueness restults: via an energy methods (featuring Sobolev estimates), and a particle-trajectory method (using H¨older spaces).
- Have seen the definition of a weak solution of the Navier–Stokes equa-tions and a discussion of further well-known existence results (at least in summary).

Books:

- Primary text: A.J. Majda and A.L. Bertozzi. Vorticity and incom¬pressible flow. CUP, Cambridge, 2002.
- A.J. Chorin and J.E. Marsden. A mathematical introduction to fluid mechanics, volume 4 of Texts in Applied Mathematics. Springer-Verlag, New York, third edition, 1993.
- J.C. Robinson, J.L. Rodrigo, and W. Sadowski. The three–dimensional Navier–Stokes equations. Classical Theory. Cambridge University Press, Cambridge, 2016.
- P. Constantin and C. Foias. Navier-Stokes Equations. The University of Chicago Press, Chicago, 1988.

Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC

MA4G6 Calculus of Variations

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4g6)

Not running in 2017/18.

Lecturer: Filip Rindler

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: Written Examination (85%), Assignments (15%)

Prerequisites:
MA209 Variational Principles (useful, but not required)
MA3G7 Functional Analysis 1 (parts of)
MA3G8 Functional Analysis 2 (parts of, can be heard concurrently, not absolutely required)

Leads To:
MA4A2 Advanced PDEs can be heard concurrently or before/after.
MASDOC A1 MA912 Analysis for Linear PDEs.
MASDOC A2 MA914 Topics in PDEs.
PhD-level courses.

Content:

- Sobolev spaces.
- The Direct Method of the Calculus of Variations and lower semicontinuity.
- Convexity and aspects of Convex Analysis (duality).
- Existence of solutions for scalar problems.
- Polyconvexity and existence of solutions semicontinuity for vector-valued problems.
- Regularity theory for minimisation problems.
- Optimal control theory and Young measures.
- Quasiconvexity, laminates and microstructure.
- Variational convergence of functionals (Γ convergence).

If time permits:

- Other variational principles (Ekeland etc.).
- Functions of bounded variations and applications.

Aims:
The Calculus of Variations is both old and new. Starting from Euler's work up to very recent discoveries, this sub-field of Mathematical Analysis has proven to be very successful in the analysis of physical, technological and economical systems. This is due to the fact that many such systems incorporate some kind of variational (minimum, maximum, extremum) principle and understanding this structure is paramount to proving meaningful results about them. Applications range from material sciences over geometry to optimal control theory. The aim of this course is to give a thoroughly modern introduction and to lead from the basics to sophisticated recent results.

Objectives:
By the end of the module the student should be able to:

- Understand why variational problems are important
- See several examples of variational problems in physics and other sciences.
- Appreciate that (and why) some problems have “classical” solutions and some do not.
- Be able to prove the existence of solutions to convex variational problems.
- Know which kinds of problems are not convex and why convexity is often an unrealistic assumption for vector-valued problems.
- Have an insight into generalised convexity conditions, such a quasiconvexity and polyconvexity and their applications.
- Be able to prove existence of solutions to quasiconvex/polyconvex variational problems.
- Have seen simple optimal control problems and can understand them as a special case of general variational problems.
- Know what microstructure is, why it forms, and what its physical significance is.
- Have seen how regularised functionals converge to a limit functional as the regularisation parameter tends to zero.

Books:
B. Dacorogna: *Introduction to the Calculus of Variations*. Imperial College Press 2004.
B. Dacorogna: *Direct Methods in the Calculus of Variations*. 2nd edition. Springer, 2008.
L. C. Evans: *Partial Differential Equations*. 2nd edition. AMS, 2010 (some chapters).
I. Fonseca and G. Leoni: *Modern Methods in the Calculus of Variations: Lp -spaces*. Springer, 2007.
E. Giusti: *Direct Methods in the Calculus of Variations*. World Scientific, 2002.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

MA4J7 Cohomology and Poincaré Duality

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j7)
Lecturer: Karen Vogtmann

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: Three hour examination

Prerequisites: MA3F1 Introduction to Topology, MA3H6 Algebraic Topology

Leads to:

Content:
1. Cochain complexes and cohomology.
2. The duality between homology and cohomology.
3. Chain approximations to the diagonal and products in cohomology.
4. The cohomology ring.
5. The cohomology ring of a product of spaces and applications.
6. The Poincaré duality theorem.
7. The cohomology ring of projective spaces and applications.
8. The Hopf invariant and the Hopf maps.
9. Spaces with polynomial cohomology.
10. Further applications of cohomology.

Aims:
To introduce cohomology and products as an important tool in topology. Give a proof of the Poincaré duality theorem and go on to use this theorem to compute products. There will be many applications of products including using products to distinguish between spaces with isomorphic homology groups. To use products to study the classical Hopf maps.

Objectives:
By the end of the module the student should be able to:
Define cup and cap products.
Use the Poincaré duality theorem.
Compute the cohomology ring of many spaces including product spaces and projective spaces.
Apply the cohomology ring to get topological results.
Define, calculate and apply the Hopf invariant.

Books:
Algebraic Topology, Allen Hatcher, CUP 2002
Algebraic Topology a first course, Greenberg and Harper, Addison-Wesley 1981

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

MA4J8 Commutative Algebra II

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j8)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List A

Commitment: 30 One hour lectures

Assessment: Three hour examination (85%), Coursework (15%)

Prerequisites: MA3G6 Commutative Algebra [Useful: MA3D5 Galois Theory]

Leads to: (PhD studies in) Algebraic Geometry or Arithmetic Geometry/Number Theory

Content:
1. Review of MA3G6 Commutative Algebra
2. Completion of local rings
3. Dimension Theory of local Noetherian Rings, Regular Noetherian Rings, Projective dimension
4. Kaehler Differentials, Smooth and Etale Extensions
5. Henselian Rings, Flatness Cohen-Macaulay, Gorenstein, Complete Intersection rings

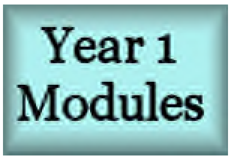
Aims:
Many introductory text books in Algebraic Geometry assume the knowledge of a heavy load of Commutative Algebra that goes far beyond our MA3G6 Commutative Algebra module. For instance, the standard book "Algebraic Geometry" by Hartshorne lists 2 pages of results from Commutative Algebra none of which are proved in the text. The purpose of the module is to provide further foundations from Commutative Ring Theory that a beginning student in Algebraic Geometry and Arithmetic Geometry/Number Theory will need. The module is a continuation of MA3G6 Commutative Algebra.

Objectives:
By the end of the module the student should be able to:
Have a firm understanding of some of the basic results from Commutative Algebra.
Read any standard texts on Commutative Algebra such as the ones listed above.
Compute the dimension of rings in simple cases.
Know examples of regular, smooth, etale algebras (if we cover them in the lectures).
Know examples of Cohen-Macaulay, Gorenstein.

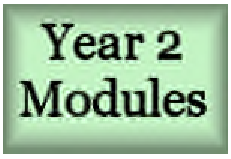
Complete Intersection rings.
Decide if a ring or an extension of rings has
a certain property (such as smooth, etale, regular, Gorenstein etc).

Books:
Atiyah, MacDonald: *Introduction to Commutative Algebra*
Eisenbud: *Commutative Algebra with a view towards algebraic geometry*
Matsumura: *Commutative Ring Theory*

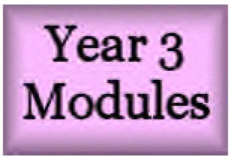
Additional Resources



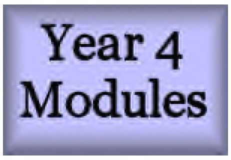
Year 1 regs and modules
G100 G103 GL11 G1NC



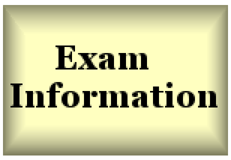
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA4K0 Introduction to Uncertainty Quantification

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4k0)

Not Running 2016/17

Lecturer: Andrew Stuart

Term(s): Term 1

Status for Mathematics students: List A

Commitment: 30 hours of lectures all within the time/location slots:
Mondays at 5-7 in MS.04 (not in week 1)
Wednesdays 5-7 in MS.B3.03

(There will be no lectures on Wednesday November 4th and Monday November 9th. The time will be made-up by extending the duration of lectures earlier in the month of October)

Assessment: Three hour exam

There will be weekly exercises in this module, which will involve a mixture of theoretical and computer-based questions. The TA Daniel Sanz-Alonso will run a weekly problem session in which solutions to some of the exercises are presented. This will take place in weeks 2-10 at 12noon, in room D1.07, except week 10 when it will be held in MS.04.

Prerequisites:
Essential: ST112 Probability B, MA3G7 Functional Analysis I and either MA359 Measure Theory or ST318 Probability Theory.

Useful or related:
MA4A2 Advanced PDEs, ST407 Monte Carlo Methods.
Some programming background in e.g. C, Mathematica, Matlab, Python, or R.

Leads to:
Graduate study in a range of problems at the interface of differential equations and probability, including UQ theory, data assimilation, inverse problems and filtering. These subjects may be studied within mathematics departments, or in applications departments throughout the sciences and engineering.

Content: This is a list of *possible* topics, not all of which will necessarily be covered in the module.

1. **Introduction and Course Outline**
    1. Typical UQ problems and motivating examples: certification, prediction, inversion.
    2. Epistemic and aleatoric uncertainty. Bayesian and frequentist interpretations of probability.
2. **Preliminaries**
    1. Hilbert space theory: direct sums; orthogonal decompositions and approximations; tensor products; Riesz representation and Lax–Milgram theorems. [Mostly recap of MA3G7 Functional Analysis I.]
    2. Probability theory: axioms, integration, sampling, key inequalities and limit theorems. [Mostly recap of MA359 Measure Theory / ST318 Probability Theory.]
    3. Optimization: least squares; linear/quadratic/convex programming; extreme points.
3. **Inverse Problems and Bayesian Perspectives**
    1. Ill-posedness of inverse problems, regularization.
    2. Bayesian inversion in Banach spaces.
    3. State estimation and data assimilation, e.g. Kálmán filter.
4. **Orthogonal Polynomials**
    1. Basic definitions and properties.
    2. Polynomial interpolation and approximation.
5. **Numerical Evaluation of Integrals**
    1. Deterministic methods: uniform sampling, Newton–Cotes formulae, Gaussian quadrature, Clenshaw–Curtis quadrature, sparse quadrature.
    2. Random methods: Monte Carlo and variants.
    3. Pseudo-random methods: low-discrepancy sequences, Koksma–Hlawka inequality.
6. **Sensitivity Analysis**
    1. Estimation of derivatives.
    2. "L^∞" sensitivity indices, e.g. McDiarmid subdiameters; associated concentration-of-measure inequalities.
    3. ANOVA and "L^2" sensitivity indices, e.g. Sobol' indices.
    4. Model reduction.
7. **Spectral Methods**
    1. Polynomial chaos: Wiener–Hermite expansions, generalized PC expansions, changes of PC basis.
    2. Intrusive (Galerkin) methods: deterministic and stochastic Galerkin projection.
    3. Non-intrusive spectral projection, stochastic collocation methods.
8. **Optimization Methods**
    1. Mixed epistemic/aleatoric uncertainty; the robust Bayesian paradigm.
    2. Finite-dimensional parametric studies; convex programs.
    3. Optimal UQ / distributionally-robust optimization: formulation, reduction, computation.

Aims:
Uncertainty Quantification (UQ) is a research area of growing theoretical and practical importance at the intersection of applied mathematics, probability, statistics, computational science and engineering (CSE) and many application areas. UQ can be seen as the theory and numerical application of probability/statistics to problems and models with a strong "real-world" (especially physics- or engineering-based) setting.

This course will provide an introduction to the basic problems and methods of UQ from a mostly mathematical point of view, with numerical exercises so that the methods can be seen to work in (small) practical settings. More generally, the aim is to provide an introduction to some relatively diverse methods of applied mathematics and applied probability as they are used in practice, through the particular unifying theme of UQ.

Objectives:
By the end of the module students should be able to understand both the basic theory of, and in example settings perform:

- sensitivity and variance analysis
- orthogonal systems of polynomials and their applications
- spectral decomposition methods
- finite- and infinite-dimensional optimization methods
- data assimilation and filtering
- Bayesian perspectives on inverse problems.

Literature:
The course will be based on two sets of lectures notes; details of how to access these are given under Additional Resources.
The following books may also be of interest:

Berger, James O. "An overview of robust Bayesian analysis." *Test* **3**(1):5–124, 1994.

Le Maître, O. P.; Knio, O. M. *Spectral methods for uncertainty quantification. With applications to computational fluid dynamics*. Scientific Computation. Springer, New York, 2010. xvi+536 pp. ISBN: 978-90-481-3519-6

Xiu, Dongbin. *Numerical methods for stochastic computations. A spectral method approach*. Princeton University Press, Princeton, NJ, 2010. xiv+127 pp. ISBN: 978-0-691-14212-8

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA4K2 Optimisation and Fixed Point Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4k2)

Not Running 2016/17

Lecturer: Charlie Elliott

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: Three hour written examination (100%)

Prerequisites: MA3G7 Functional Analysis I and MA3G1 Theory of PDEs

Leads To: Graduate studies in Applied Mathematics (eg MASDOC)

Content:
We will cover some of the following topics:-

- Optimisation in Banach spaces.
- Optimisation in Hilbert spaces with and without constraints.
- Optimality conditions and Lagrange multipliers.
- Lower semi-continuity.
- Convex functionals.
- Variational inequalities
- Gradient descent and iterative methods.
- Banach, Brouwer Schauder fixed point theorems.
- Monotone mappings.
- Applications in differential equations, inverse problems, optimal control, obstacle problems, imaging.

Aims:
The module will form a fourth year option on the MMath Degree.It builds upon modules in the second and third year like Metric Spaces, Functional Analysis I and Theory of PDEs to present some fundamental ideas in nonlinear functional analysis with a view to important applications, primarily in optimisation and differential equations. The aims are: introduce the concept of unconstrianed and constrained optimisation in Banach and Hilbert spaces; existence theorems for nonlinear equations; importance in applications to calculus of variations, PDEs, optimal control and inverse problems.

Objectives:
By the end of the module the student should be able to:-

- Recognise situations where existence questions can be formulated in terms of fixed point problems or optimisation problems.
- Recognise where the Banach fixed point approach can be used.
- Apply Brouwers and Schauders fixed point theorems.
- Apply the direct method in the calculus of variations.
- Apply elementary iterative methods for fixed point equations and optimisation.

Books:
The instructor has own printed lecture notes which will provide the primary source. The printed lecture notes will also have a bibliography.

List A (These books contain material directly relevant to the module):-

- G. Allaire, Numerical analysis and optimisation, Oxford Science Publications 2009
- P.G. Ciarlet, Linear and nonlinear functional analysis with applications. SIAM 2013
- P. G. Ciarlet, Introduction to numerical linear algebra and optimisation, Cambridge 1989
- L.C. Evans, Partial Differential Equations , Graduate Studies in Mathematics 19, AMS, 1998.
- F. Troltzsch, Optimal control of partial differential equations AMS Grad Stud Math Vol 112 (2010)

List B (The following texts contain relevant and more advanced material):-

- G. Aubert and P. Kornprobst. Mathematical problems in Image Processing, Applied Mathematical Sciences (147). Springer Verlag 2006.
- M. Chipot. Elements of nonlinear analysis . Birkhauser, Basel-Boston-Berlin, 2000.
- D. Kinderleher and G. Stampacchia, An introduction to variational inequalities and their applications Academic Press 1980
- E. Zeidler, Nonlinear functional analysis and its applications I, Fixed Point theorems , Springer New York, 1986

Additional Resources

MA4K3 Complex Function Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4k3)
Lecturer: Polina Vytnova

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: Assignments 15%, 3 hour written exam 85%

Prerequisites:
MA3B8 Complex Analysis is essential.
MA359 Measure Theory and MA3G7 Functional Analysis I are desirable but not essential.

Leads To: PhD level research in function spaces.

Content:
1. Problems on the Hardy space.
1.1. Overview. Understanding functions through problems in Complex Function Theory.
1.2. Review of Complex Analysis I, Functional Analysis I and Measure Theory.
1.3. The Hardy space. Basic properties. Other important spaces.

2. Problems on functions.
2.1. Evaluation at one point. Reproducing kernel.
2.2. Multipliers. Bounded functions.
2.3. Existence of boundary values.
2.4. Zero sets. Blaschke products.
2.5. Inner-outer factorization.

3. Problems on operators and functionals.
3.1. Examples of operators. Boundedness. Spectrum. Spectral theorem.
3.2. The shift operator. Subspaces. Polynomials. Cyclicity. Invariant subspaces.
3.3. The restriction operator. Interpolation and sampling. Embeddings.
3.4. Optimization of functionals. Distances. Extremal problems. Cyclicity revisited.

4. What else?
4.1. More spaces and operators. Domains. Several variables. Meromorphic and entire functions. Dirichlet series. Banach spaces. Random functions. More operators.
4.2. More problems. Approximation. Corona. Growth. Other operator properties. Univalence. Completeness. Conformal representations.

Aims:
To provide to the students a variety of roads they can follow on their private further research.
To introduce them to the results in analytic function spaces through a fundamental example.
To show to the students how natural problems motivate this study.

Objectives:
By the end of the module the student should be able to:

Understand the fundamental properties of the Hardy space.
Understand the fundamental properties of the Hardy space, that this is the case for complex function theory.
Produce proofs of simple facts and solve particular cases of the classical problems.

Books:
P. L. Duren, Theory of Hp spaces.
J. E. Garnett, Bounded Analytic Functions.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA4K4 Topics in Interacting Particle Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4k4)

Not Running 2016/17

Lecturer: Paul Chleboun

Term(s): Term 2

Lectures:

- Wed 11-12 in B1.01
- Thurs 12-1 in B3.01
- Fri 3-4 in B2.03 (sci-conc.)

Support Classes:

- Wednesday 12-1 in A1.01

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: 3 Hour written Exam 85%, Assignments 15%

Prerequisites: Undergraduate Probability Theory, Linear Algebra and Markov Processes (eg. MA3H2 Markov Processes and Percolation Theory or ST333 Applied Stochastic Processes)

Leads To:

Content:
1] Interacting Particle Systems
- Construction and definitions (graphical construction, semigroups and generators).
- Revision of basic concepts like stationary distributions and reversibility.
- Classical examples (to be used throughout the course).

2] Relaxation and Mixing Times
- Introduction and definitions of mixing times.
- Basic bounds and techniques.
- Spectral methods and relaxation times.
- Basics of Potential Theoretic approach, resistor networks for reversible Markov Processes.

3] Large Deviations
- Introduction with examples.

4] Metastability
- Application of Large Deviations.
- Application of Potential Theory.

Aims:
The principle aim is firstly to introduce basic stochastic models of collective phenomena arising from the interactions of a large number of identical components, called interacting particle systems. The module will then introduce several key topics which are currently at the forefront of mathematical research in interacting particle systems. In particular we fill focus on the study of large-scale dynamics.

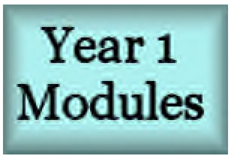
Objectives:
By the end of the module the student should be able to:

- Have a good working knowledge of key prototypical models of interacting particle systems such as the Ising model, the exclusion process and the zero-range process.
- Understand the main concepts used in current research into the large scale dynamics of interacting particle systems.
- Work in an independent and practical manner on topics related to interacting particle systems. Students should gain an advanced-level understanding of continuous time Markov processes on finite state spaces.
- Build and run stochastic simulations using their preferred method (simple examples of C-code will be given, requiring straightforward adaptation, for those who do not have a strong background in this area). This module should also help students building team working skills.

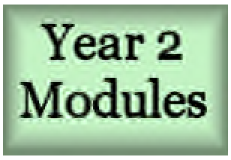
Books:
- Levin, Peres, Wilmer: *Markov Chains and Mixing Times*, AMS (2009) [Available Online]
- T.M. Liggett: *Interacting Particle Systems - An Introduction*, ICTP Lecture Notes 17 (2004) [Available Online]

- F. den Hollander: *Large Deviations*, AMS (2000)
- A. Bovier: *Metastability, Lecture notes* - Prague (2006) [Available Online]
- Montenegro, Tetali: *Mathematical aspects of mixing times in Markov chains* (2006) [Available Online]

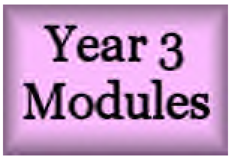
Additional Resources



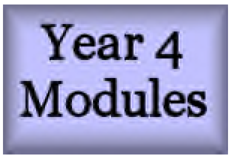
Year 1 regs and modules
G100 G103 GL11 G1NC



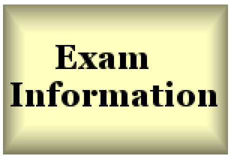
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA4K5 Introduction to Mathematical Relativity

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4k5)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: Written Examination 100%

Prerequisites:
MA3H5 Manifolds; MA3G1 Theory of PDEs (strongly recommended)
MA4C0 Differential Geometry (recommended)
PX148 Classical Mechanics & Relativity

Leads To:

Content:
* The wave equation and Special Relativity (Propagation of signals: the light-cone; finite speed of propagation; Transformations preserving the wave equation; the Lorentz group; Minkowski spacetime)

* Brief review of (pseudo-)Riemannian geometry (Vectors, one-forms and tensors; the metric tensor; the Levi-Civita connection and curvature; Stoke's theorem)

* Lorentzian geometry (Lorentzian metrics; causal classification of vectors and curves; global hyperbolicity; The d'Alembertian operator; Energy-momentum tensor for a scalar field; finite speed of propagation for a scalar field)

* General Relativity (Einstein's equations; discussion of local well posedness; Example: The Schwarzschild black hole; The Cauchy problem; discussion of open problems)

Aims:
One of the crowning achievements of modern physics is Einstein's theory of general relativity, which describes the gravitational field to a very high degree of accuracy. As well as being an astonishingly accurate physical theory, the study of general relativity is also a fascinating area of mathematical research, bringing together aspects of differential geometry and PDE theory. In this course, I will introduce the basic objects and concepts of general relativity without assuming a knowledge of special relativity. The ultimate goal of the course will be a discussion of the Cauchy problem for the vacuum Einstein equations, including a statement of the relevant well-posedness theorems and a discussion of their relevance. We will take a 'field theory' approach to the subject, emphasising the deep connection between Lorentzian geometry and hyperbolic PDE. In contrast to the course PX436 General Relativity offered by the department of physics, we concentrate on the mathematical structure of the theory rather than its physical implications.

Objectives:
By the end of the module the student should be able to:

- Understand how the Minkowski geometry and Lorentz group arise from considerations of signal propagation for the scalar wave equation.
- Understand the basics of Lorentzian geometry: the metric; causal classification of vectors; connection and curvature; hypersurface geometry; conformal compacti cations; the d'Alembertian operator.
- Be able to state the well-posedness theorems for the Cauchy problem for the Einstein equations and sketch the proof of local well posedness.

Books:
General Relativity and the Einstein Equations, Yvonne Choquet-Bruhat, Oxford University Press, 2009. (Available as an electronic resource.)
The large scale structure of spacetime, S.W. Hawking and G.F.R. Ellis, Cambridge University Press, 1973.
Gravitation, Charles W. Misner, Kip S. Thorne and John Archibald Wheeler.
General Relativity, Robert M. Wald, University of Chicago Press, c1984.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

MA4K6 Data Assimilation

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4k6)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List C

Commitment: 30 hours of lectures

Assessment: Written Examination 70%, MATLAB based Coursework 30%

Prerequisites: ST112 Probability B and MA254 Theory of ODEs

Leads To: Graduate studies in Applied Mathematics (eg MASDOC)

Content:
1. Problem Formulation
(i) Dynamical Systems: iterated maps, Markov kernels, time-averaging and ergodicity, explicit examples.
(ii) Bayesian Probability: joint, marginal and conditional probabilities; Bayes' formula.
(iii) Smoothing, Filtering: formulation of these off-line and on-line probability distributions using Bayes' theorem and the links between them.
(iv) Well-Posedness: introduction of metrics on probability measure and demonstration that smoothing and filtering distributions are Lipschitz with respect to data, using these metrics.

2. Smooting Algorithms
(i) Monte Carlo Markov Chain: Random walk Metropolis, Metropolis-Hastings, proposals tuned to the data assimilation scenario.
(ii) Variational Methods: relationship between maximizing probability and minimizing a cost function; demonstration of multi-modal behaviour.

3. Filtering Algorithms
(i) Kalman filter: derivation using precision matrices and use of Sherman-Woodbury identity to formulate with covariances.
(ii) 3DVAR: derivation as a minimization principle compromising between fit to model and to data.
(iii) Extended and Ensemble Kalman Filter. Generalize 3DVAR to allow for adaptive estimation of (covariance) weights in the minimization principle.
(iv) Particle Filter. Sequential importance sampling, proof of convergence.

Aims:
The module will form a fourth year option on the MMath Degree. Data Assimilation is concerned with the principled integration of data and dynamial models to produce enhanced predictive capability. As such it finds wide-ranging applications in areas such as weather forecasting, oil reservoir management, macro and micro economic modelling and traffic flow. This module aim is to describe the mathematical and computational tools required to study data assimilation.

Objectives:
By the end of the module the student should be able to understand a range of important subjects in modern applied mathematics, namely:

- Stochastic dynamical systems
- Long-time behaviour of dynamical systems
- Bayesian probability
- Metrics on probability measures
- Monte Carlo Markov Chain
- Optimization
- Control
- Matlab programming

Books:
Instructor has has own printed lecture notes (draft of a book) which will provide the primary source. These notes have an extensive bibliography and include matlab codes which will be made available to the students.

Additional Resources

MA4L0 Advanced Topics in Fluids

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l0)

Not running in 2017/18.

Lecturer: Sergey Nazarenko

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: Three hour written examination

Prerequisites: MA371 Qualitative Theory of ODEs, MA3D1 Fluid Dynamics, MA3G1 Theory of PDEs, or similar modules from other departments or universities.

Leads To:

Content:
Topics will include several of the following themes:
• Linear and nonlinear waves in fluids and other continuous media, such as plasmas, MHD fluids, Bose-Einstein condensates, superfluid helium, nonlinear optics crystals. Waves in inhomogeneous or/and moving media, scale separation, WKB and ray tracing approach, Born approximation for wave scattering on inhomogeneities and vortices. Hamiltonian and Lagrangian formulations for nonlinear waves. Solitons. Waves in excitable media, eg. spiral waves in cardiac tissue.
• Classical turbulence theory. Richarson cascade and Kolmogorov spectrum. Single and dual cascade systems. Structure functions and intermittency. Scalings in stationary and in evolving turbulence. Near-wall turbulence. Pipe turbulence. Rapid distortion theory.
• Quantum turbulence. Polarised and unpolarised tangles of quantized vortex lines. Biot-Savart-Rios description. Vortex line reconnections. Kelvin waves on vortex lines. Classical-quantum crossover scales. Sound emission by moving vortices.
• Turbulence in Bose-Einstein condensates. Gross-Pitaevskii equation model. Dark solitons and quantized vortices. Inverse cascade and condensation phenomenon. Wave turbulence description. Bogoliubov transformation. Berezinskii_Kousterlitz-Thouless and Kibble-Zurek phase transitions.

• Astrophysical and plasma turbulence. Alfen waves and drift waves. Wave turbulence approach to weak MHD and drift turbulence. Strong turbulence and critical balance.
• Large-scale waves and vortices in atmosphere and oceans. Quasi-geostrophic model. Planetary Rossby waves. Anisotropic cascades. Generation of zonal jets. Transport barriers. Two-layer model. Interaction of barotropic and baroclinic modes.

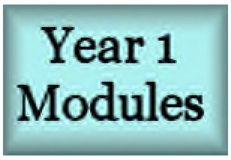
Aims:
•To provide a useful course for our 1st year PhD students, Master students, DTC students, 4th year MMATHs, Master of Advanced Study (MASt) interested in fluid dynamics related subjects, nonlinear waves, superfluids, plasmas, geophysical flows, Bose-Einstein condensates, turbulence in all of these settings.
•Have a module which is flexible enough to adjust to the needs of the current students and to the expertise of available lecturers by choosing a topic from a broad range of interrelated themes.
•Build on entry knowledge towards topics of current interest or research.

Objectives:
(By the end of the module the student should be able to....)

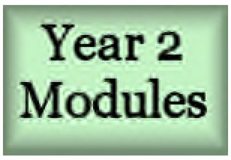
- Appreciate universality of the fluid dynamics processes in diverse applications, from quantum fluids to astrophysical systems.
- Understand the nonlinear phenomena in fluids within the considered application and in the general fluid flow. The nonlinear processes are omitted from most UG fluids courses.
- Be able to use statistical techniques for fluid systems arising in turbulent flows, e.g. manipulating spectra, structure functions and probability density functions, averaging over ensemble, space, time or initial data, derive and use turbulent closures, e.g. the kinetic equations, derive Kolmogorov spectrum and its analogues.
- Be able to recognise that similar techniques may be used to study fluids and other physical systems described by nonlinear PDE's, e.g. non-harmonic crystals or electromagnetic waves. Be capable to use these techniques in future research projects.

Books:
Whitham, G.B., Linear and Nonlinear Waves, 2011, Wiley
Frisch, U. Turbulence: The Legacy of A. N. Kolmogorov, 1995, Cambridge University Press
Nazarenko, S., Fluid Dynamics via Examples and Solutions, 2015, CRC Press
Sulem, C., Sulem, P.L., The Nonlinear Schrödinger Equation: Self-Focusing and Wave Collapse, 1999, Springer
Biskamp, D., Nonlinear Magnetohydrodynamics, 1997, Cambridge University Press
Pitaevskii, L., Stringari, S., Bose-Einstein Condensation (International Series of Monographs on Physics), 2003, Oxford University Press
Nazarenko, S., Wave Turbulence, 2011, Springer
Sinha, S., Sridhar, S., Patterns in Excitable Media: Genesis, Dynamics, and Control, 2014, Taylor & Francis
Donnelly, R.J., Quantized Vortices in Helium II, 1991, Cambridge University Press
Pomeau, Y., Pismen, L.M., Patterns and Interfaces in Dissipative Dynamics, 2006, Springer Berlin Heidelberg
Kadomtsev, B.B., Collective Phenomena in Plasmas, 1982, Elsevier Science Limited
McWilliams, J.C., Fundamentals of Geophysical Fluid Dynamics, 2006, Cambridge University Press

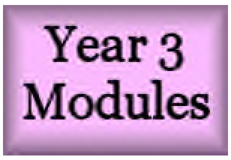
Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103

MA4L1 Mathematical Modelling in Biology and Medecine

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l1)
Lecturer: Markus Kirkilionis

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 Lectures

Assessment: Written examination (50%), Project work (50%)

Prerequisites: no formal requirements

Leads To:

Content:
Part A Mathematical Modeling in the Life Sciences

Week 1: Mathematical Foundations (Repetition as warming up)
Lecture 1 Introduction to graph theory, relevance for the Life Sciences, degree distributions and their characteristics, examples.
Lecture 2 Random variables and probability distributions, stochastic processes, examples.
Lecture 3 Statistics and data analysis

Week 2: Biochemical Reaction Systems and Rule Based Systems
Lecture 1 Introduction to reaction schemes.
Lecture 2 Hypergraphs and chemical complexes.
Lecture 3 Extended reaction schemes.

Part B Applications.

Week 3: Morphogenesis, Cellular Transport Processes
Lecture 1 Dynamical systems, semi-Flows and functional analysis.
Lecture 2 Reaction-diffusion equations and models of pattern formation/morphogenesis.
Lecture 3 Qualitative behaviour, more pattern formation, modeling transport and reaction.

Week 4: Cell Biology and Cell Cultures
Lecture 1 Modeling in Genetics.
Lecture 2 The Cell Nucleus.
Lecture 3 The Chemostat.

Week 5: Cell Cultures and Physiology
Lecture 1 Physiologically Structured Populations.
Lecture 2 The Cell Cycle.
Lecture 3. Structured Populations in the Chemostat.

Week 6: Future Medicine
Lecture 1 Learning Algorithms I.
Lecture 2 Learning Algorithms II.
Lecture 3. Data mining in medicine.

Week 7: Future Medicine
Lecture 1 Numerical simulation in medicine.
Lecture 2 Numerical simulation in medicine.
Lecture 3 Numerical simulation in medicine.

Week 8: Global Ecology
Lecture 1 Population Dynamics and Global Disturbances.
Lecture 2 Models of Biodiversity.
Lecture 3 The Growth of Cities and Landscape Patterns.

Week 9: Evolutionary theory
Lecture 1 Models of evolution.
Lecture 2 Examples of complex evolving systems, biology and language.
Lecture 3 Examples of complex evolving systems, game theory.

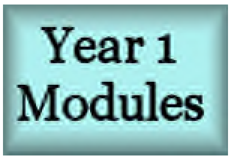
Week 10: Climate Change and Feedback to Living Systems
Lecture 1 The global climate and its modeling.
Lecture 2 The global climate and oceans.
Lecture 3 The global climate and vegetation.

Aims:
- Introduce the student to advanced mathematical modelling in the Life Sciences in a systematic way.
- Making the student aware how to choose and use different modelling techniques in different areas of the Life Sciences.
- A clarification about the mathematical content and structure of mathematical models in the Life Sciences.
- A general introduction to modern systems analysis tailored to the Life Sciences.

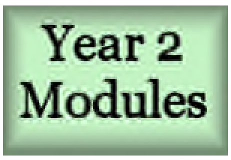
Objectives:
By the end of the module the student should be able to:
Orient in the latest research on Mathematical Biology
Apply methods learned in the module to new problems inside the scope of Mathematical Biology.
Quickly solve standard problems occurring in Mathematical Biology

Books:
Newman, M. 2010 Networks: an introduction. Oxford University Press.
Metz, J. A. J. and Diekmann, O. 1986. The dynamics of physiologically structured populations. Lecture Notes in Biomathematics. 68.
Keener, J. and Sneyd, J. 1998 Mathematical Physiology. Springer-Verlag.
Murray J.D. 2002. Mathematical Biology. New York: Springer.
Iannelli, M., Martcheva, M., and Milner, F. A. 2005 Gender-Structured Population Modeling: Mathematical Methods.

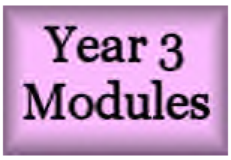
Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103

MA4L2 Statistical Mechanics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l2)
Lecturer: Daniel Ueltschi

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 Lectures

Assessment: 100% exam

Prerequisites: There are no strict prerequisites. But a basic knowledge of probability theory will be assumed.

Leads To: Academic and non-academic research in probability theory and complexity.

Content: Statistical mechanics describes physical systems with a huge number of particles.

In physics, the goal is to describe macroscopic phenomena in terms of microscopic models and to give a meaning to notions such as temperature or entropy. Mathematically, it can be viewed as the study of random variables with spatial dependence. Models of statistical mechanics form the background for recent advances in probability theory and stochastic analysis, such as SLE and the theory of regularity structures. So, they form an important background for understanding these topics of modern mathematics.

The module will give a thorough mathematical introduction to the Ising model and to the gaussian free field on regular graphs, and to the theory of infinite volume Gibbs measures.

Aims: To familiarise students with statistical mechanicsmodels, phase transitions, and critical behaviour.

Objectives: By the end of the module students should be able to:

- Apply basic ideas of phase transitions and critical behaviour to lattice systems of statistical mechanics
- Understand the theory of infinite volume Gibbs measures
- Understand how large complex systems at equilibrium can be described from microscopic rules
- Have understood basic ideas of phase transitions and critical behaviour in the case of the Ising model and the gaussian free field; they will have mastered the theory of infinite volume Gibbs measures.

Books: We will mainly follow Chapters 3, 6, 7 of the new introductory textbook:

Sacha Friedli and Yvan Velenik, Equilibrium Statistical Mechanics of Classical Lattice Systems: a Concrete Introduction. Available at

http://www.unige.ch/math/folks/velenik/smbook/index.html

Interested students can also look into:

David Ruelle, Statistical Mechanics: Rigorous Results, World Scientific, 1999.

James Sethna: Statistical Mechanics: Entropy, Order Parameters and Complexity Oxford Master Series in Physics, 2006.

Additional Resources

MA4L3 Large Deviation Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l3)
Lecturer: Stefan Adams

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 Lectures

Assessment: 85% Exam and 15% Homework

Prerequisites:

MA359 Measure Theory (or equivalently any of ST342 Maths of Random Events or MA3H2 Markov Processes and Percolation Theory)

MA250 Introduction to Partial Differential Equations (or equivalently any of MA209 Variational Principles, or MA3G7 Functional Analysis I or MA3G1 Theory of PDEs)

Leads To: MA4K4 Topics in Interacting Particle Systems, MA4F7 Brownian Motions, MA427 Ergodic Theory or MA424 Dynamical Systems.

Content:

- Basic understanding of large deviation techniques (definition, basic properties, Cramer's theorem, Varadhan's lemma, Sanov's theorem, the Gärtner-Ellis Theorem).
- Large deviation approach to Gibbs measure theory (free energy; entropy; variational analysis; empirical process; mathematics of phase transition).
- Large deviation theory for stochastic processes and its connections with PDEs (Fleming semi group; viscosity solutions; control theory).
- Applications of large deviation theory (at least one of the following list of topics: interface models; pinning/wetting models; dynamical systems; decay of connectivity in percolation; Gaussian Free Field; Free energy calculations; Wasserstein gradient flow; renormalisation theory (multi-scale analysis)).

Aims:

- Basic understanding of large deviation theory (rate function; free energy; entropy; Legendre-transform).
- Understanding that large deviation principles provide a bridge between probability and analysis (PDEs, convex and variational analysis).
- Large deviation theory as the mathematical foundation of mathematical statistical mechanics (Gibbs measures; free energy calculations; entropy-energy competition).
- Understanding large deviation in terms of the nonlinear Fleming semi group and its links to control theory.
- Discussion of the role of large deviation methods and results in joining different scales, e.g. as the micro-macro passage in interacting systems.
- Connection of large deviation theory with stochastic limit theorems (law of large numbers; ergodic theorems (time and space translations); scaling limits).

Objectives: By the end of the module students should be able to:

- Derive basic large deviation principles
- Be familiar with the variational principle and the large deviation approach to Gibbs measure
- Distinguish all three level of large deviation
- To calculate Legendre-Fenchel transform for most relevant distributions
- Understand basic variational problems
- Be familiar with some application of large deviation theory
- Link basic large deviation principle for stochastic processes to PDEs
- Compute of rare probabilities via large deviation rate functions given as variational problems in analysis and PDE theory. Be able to use Legendre-transform techniques, basic convex analysis and Laplace integral methods.
- Understand the role of free energy calculations and representations in analysis (PDEs and control problems and variational problems). Be able to provide a variational description of Gibbs measures.
- Be able to analyse the minimiser of large deviation rate functions of basic examples and to provide interpretation of the possible occurrence of multiple minimiser.
- Explain the role of the free energy in interacting systems and its link to stochastic modelling. Be able to provide different representations of the free energy for some basic examples.
- Be able to estimate probabilities for interacting systems using Laplace integral techniques and basic understanding of Gibbs distributions.
- Apply large deviation theory to one topic from the following list: interface models; pinning/wetting models (random walk models); dynamical systems; decay of connectivity in percolation; Gaussian Free Field; Free energy calculations; Wasserstein gradient flow; renormalisation theory (multi-scale analysis).

Books: We won't follow a particular book and will provide lecture notes. The course is based on the following three books:

[1] Frank den Hollander, Large Deviations (Fields Institute Monographs), (paperback), American Mathematical Society (2008).

[2] Amir Dembo & Ofer Zeitouni, Large Deviations Techniques and Applications (Stochastic Modelling and Applied Probability), (paperback), Springer (2009).

[3] Jin Feng and Thomas G. Kurtz, Large Deviations for Stochastic Processes, American Mathematical Society (2006).

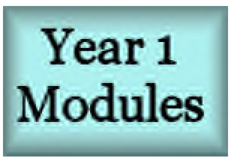
Other relevant books and lecture notes:

[a] Hans-Otto Georgii, Gibbs measures and Phase Transitions, De Gruyter (1988).

[b] Stefan Adams, Lectures on mathematical statistical mechanics, Communications of the Dublin Institute for Advanced Studies Series A (Theoretical Physics), No. 30 , available online http://www2.warwick.ac.uk/fac/sci/maths/people/staff/stefan adams/lecturenotestvi/cdias-adams-30.pdf

[c] Stefan Adams, Large deviations for stochastic processes, EURANDOM reports 2012-25, (2012); available online http://www.eurandom.tue.nl/reports/2012/025-report.pdf

Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC

MA4L4 Mathematical Acoustics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l4)
Lecturer: Ed Brambley

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one hour lectures

Assessment: 100% Exam (3 hours)

Prerequisites: MA231 Vector Analysis (for contour integration); MA250 Introduction to PDEs (for Green's functions). MA3D1 Fluid Dynamics is useful but not necessary.

Content:

- Some general acoustic theory
- Sound generation by turbulence and moving bodies (including the Lighthill and Ffowcs Williams-Hawkings acoustic analogies)
- Wave scattering (including the scalar Wiener-Hopf technique applied to the Sommerfeld problem of scattering by a sharp edge)
- Long-distance sound propagation, including nonlinear and viscous effects
- Wave-guides.

Aims:
The application of wave theory to problems involving the generation, propagation and scattering of acoustic and other waves is of considerable relevance in many practical situations. These include, for example, underwater sound propagation, aircraft noise, remote sensing, the effect of noise in built-up areas, and a variety of medical diagnostic applications. This course aims to provide the basic theory of wave generation, propagation and scattering, and an overview of the mathematical methods and approximations used to tackle these problems, with emphasis on applications to aeroacoustics.

Objectives:
By the end of the module the student should be able to:

- Reproduce standard models and arguments for sound generation and propagation
- Apply mathematical techniques to model sound generation and propagation in simple systems
- Understand and apply Wiener-Hopf factorisation in the scalar case

Books:

- A.D. Pierce, "Acoustics", McGraw-Hill 1981

- D.G. Crighton, A.P. Dowling, J.E. Ffowcs Williams, et al, "Modern Methods in Analyticial Acoustics", Springer 1992
- L.D. Landau & E.M. Lifshitz, "Fluid Mechanics", Elsevier 1987

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA4L6 Analytic Number Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l6)
Lecturer: Adam Harper

Term(s): Term 2

Status for Mathematics Students: List C

Commitment: 30 one hour lectures

Assessment: 100% Exam (3 hour)

Prerequisites: The only essential prerequisite is some basic real and complex analysis, up to Cauchy's Residue Theorem (e.g. the modules MA244 Analysis III and MA3B8 Complex Analysis). The course will have a flavour of estimating objects and handling error terms, which might be familiar from previous courses in analysis or probability. There are no number theory prerequisites, but Algebra II (MA249) and Introduction to Number Theory (MA257) might be helpful in a few places.

Content:
The course will cover some of the following topics, depending on time and audience preferences:

- Warm-up:
  The counting functions $\pi(x)$, $\Psi(x)$ of primes up to x. Chebychev's upper and lower bounds for $\Psi(x)$.
- Basic theory of the Riemann zeta function:
  Definition of the zeta function $\zeta(s)$ when $\Re(s) > 1$, and then when $\Re(s) > 0$ and for all s. The connection with primes via the Euler product. Proof that

$\zeta(s) \neq 0$ when $\Re(s) \geq 1$, and deduction of the Prime Number Theorem (asymptotic for $\Psi(x)$).

- More on zeros of zeta:
  Non-existence of zeta zeros follows from estimates for $\sum_{N<n<2N} n^{it}$. The connection with exponential sums, and outline of the methods of Van der Corput and Vinogradov. Wider zero-free regions for $\zeta(s)$, and application to improving the Prime Number Theorem. Statement of the Riemann Hypothesis.
- Primes in arithmetic progressions:
  Dirichlet characters χ and Dirichlet L-functions $L(s, \chi)$. Non-vanishing of $L(1, \chi)$. Outline of the extension of the Prime Number Theorem to arithmetic progressions.

Aims:
Multiplicative number theory studies the distribution of objects, like prime numbers or numbers with "few" prime factors or "small" prime factors, that are multiplicatively defined. A powerful tool for this is the analysis of generating functions like the Riemann zeta function $\zeta(s)$, a method introduced in the 19th century that allowed the resolution of problems dating back to the ancient Greeks. This course will introduce some of these questions and methods.

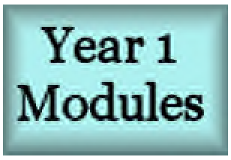
Objectives:
By the end of the module the student should be able to:

- Consolidate existing knowledge from real and complex analysis and be able to place in the context of Analytic Number Theory
- Have a good understanding of the Riemann zeta function and the theory surrounding it up to the Prime Number Theorem
- Understand and appreciate the connection of the zeros of the zeta function with exponential sums and the statement of the Riemann Hypothesis
- Demonstrate the necessary grasp and understanding of the material to potentially pursue further postgraduate study in the area

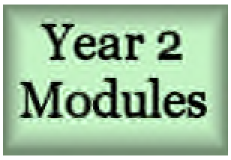
Books:

- H. Davenport. Multiplicative Number Theory. Third edition, published by Springer Graduate Texts in Mathematics. 2000
- A. Ivi'c. The Riemann Zeta-Function. Theory and Applications. Dover edition, published by Dover Publications, Inc.. 2003
- H. Montgomery and R. Vaughan. Multiplicative Number Theory I. Classical Theory. Published by Cambridge studies in advanced mathematics. 2007
- E. C. Titchmarsh. The Theory of the Riemann Zeta-function. Second edition, revised by D. R. Heath-Brown, published by Oxford University Press. 1986

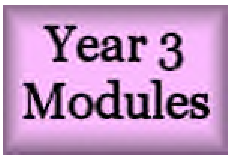
Additional Resources



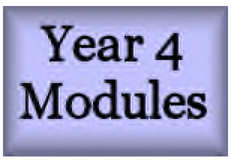
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

MA5Q5 First year MSc project

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma5q5)

Lecturer: Sergey Nazarenko

Term(s): Term 1

Status for Mathematics students:

Commitment:

Assessment: 5000 word Essay

Prerequisites:

Leads To: MA5P1 Dissertation

Content:

The project will be undertaken by MSc students enrolled in the two-year MSc course during their first year of study via study of relevant literature, possibly elements of research, independently but under the guidance of their MSc. supervisor. It will result in a scholarly report written mostly over summer. Before the beginning of the second year, the student must submit a project scholarly report worth 24 CATS which will be marked by the supervisor and a second marker. The project will contribute to the first year mark. An average of 60% including the module and project marks is required to proceed to the second year. However, the first year project will not contribute to the final mark at the end of the second year: this will be reflected in the regulations for G1PC.

Aims:

•to develop an ability to communicate mathematics to diverse audiences.

•to give a deeper appreciation of how mathematics underpins the modern world.

Objectives:

By the end of the module:

The student will learn how to communicate written mathematics.

The student will get ready to undertake similar tasks at a higher depth and scholarly level needed for writing their MSc. dissertation in year 2.

Books:

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

G100 G103

MA5Q6 Graduate Algebra

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma5q6)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List D

Commitment: 30 one hour lectures

Assessment: Three hour examination (85%), weekly assignments (15%)

Prerequisites: This module is aimed at first year PhD/MPhil students. While technically only Algebra II will be assumed, the more important prerequisite is mathematical maturity. 4th year MMath students make take the module only with the permission of the lecturer.

Leads to: : Algebra-oriented TCC modules.

Content: Revision of groups/rings/fields/modules. Basics of category theory, free groups, group presentations, tensor products, multilinear and homological algebra. Brief introduction to representation theory and Galois theory.

Aims: The main aim is to give an overview of various topics in advanced algebra to prepare PhD students for research in all fields.

Objectives: By the end of the module the student should have a more solid and sophisticated understanding of material covered in the undergraduate curriculum, and also familiarity with topics that are not normally part of the undergraduate curriculum, but are assumed by research seminar speakers, such as the basics of category theory and homological algebra.

Books: Sample reference texts:

1. Dummit and Foote "Abstract Algebra"

2. Hungerford "Algebra"

3. Lang "Algebra"

Additional Resources

MA611 Random Matrices and Applications

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma611)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: MA6xx courses are not approved by the University and so you cannot register to take them for credit in the usual way

Commitment:

Assessment:

Prerequisites:

Leads To:

Content:

Content

Additional Resources

MA612 Probability on Function Spaces and Bayesian Inverse Problems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma612)

Not Running in 2015/16

Lecturers:

Term(s):

Status for Mathematics students: Not available for credit

Commitment:
Lectures will take place on Tuesdays and Thursday from 5–7 in room B3.03.
Lectures start on Tuesday October 1st.

Assessment:
Not available

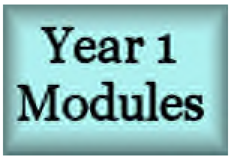
Prerequisites:
Undergraduate probability and differential equations, plus an interest in the topics to be covered.

Content:
Gaussian measures on infinite-dimensional spaces.
Chaining arguments.
Non-Gaussian measures.
Introduction to Bayesian inversion.

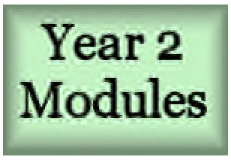
Priors as random functions.
Posterior distribution.
Well-Posedness and approximation of the posterior.
Posterior-preserving stochastic dynamics (SPDEs and MCMC).

Books:
Preliminary reading comprises:
Martin's lectures on SPDEs, which may be found at:
http://arxiv.org/abs/0907.4178. (See, in particular, Chapters 3 and 4);
Andrew's lectures on Inverse Problems, which may be found at:
http://arxiv.org/abs/1302.6989.

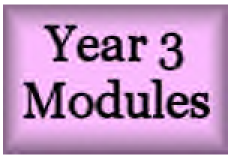
Additional Resources



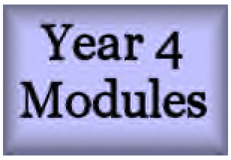
Year 1 regs and modules
G100 G103 GL11 G1NC



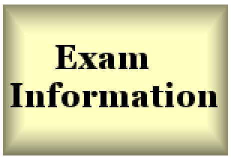
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA613 Topics in Algebraic Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma613)
Lecturer: Miles Reid

Term(s): 1-3

Status for Mathematics students: Not available for credit

Assessment:
Not available

Commitment:

Approximate contents:

-> Introductory examples with easy calculations.

-> How to list the finite subgroups G in SL(2,CC), GL(2,CC), SL(3,CC)

-> Invariants of finite group actions on affine varieties

-> Klein's calculation of invariants

-> Invariants, equations, surface singularities and resolutions in algebraic geometry

-> Representation theory of finite groups

-> G-Hilb and G-Cons and calculations for Abelian groups

-> Moduli problems and correspondences

-> Introduction to DCat and Fourier-Mukai transforms

-> More general theory of DCat and the BKR proof

-> Hilb^n CC^2 and BKR following Haiman

-> Reid's recipe for Abelian groups

-> Theta stability, constellations

-> Other groups: some easy solvable groups, the terminal group 1/r(1,a,r-a) in GL(3,CC), some Abelian subgroups of SL(4,CC) and SL(n,CC)

-> etc.: motivic integration, topology, relations with string theory, Calabi-Yau 3-folds, CY3-algebras.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA408 Algebraic Topology

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma408)
Please note that this module is now being taught as MA3H6

Status for Mathematics students: List C . Suitable for Year 3 MMath

Commitment: 30 one-hour lectures. Suitable for Third Year MMath.

Assessment: Three-hour examination (85%), assessed work (15%)

Prerequisites: MA3F1 Introduction to Topology (keen students can take this module at the same time), MA455 Manifolds (when available) can be taken at the same time as Algebraic Topology

Leads To: MA447 Homotopy Theory and advanced modules in Geometry and Topology

Content: Algebraic topology is concerned with the construction of algebraic invariants (usually groups) associated to topological spaces which serve to distinguish between them. Most of these invariants are "homotopy'' invariants. In essence, this means that they do not change under continuous deformation of the space and homotopy is a precise way of formulating the idea of continuous deformation. This module will concentrate on constructing the most basic family of such invariants, homology groups, and the applications of these homology groups.

The starting point will be simplicial complexes and simplicial homology. An n-simplex is the n-dimensional generalisation of a triangle in the plane. A simplicial complex is a topological space which can be decomposed as a union of simplices. The simplicial homology depends on the way these simplices fit together to form the given space. Roughly speaking, it measures the number of p-dimensional "holes'' in the simplicial complex.

Singular homology is the generalisation of simplicial homology to arbitrary topological spaces. The key idea is to replace a simplex in a simplicial complex by a continuous map from a standard simplex into the topological space. It is not that hard to prove that singular homology is a homotopy invariant but it is quite hard to compute singular homology from the definition. One of the main results in the module will be the proof that simplicial homology and singular homology agree for simplicial complexes. This result means that we can combine the theoretical power of singular homology and the computational power of simplicial homology to get many applications. These applications will include the Brouwer fixed point theorem, the Lefschetz fixed point theorem and applications to the study of vector fields on spheres.

Aims: To introduce homology groups for simplicial complexes; to extend these to the singular homology groups of topological spaces; to prove the topological and homotopy invariance of homology; to give applications to some classical topological problems.

Objectives: To give the definitions of simplicial complexes and their homology groups and a geometric understanding of what these groups measure; to give techniques for computing these groups; to give the extension to singular homology; to understand the theoretical power of singular homology; to develop a geometric understanding of how to use these groups in practice.

Books:

There is no book which covers the module as it will be taught. However, there are several books on algebraic topology which cover some of the ideas in the module, for example:

JW Vick, *Homology Theory*, Academic Press.

MA Armstrong, *Basic Topology*, McGraw-Hill.

Additional references:

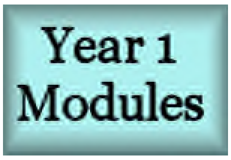
CRF Maunder, *Algebraic Topolgy*, CUP.

A Dold, *Lectures on Algebraic Topology*, Springer-Verlag.

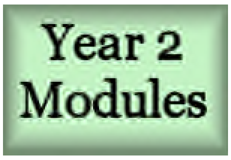
C Kosniowski, *A first course in algebraic topology*, CUP.

MJ Greenberg and JR Harper, *Algebraic Topology: A first course*, Addison-Wesley.

Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

G100 G103

Year 4 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages

MA424 Dynamical Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma424)

Lecturer: Mark Pollicott

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 lectures and weekly assignments

Assessment: 3 hour exam 100%

Prerequisites: MA222 Metric Spaces, MA225 Differentiation

Leads To: Ergodic Theory, Advanced modules in dynamical systems

Content: Dynamical Systems is one of the most active areas of modern mathematics. This course will be a broad introduction to the subject and will attempt to give some of the flavour of this important area.

The course will have two main themes. Firstly, to understand the behaviour of particular classes of transformations. We begin with the study of one dimensional maps: circle homeomorphisms and expanding maps on an interval. These exhibit some of the features of more general maps studied later in the course (e.g., expanding maps, horseshoe maps, toral automorphisms, etc.). A second theme is to understand general features shared by different systems. This leads naturally to their classification, up to conjugacy. An important invariant is entropy, which also serves to quantify the complexity of the system.

Aims: We will cover some of the following topics:

- circle homeomorphisms and minimal homeomorphisms,
- expanding maps and Julia sets,
- horseshoe maps, toral automorphisms and other examples of hyperbolic maps,
- structural stability, shadowing, closing lemmas, Markov partitions and symbolic dynamics,
- conjugacy and topological entropy,
- strange attractors.

Books: R.L. Devaney, *An introduction to chaotic dynamical systems*, Benjamin.

B.Hasselblat and A.Katok, *Dynamics: A first course* , CUP, 2003.

S. Sternberg, Dynamical Systems, Dover

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

MA426 Elliptic Curves

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma426)

Lecturer: Damiano Testa

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: 85% by 3-hour examination 15% coursework

Prerequisites: This is a sophisticated module making use of a wide palette of tools in pure mathematics. In addition to a general grasp of first and second year algebra and analysis modules, the module involves results from MA246 Number Theory (especially factorisation, modular arithmetic). Parts of MA3B8 Complex Analysis, MA3D5 Galois Theory, MA3A6 Algebraic Number Theory or MA4A5 Algebraic Geometry may be helpful but are not essential.

Leads To: Ph.D. studies in number theory or algebraic geometry

Content: We hope to cover the following topics in varying levels of detail:

1. Non-singular cubics and the group law; Weierstrass equations.
2. Elliptic curves over the rationals; descent, bounding $E()/2E()$, heights and the Mordell-Weil theorem, torsion groups; the Nagell-Lutz theorem.
3. Elliptic curves over complex numbers, elliptic functions.
4. Elliptic curves over finite fields; Hasse estimate, application to public key cryptography.
5. Application to diophantin equations: elliptic diophantine problems, Fermat's Last Theorem.
6. Application to integer factorisation: Pollard's $p-1$ method and the elliptic curve method.

Leads to: Ph.D. studies in number theory or algebraic geometry.

Books:

Our main text will be Washington; the others may also be helpful:

- Lawrence C. Washington, Elliptic Curves: Number Theory and Cryptography, Discrete Mathematics and its applications, Chapman & Hall / CRC (either 1st edition (2003) or 2nd edition (2008)
- Joseph H. Silverman and John Tate, Rational Points on Elliptic Curves, Undergraduate Texts in Mathematics, Springer-Verlag, 1992.
- Anthony W. Knapp, Elliptic Curves, Mathematical Notes 40, Princeton 1992.
- J. W. S. Cassels, Lectures on Elliptic Curves, LMS Student Texts 24, Cambridge University Press, 1991.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA427 Ergodic Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma427)
Lecturer: Richard Sharp

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 Lectures

Assessment: 3-hour examination (100%).

Prerequisites: Measure theory, metric spaces, and basic analysis. Some familiarity with linear analysis would be helpful but this is not essential. Term 1's MA424 Dynamical Systems is related to this module but it is not a prerequisite.

Leads To:

Content: Consider the following maps:

1. A fixed rotation of a circle through an angle which is an irrational multiple of 2π.
2. The map of a circle which doubles angles.

If we choose two points of the circle which are close to each other and repeatedly apply the first map the behaviour of each point closely resembles the behaviour of the other point. On the other hand if we apply the second map repeatedly this is no longer the case - the behaviour of each point can be wildly different. The first example can be described as `deterministic' or `rigid' and the second as `random' or `chaotic'. We shall examine many examples of such maps displaying various degrees of randomness, and one of our aims will be to classify different types of behaviour using measure theoretic techniques. A key result (which we will prove) is the ergodic theorem. This is a basic tool in our analysis. We shall also consider applications to number theory and to Markov chains. For most of the module rigorous proofs will be provided. Occasionally we shall give proofs which depend on references which you will be encouraged to read. The written examination will depend only on module lectures.

Aims: To study the long term behaviour of dynamical systems (or iterations of maps) using methods developed in Measure Theory, Linear Analysis and Probability Theory.

Objectives: At the end of the module the student is expected to be familiar with the ergodic theorem and its application to the analysis of the dynamical behaviour of a variety of examples.

Books:

(recommended reading)

A. Katok & B. Hasselblatt, *Introduction to the modern theory of dynamical systems*, C.U.P., 1995.

K. Petersen, *Ergodic Theory*, C.U.P., 1983.

P. Walters, *An introduction to ergodic theory*, Springer, 1982.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA433 Fourier Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma433)
Lecturer: José Rodrigo

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: 3 hour exam

Prerequisites: Familiarity with measure theory at the level of MA359 Measure Theory. A knowledge of Hilbert spaces (e.g., MA3G7 Functional Analysis) is helpful but not necessary.

Leads To: Advanced courses in analysis and probability, for example MA4A2 Advanced Partial Differential Equations, MA4J0 Advanced Real Analysis, and MA911 Probability: Theory and Examples.

Content: Fourier analysis lies at the heart of many areas in mathematics. This course is about the *applications* of Fourier analytic methods to various problems in mathematics and sciences. The emphasis will be on developing the ability of using important tools and theorems to solve concrete problems, as well as getting a sense of doing formal calculations to predict/verify results. Topics will include:

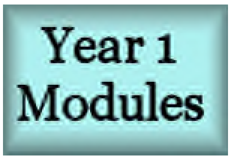
1. Fourier series of periodic functions, Gibbs phenomenon, Fejer and Dirichlet kernels, convergence properties, etc.
2. Basic properties of the Fourier transform on R^d, including L^p theory.
3. Topics on the Fourier inversion formula, including the Gauss-Weierstrass and Abel Poisson kernels, and connections to PDE.
4. A selection of more advanced topics, including the Hilbert transform and an introduction to Singular Integrals.

Aims: The aim of the module is to convey an understanding of the basic techniques and results of Fourier analysis, and of their use in different areas of maths.

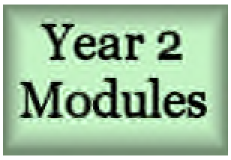
References (optional): The following books may also contain useful materials

- Stein, E. & Shakarchi, R. Fourier Analysis, an Introduction. Princeton University Press 2003.
- Duoandikoetxea, J. Fourier Analysis - American Mathematical Society 2001.
- Körner, T. *Fourier Analysis*, CUP 1988.
- Strichartz, R. *A Guide to Distribution Theory and Fourier Transforms*, CRC Press 1994.
- Folland, G. *Real Analysis: Modern Techniques and their applications*, Wiley 1999.
- Grafakos, L. *Classical Fourier Analysis* - Springer 2008.
- Grafakos, L. *Modern Fourier Analysis* - Springer 2008.
- Stein, E.M. *Singular Integrals and differentiability properties of functions and differentiability properties of functions.* Princeton Univesity Press.

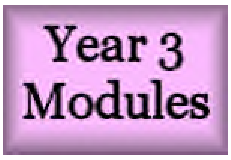
Additional Resources



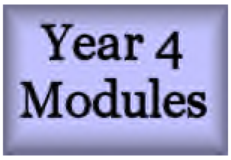
Year 1 regs and modules
G100 G103 GL11 G1NC



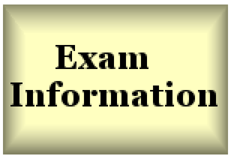
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA442 Group Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma442)

Lecturer: Derek Holt

Term: 2

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: Three-hour written examination (100%)

Prerequisites: MA251 Algebra I: Advanced Linear Algebra, MA249 Algebra II: Groups and Rings

Leads To:

Content: The main emphasis of this course will be on finite groups, and the classification of groups of small order. However, results will be stated for infinite groups too whenever possible.

Permutation groups and groups acting on sets. The Orbit-Stabiliser Theorem. Conjugacy Classes. (Much of this material will have been covered already in MA249.)

The Sylow Theorems. Direct and semidirect products of groups.

Classification of groups of order up to 20 (except 16).

Nilpotent and soluble groups.

More on permutation groups. Primitivity and multiple transitivity.

Groups of matrices. Simplicity of the alternating groups and the groups PSL(n,K).

The transfer homomorphism. Burnside's transfer theorem.

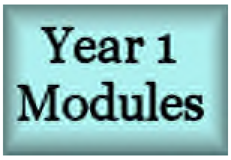
Classification of finite simple groups of order up to 500.

Aims: The main aim of this module is to classify all simple groups of order up to 500. Techniques will include the theorems of Sylow and Burnside, which will be proved in the module, and you will become familiar with different classes of groups, such as finite groups and dihedral groups. The module will give some of the flavour of the greatest achievement in group theory during the 20th century.

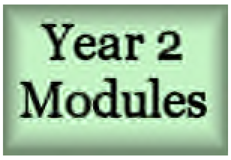
Objectives: By the end of the module students should be familiar with the topics listed above under `Contents'. In particular, they should be able to prove Sylow's Theorems, and to use them and other techniques as a tool for analysing the structure of a finite group of a given order.

Books: No specific books are recommended for this module. There are many groups on Group Theory in the library, and some of these might be helpful for parts of the module, but no single book is likely to cover the whole syllabus.

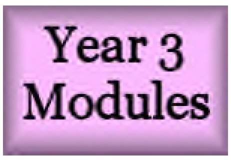
Additional Resources



Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103

MA448 Hyperbolic Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma448)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: List C

Commitment: 30 Lectures

Assessment: 3-hour examination, 100%.

Prerequisites: MA225 Differentiation and MA3F1 Introduction to Topology. MA3B8 Complex Analysis strongly recommended. Closely related to Geometric Group Theory MA4H4, MA475 Riemann surfaces, MA455 Manifolds

Leads To:

Content: An introduction to hyperbolic geometry, mainly in dimension two, with emphasis on concrete geometrical examples and how to calculate them. Topics include: basic models of hyperbolic space; linear fractional transformations and isometries; discrete groups of isometries (Fuchsian groups); tesselations; generators, relations and Poincaré's theorem on fundamental polygons; hyperbolic structures on surfaces.

Aims: To introduce the beautiful interplay between geometry, algebra and analysis which is involved in a detailed study of the Poincaré model of two-dimensional hyperbolic geometry.

Objectives: To understand

- the non-Euclidean geometry of hyperbolic space.
- tesselations and groups of symmetries of hyperbolic space.
- hyperbolic geometry on surfaces.

Books:

J.W. Anderson, *Hyperbolic geometry*, Springer Undergraduate Math. Series.

S. Katok, *Fuchsian groups*, Chicago University Press.

S. Stahl, *The Poincaré half-plane*, Jones and Bartlett.

A. Beardon, *Geometry of discrete groups*, Springer.

J. Lehner, *Discontinuous groups and automorphic functions*. AMS.

L. Ford, *Automorphic functions*, Chelsea (out of print but in library).

J. Stillwell, *Mathematics and its history*, Springer.

Additional Resources

MA453 Lie Algebras

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma453)

Not running in 2017/18.

Lecturer: Inna Capdeboscq

Term(s): Term 2

Status for Mathematics students: List C . Suitable for Year 3 MMath

Commitment: 30 Lectures

Assessment: 3 hour exam (85%), Assessed Work (15%)

Prerequisites:

Leads To:

Content: Lie algebras are related to Lie groups, and both concepts have important applications to geometry and physics. The Lie algebras considered in this course will be finite dimensional vector spaces over endowed with a multiplication which is almost never associative (that is, the products $(ab)c$ and $a(bc)$ are different in general). A typical example is the n^2-dimensional vector space of all $n \times n$ complex matrices, with *Lie product* $[A, B]$ defined as the commutator matrix $[A, B] = AB - BA$. The main aim of the course is to classify the building blocks of such algebras, namely the simple Lie algebras of finite dimension over .

Books:

J.E. Humphreys, *Introduction to Lie algebras and representation theory*, Springer, 1979

T.O. Hawkes, *Lie algebras*, Notes available from Maths Dept.

N. Jacobson, *Lie algebras*, Dover, 1979

Additional Resources

MA455 Manifolds

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma455)

Please note that this module is now being taught as MA3H5

Lecturer:

Term(s):

Status for Mathematics students: List C . Suitable for Year 3 MMath

Commitment: 30 lectures

Assessment: Two pieces of assessed homework 15%, three-hour written exam 85%

Prerequisites: Basic theory of differentiation, including statements (though not proofs) of Inverse and Implicit Function Theorems MA225 Differentiation. Basic topology MA3F1 Introduction to Topology.

Leads To:

Content: Smooth manifolds are generalizations of the notion of curves and surfaces in R^3 and provide a rigorous mathematical concept of space as well as a natural setting for analysis. They form a fundamental part of modern mathematics and are used widely in pure and applied subjects such as differential geometry, general relativity and partial differential equations.

We begin the module with the definition of an abstract smooth manifold and vector bundles, in particular, the tangent and cotangent bundle. We will introduce submanifolds and learn to use the implicit function theorem to construct such objects and learn how manifolds can be concretely realized as subsets of Euclidean space. We will also study Lie groups and their algebras as examples of manifolds and how to construct manifolds using group actions. Next, we return to the tangent bundle to study vector fields and their integral curves. We continue with differential forms and Stokes theorem, the generalization to manifolds of the divergence theorem and touch on de Rham cohomology. Then we consider integrable distributions and the Frobenius theorem.

Aims: To introduce notion of an abstract smooth manifold and to develop students geometric intuition of manifolds together with rigorous analysis.

Objectives: To introduce students to some important ideas that underlie the theory of differentiable manifolds and to develop skills in manipulation of differentiable objects;

1. Construction of manifolds using the implicit function theorem and quotients by group actions;
2. Manipulation of differential forms and Stokes theorem;
3. Vectors fields as local infinitesimal generators and the integration of flows;

4. Frobenius theorem.

Books:

The course text is:

Lee, J .M. *Introduction to Smooth Manifolds*, Springer-Verlag;

Additional texts:

Warner, F. Foundations of differentiable manifolds and Lie groups, Springer-Verlag;

Boothby, W. An introduction to differentiable manifolds and Riemannian geometry, Academic Press;

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA467 Presentations of Groups

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma467)
Lecturer: Derek Holt

Term: 2

Status for Mathematics students: List C . This module is suitable for Third Year MMath students

Commitment: 30 one-hour lectures

Assessment: Three-hour written examination (100%).

Prerequisites: MA251 Algebra I and MA249 Algebra II

Leads To: Postgraduate work in Group Theory

Content: This module is about groups that are defined by means of a presentation in terms of generators and relations. This means that a set of generators X is given for the group G, and a set of defining relations R. Defining relations are equations involving the generators and their inverses, which are required to hold in G. Then G is defined to be essentially the largest group that is generated by a set X for which the defining relations hold. For example, the dihedral group of order 6 could be defined as the group with generating set $X = \{x, y\}$ and relations $R = \{x^3 = 1, y^2 = 1, yxy = x^{-1}\}$.

This method of defining a group has the advantage that it is often the most concise description of the group possible. Furthermore, groups arising from algebraic topology often appear naturally in this form. The disadvantage of the method is that it can be very difficult (and even theoretically impossible in some cases) to derive important properties of a group *G* that is given only by a presentation, such as whether it is finite, abelian, etc., However, as a result of the frequency with which group presentations crop up in other branches of mathematics, the development of techniques for finding out information about these groups has become a major branch of mathematical research.

In this module, we shall be developing the basic theory of group presentations, and looking at some particular techniques for analysing them. We start with free groups (groups with no defining relations) and prove a fundamental theorem of Schreier, that a subgroup of a free group is itself free. We then move on to presentations in general, and look at lots of examples. In the later part of the module, we shall be looking at some algorithmic methods for studying group presentations, including the Todd-Coxeter algorithm for calculating the index of a subgroup *H* of finite index in *G*, and the Reidemeister-Schreier method for calculating a presentation of *H*. (These algorithms are highly suitable for computer implementation, although we will not be studying that aspect of them in detail in this course.)

Aims: To illustrate the important general notion of definition of an algebraic structure by generators and defining relations in the context of group theory.

To develop some examples of the use of algorithmic methods in pure mathematics.

Objectives: To give a mathematically precise but comprehensible treatment of the definition of a group by generators and relations, and to teach students how to start extracting elementary information about the group from its presentation.

To teach students how to carry out the Todd-Coxeter coset enumeration algorithm by hand in simple examples, and how to compute presentations of subgroups of groups.

Books:

D.L. Johnson, *Presentations of Groups* (Second Edition), LMS Student Texts 15 C.U.P. 1997, Chapters 1,2,4,5,8,9.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA472 Reading Course

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma472)
Lecturer:

Term(s): Terms 1-2

Status for Mathematics students: List C

Commitment:

Assessment: 3 hour exam

This scheme is designed to allow any student to offer for exam any reasonable piece of mathematics not covered by the lectured modules, for example a 4th year or M.Sc. module given at Warwick in a previous year. Any topic approved for one student will automatically be brought to the attention of the other students in the year. Note that a student offering this option will be expected to work largely on his or her own.

The aims of this option are (a) to extend the range of mathematical subjects available for examination beyond those covered by the conventional lecture modules, and (b) to encourage the habit of independent study. In the following outline regulations, the term ``book'' includes such items as published lecture notes, one or more articles from mathematical journals, etc.

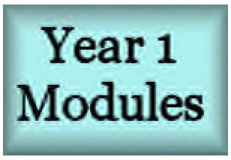
1. A student wishing to offer a book for a reading module must first find a member of staff willing to act as moderator. The moderator will be responsible for obtaining approval of the module from the Director of Undergraduate Studies of the Mathematics Department, and for circulating a detailed syllabus to all MMath students before the end of the Term 1 registration period (week 3).

2. The moderator will be responsible for setting a three-hour exam paper, to be taken during one of the examination sessions in Term 3.

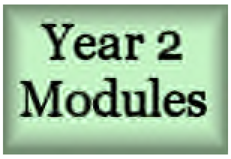
3. The mathematical level and content of a reading module must be at least that of a standard 18 CATS List C module. A reading module must not overlap significantly with any other module in the university available to MMath students.

4. Students may not take more than one reading module in any one year (MA372, MA472 or a reading module with its own code).

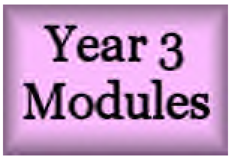
Additional Resources



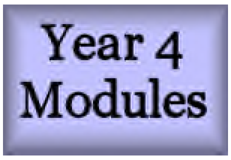
Year 1 regs and modules
G100 G103 GL11 G1NC



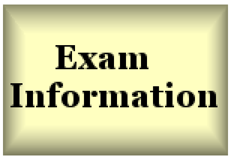
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA473 Reflection Groups

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma473)

Not Running in 2015/16

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: 3 hour exam.

Prerequisites: The only formal prerequisite is MA249 Algebra II. Some of the material is closely related to the material in MA453 Lie Algebras or MA3E1 Groups and Representations but neither of them is a formal prerequisite.

Leads To:

Content: A reflection is a linear transformation that fixes a hyperplane and multiplies a complementary vector by -1. The dihedral group can be generated by a pair of reflections. The main goal of the module is to classify finite groups (of linear transformations) generated by reflections. The question appeared in 1920s in the works of Cartan and Weyl as the Weyl group is a finite crystallographic reflection group. In fact, if you have done MA453 Lie Algebras then you are already familiar with classification of semisimple Lie algebras, which is essentially the classification of crystallographic reflection groups.

Besides classifications, we will concentrate on examples and polynomial invariants.

Reference: R. Goodman, *The Mathematics of Mirrors and Kaleidoscopes*, American Mathematical Monthly.

www.math.rutgers.edu/~goodman/pub/monthly.pdf

Book:

J. E. Humphreys, *Reflection groups and Coxeter groups*, Cambridge University Press, 1992.

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

G100 G103

Year 4 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages

MA475 Riemann Surfaces

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma475)

Lecturer: John Smillie

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one-hour lectures, and fortnightly example sheets.

Assessment: 100% by a three-hour written exam.

Prerequisites: Complex Analysis and MA3F1 Introduction to Topology

Leads To: MA505 Algebraic Geometry, MA455 Manifolds

Content: Riemann Surfaces arose naturally in the study of complex analytic functions. They are abstract objects, patched together from open domains of the complex plane according to a rigid set of patching data. The beauty of complex analysis carries over to this abstract setting: the apparently very general definition turns out to constrain the objects in a rather strong way. This leads to interesting geometric, analytic and topological theorems about Riemann surfaces, showing also their ubiquity in much of modern mathematics.

We will first review some of the important features of complex analysis in the plane, before moving on to defining Riemann surfaces as abstract objects modelled on planar domains, and give several examples such as the Riemann sphere, complex tori, and so on. We will explore how Riemann surfaces can be classified and uniformised, along the way taking in such results as the Monodromy theorem, the Riemann mapping theorem and introducing concepts such as universal covers and the covering group of deck transformations. The rest of the module will explore further topics: the degree of a mapping, triangulations and the Riemann-Hurwitz formula, the construction of holomorphic differentials and meromorphic functions on Riemann surfaces, metrics of constant curvature and the pants decompositions of Riemann surfaces, quasiconformal maps and the deformation of complex structures.

Aims: To motivate the idea of a Riemann surface along the lines of Riemann's original reasoning; to introduce the abstract concepts supported by examples; to explain the modern way of understanding Riemann surfaces and discuss their geometry and topology.

Objectives: Students at the end of the module should be able to define abstract Riemann surfaces with maps between them and give examples; use hyperbolic geometry and other geometries to construct Riemann surfaces; analyse topological and numerical properties of analytic mappings between Riemann surfaces; understand the classification of complex tori; and have an overall understanding of all Riemann surfaces as quotients of their universal covers using the statement of the Uniformisation Theorem.

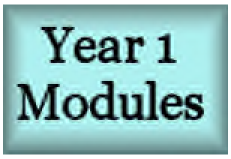
Books:

L V Ahlfors, *Complex Analysis: an introduction to the theory of analytic functions of one complex variable*, McGraw-Hill.

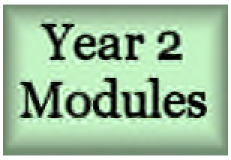
A Beardon, *A primer on Riemann surfaces*, CUP.

O Forster, *Lectures on Riemann Surfaces*, Chapter I, Springer.

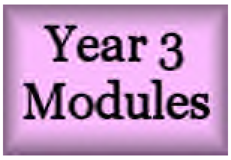
Additional Resources



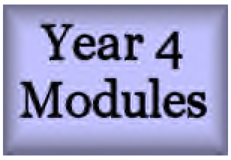
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

MA482 Stochastic Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma482)
Lecturer: Hendrick Weber

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: 3-hour examination

Prerequisites: A willingness, even an enthusiasm, to work with random variables is the key prerequisite. No single module is a prerequisite. Earlier probability modules will be some use. The framework is measure theory, so it is a nice illustration of the ideas from MA359 Measure Theory, or ST342 Maths of Random Events, or ST318 Probability Theory. The content will also link with some content from modules on ODE's and PDEs. A student without any of the above would have to work hard.

Leads To:
The module complements the module MA4F7/ ST403 Brownian Motion.

Content:
We will introduce continuous time martingales, stochastic integration, and basic tools in stochastic analysis including Ito's formula, various inequalities for local martingales and for stochastic integrals. We will also introduce stochastic differential equations and study their basic properties. Time permitting, we will also discuss completeness, strong completeness of SDEs and differentiation of probabilistic semi-groups.

Books:
Revuz and Yor, Continuous Martingales and Brownian Motion
Ikeda and Watanabe: Stochastic Differential Equations and Diffusion Processes

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

G100 G103

Year 4 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages

MA4A2 Advanced Partial and Differential Equations

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4a2)
Lecturers: Grzegorz Jamroz

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 lectures

Assessment: 3 hour exam (85%), Assessment (15%, "take home mid-term exam").

Prerequisites: Strongly recommended to have taken MA3G7 Functional Analysis I and MA359 Measure Theory.

Leads To: MA4G6 Calculus of Variations and MA592 Topics in PDE.

Content: The theory of partial differential equations (PDE) is important in both pure and applied mathematics. This module will deal with the basic concepts of the modern functional-analytic approach to the study of PDE: the notions of PDE and boundary value problems; questions of existence, uniqueness and properties of the solution for general domains and data. To address these questions, modern tools like Sobolev spaces will be introduced. They allow us to give a precise meaning to these questions and answer them for many examples.

Aims: To introduce the rigorous, abstract theory of partial differential equations.

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules

G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules

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Year 4 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages

MA4A5 Algebraic Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4a5)
Lecturer: Christian Boehning

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 lectures plus assignments

Assessment: Assignments (30%), 3 hour written exam (70%).

Prerequisites:
A background in algebra (especially MA249 Algebra II) is essential. The module develops more specialised material in commutative algebra and in geometry from first principles, but MA3G6 Commutative Algebra will be useful. More than technical prerequisites, the main requirement is the sophistication to work simultaneously with ideas from several areas of mathematics, and to think algebraically and geometrically. Some familiarity with projective geometry (e.g. from MA243 Geometry) is helpful, though not essential.

Leads To:
A first module in algebraic geometry is a basic requirement for study in geometry, number theory or many branches of algebra or mathematical physics at the MSc or PhD level. Many MA469 projects are on offer involving ideas from algebraic geometry.

Content:
Algebraic geometry studies solution sets of polynomial equations by geometric methods. This type of equations is ubiquitous in mathematics and much more versatile and flexible than one might as first expect (for example, every compact smooth manifold is diffeomorphic to the zero set of a certain number of real polynomials in R^N). On the other hand, polynomials show remarkable rigidity properties in other situations and can be defined over any ring, and this leads to important arithmetic ramifications of algebraic geometry.

Methodically, two contrasting cross-fertilizing aspects have pervaded the subject: one providing formidable abstract machinery and striving for maximum generality, the other experimental and computational, focusing on illuminating examples and forming the concrete geometric backbone of the first aspect, often uncovering fascinating phenomena overlooked from the bird's eye view of the abstract approach.

In the lectures, we will introduce the category of (quasi-projective) varieties, morphisms and rational maps between them, and then proceed to a study of some of the most basic geometric attributes of varieties: dimension, tangent spaces, regular and singular points, degree. Moreover, we will present many concrete examples, e.g., rational normal curves, Grassmannians, flag and Schubert varieties, surfaces in projective three-space and their lines, Veronese and Segre varieties etc.

Books:

- Atiyah M.& Macdonald I. G., Introduction to commutative algebra, Addison-Wesley, Reading MA (1969)
- Harris, J., Algebraic Geometry, A First Course, Graduate Texts in Mathematics 133, Springer-Verlag (1992)
- Mumford, D., Algebraic Geometry I: Complex Projective Varieties, Classics in Mathematics, reprint of the 1st ed. (1976); Springer-Verlag (1995)
- Reid, M., Undergraduate Algebraic Geometry, London Math. Soc. Student Texts 12, Cambridge University Press (2010)
- Shafarevich, I.R., Basic Algebraic Geometry 1, second edition, Springer-Verlag (1994)
- Zariski, O. & Samuel, P., Commutative algebra, Vol. II, Van Nos- trand, New York (1960)

Additional Resources

Year 1 Modules

Year 1 regs and modules

G100 G103 GL11 G1NC

MA4A7 Quantum Mechanics: Basic Principles and Probabilistic Methods

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4a7)
Lecturer: Vassili Gelfreich

Term(s): Term 2

Status for Mathematics students:

Commitment: 30 lectures

Assessment: 3 hour examination (100%)

Prerequisites: There are no strict prerequisites. But knowledge of Partial differential equations and, in some parts, Functional Analysis, will be helpful.

Leads To:

Content:

Quantum mechanics is one of the most successful and most fundamental scientific theories. It provides mathematical tools capable of describing properties of microscopic structures of our World. It is fundamental to the understanding of a variety of physical phenomena, ranging from atomic spectra and chemical reactions to superfluidity and Bose-Einstein condensation.

In the lectures we will discuss mathematical foundations of quantum theory: This includes the concepts of mixed and pure states, observables and evolution operator, a wave function in Hilbert space, the stationary and time-dependent Schrödinger equations, the uncertainty principle and the connections with classical mechanics (Ehrenfest theorem).

We will give simple, exactly soluble examples of both time-dependent and time-independent Schrodinger equations. We will also touch some more advanced topics of the theory.

Aims:
To introduce the basic concepts and mathematical tools used in quantum mechanics, preparing students for areas which are at the forefront of current research.

Objectives:
The students should obtain a good understanding of the basic principles of quantum mechanics, and to learn the methods used in the analysis of quantum mechanical systems.

Books:

S.J. Gustafson, I.M. Sigal, Mathematical concepts of quantum mechanics, Springer, 2011.

A. Messiah, Quantum mechanics, Dover, 1999.

L. D. Faddeev, O. A. Yakubovskiĭ, Lectures on quantum mechanics for mathematics students. Student Mathematical Library, 47. American Mathematical Society, Providence, RI, 2009, 234 pp

W.G. Faris, Outline of Quantum Mechanics, in Entropy and the Quantum, Contemp. Math. 529, 1-52 (2010)

J. Fröhlich, B. Schubnel, Do we understand quantum mechanics - finally? (2012)

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA4C0 Differential Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4c0)
Lecturers: Peter Topping

Term(s): Term 1

Status for Mathematics students: List C

Commitment:

Assessment: Examination (100%)

Prerequisites: A knowledge of manifolds, e.g. MA3H5 Manifolds is required. These topics will be covered rapidly in the first few lectures. A thorough knowledge of linear algebra, including bilinear forms, dual spaces, eigenvalues and eigenvectors is essential, as is a thorough knowledge of differentiation of functions of several variables, including the Chain Rule and Inverse and Implicit Function theorems. Familiarity with basic point set topology, including quotient/identification topology, will be assumed, as well as the statement of the theorem on the existence and uniqueness of solutions to ODEs and their smooth dependence on parameters, in particular on initial conditions.

Outline: The core of this course will be an introduction to Riemannian geometry - the study of Riemannian metrics on abstract manifolds. This is a classical subject, but is required knowledge for research in diverse areas of modern mathematics. We will try to present the material in order to prepare for the study of some of the other geometric structures one can put on manifolds.

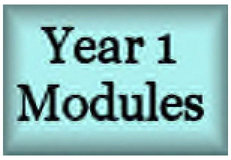
Summary:

- Review of basic notions on smooth manifolds; tensor fields.
- Riemannian metrics.
- Affine connections; Levi-Civita connection; parallel transport.
- Geodesics; exponential map; minimising properties of geodesics.
- The curvature tensor; sectional, Ricci and scalar curvatures.
- Training in making calculations: switching covariant derivatives; Bochner/Weitzenböck formula.
- Jacobi fields; geometric interpretation of curvature; second variation of length.
- Classical theorems in Riemannian Geometry: Bonnet-Myers, Hopf-Rinow and Cartan-Hadamard.

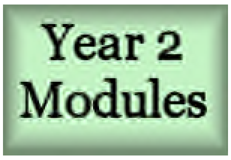
Leads To: MA469 Project.

Books:
Lee, J. M.: Riemannian Manifolds: An Introduction to Curvature. Graduate Texts in Mathematics, 176. Springer-Verlag, 1997.
Gallot, S., Hulin, D., Lafontaine, J.: *Riemannian geometry*. Springer. 2nd edition (1993)
Jost, J.: Riemannian Geometry and Geometric Analysis 5th edition. Springer-Verlag, 2008
Petersen, P.: *Riemannian Geometry* Graduate Texts in Mathematics, 171. Springer-Verlag, 1998
Kobayashi, S., Nomizu, K.: Foundations of differential geometry.
do Carmo, M: Riemannian geometry. Birkhäuser, Boston, MA, 1992.

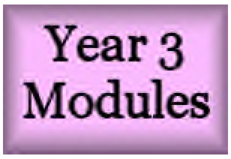
Additional Resources



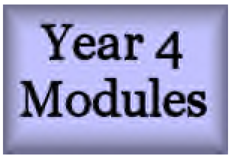
Year 1 regs and modules
G100 G103 GL11 G1NC



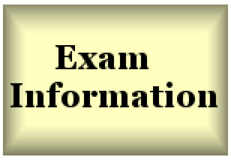
Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103



Past Exams
Core module averages

MA4E0 Lie Groups

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4e0)
Lecturer: Weiyi Zhang

Term(s): Term 1

Status for Mathematics students: List C

Commitment: 30 Lectures

Assessment: 3 hour exam

Prerequisites: A knowledge of calculus of several variables including the Implicit Function and Inverse Function Theorems, as well as the existence theorem for ODEs. A basic knowledge of manifolds, tangent spaces and vector fields will help. Results needed from the theory of manifolds and vector fields will be stated but not proved in the course.

Content: The concept of continuous symmetry suggested by Sophus Lie had an enormous influence on many branches of mathematics and physics in the twentieth century. Created first as a tool in a small number of areas (e.g. PDEs) it developed into a separate theory which influences many areas of modern mathematics such as geometry, algebra, analysis, mechanics and the theory of elementary particles, to name a few.

In this module we shall introduce the classical examples of Lie groups and basic properties of the associated Lie algebra and exponential map.

Books:

The lectures will not follow any particular book and there are many in the Library to choose from. See section QA387. Some examples:

C. Chevalley, *Theory of Lie Groups, Vol I*, Princeton.

J.J. Duistermaat, J.A.C. Kölk, *Lie Groups*, Springer, 2000.

F.W. Warner, *Foundations of Differentiable Manifolds and Lie Groups*, (Graduate Texts in Mathematics), Springer, 1983.

Additional Resources

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 Modules

Year 3 regs and modules
G100 G103

Year 4 Modules

Year 4 regs and modules
G103

Exam Information

Past Exams
Core module averages

MA4E7 Population Dynamics: Ecology & Epidemiology

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4e7)
Lecturer: Louise Dyson

Term(s): Term 2

Status for Mathematics students: List C

Commitment: 30 one-hour lectures

Assessment: Three-hour exam.

Prerequisites: MA390 Topics in Mathematical Biology provides some useful background material. This course complements the work covered by MA480 Mathematics in Medicine.

Leads To:

Content: This course deals with the mathematics behind the dynamics of populations; both populations of free-living organisms (from plants to predators) and those that cause disease. Once the basic models and concepts have been introduced attention will focus on understanding the many complexities that can arise, such as age-structure, spatial structure, temporal forcing and stochasticity. The focus of the course will be how mathematical models can help us both predict the future behaviour of populations and understand their dynamics.

Research into the dynamics of ecological populations allows us to understand the conservation of endangered species, make predictions about the effects of global climate change and understand the population fluctuations observed in the natural world. Work on infectious diseases clearly has important applications to public-health, allowing us to predict the spread of an epidemic (such as Foot-and-Mouth or SARS virus) and determine the effect of control measures.

Throughout, use will be made of examples in the recent literature, with a strong bias towards read-world problems. Special attention will be given to the applied use of the models developed and the necessity of good quality biological data and understanding.

Books:

Much of this course will be based on research papers and comprehensive references will be given throughout the course. Four useful books are:

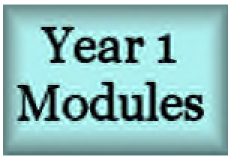
R.M. Anderson and R.M. May *Infectious Diseases of Humans*, Oxford University Press, 1992. (ISBN 019854040X)

S.P. Ellner and J. Guckenheimer *Dynamic Models in Biology*, Princeton University Press, 2006 (ISBN 0691125899)

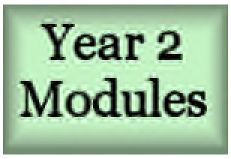
R.M. May and A. McLean *Theoretical Ecology: Principles and Applications*, Oxford University Press, 2007 (ISBN 0199209995)

M.J. Keeling and P. Rohani *Modeling Infectious Diseases in Humans and Animals*, Princeton University Press, 2007 (ISBN 0691116172)

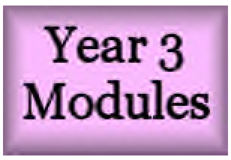
Additional Resources



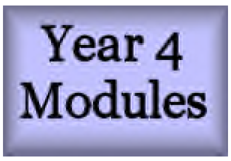
Year 1 regs and modules
G100 G103 GL11 G1NC



Year 2 regs and modules
G100 G103 GL11 G1NC



Year 3 regs and modules
G100 G103



Year 4 regs and modules
G103

Exam Information

Past Exams

Core module averages

MA4F7 Brownian Motion

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4f7)
This module is the same as ST403 Brownian Motion. Students may not register for both.

Term 2

Status for Mathematics students: List C

Lecturer(s)

Dr Nikos Zygouras

Also offered by Maths as MA4F7

WHAT IS IT?

Brownian motion was originally the description given in physics for the random erratic movement of molecules. In 1905 Einstein made a detailed study in which he postulated certain properties should hold. In 1923 mathematical Brownian motion was born when a famous mathematician, Norbert Wiener, showed how to construct a random function *W*(*t*) giving the molecules "position" at time *t* which had Einstein's properties.

WHY IS IT INTERESTING?

- It is a beautiful mathematical object worth studying both for its own sake and because of the deep links it has with other areas of mathematics, particularly in analysis.
- Brownian motion is a fundamental tool for modelling processes which evolve randomly in time. It is used widely in many areas of applied maths and in the last few decades it has become essential to the study of financial maths as a model of stock prices.

WHAT WILL WE LEARN?

- **Construction.** According to Einstein

- the function *t* ® *W*(*t*) must be continuous – the molecule never jumps

- the displacement between times *s* and *t*, that is *W*(*t*) – *W*(*s*), should be independent of the past motion and its distribution should be Gaussian with mean zero and variance *t* – *s*.

We will investigate methods of constructing such random functions. It turns out the Gaussian distribution is essential – it is impossible to do with any other distribution.

- **Properties of the paths.** The path *t* ® *W*(*t*) cannot be smooth. Look at http://users.stat.umn.edu/~geyer/Stoch/brown.html to see a simulation. The applet at this web site allows you to zoom in on a simulated path – notice it seems to look the same no matter how much it is magnified: Brownian motion is the ultimate fractal!
- **The stochastic calculus.** Ordinary calculus is a powerful method of doing calculations with smooth functions. As we have just seen Brownian paths are not smooth, but miraculously there is a "stochastic calculus" which was developed by a Japanese mathematician Ito in the 1940s and which allows us to do computations with Brownian motion.
- **Differential equations.** Differential equations are essential to modelling deterministic phenomena in applied maths and physics.

Somewhat surprisingly this can be solved probabilistically using Brownian motion – a fact that lies at the heart of the links between probability theory and analysis, and which is still today yielding new discoveries.

***Prerequisite(s)*:**

AT LEAST ONE OF: ST318 Probability Theory, MA359 Measure Theory.

This module runs in Term 2.

***Assessment*:** 100% by 2 hour examination.

Books:
Peter Mörters and Yuval Peres, *Brownian Motion*
R. Durrett, *Stochastic Calculus: a practical introduction*

MA4G0 Probability and Statistical Mechanics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4g0)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students:

Commitment:

Assessment:

Prerequisites:

Leads To:

This page has no content yet.

Additional Resources

Year 1 Modules
Year 1 regs and modules
G100 G103 GL11 G1NC

MA4G4 Introduction to Theoretical Neuroscience

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4g4)

Not running in 2017/18.

Lecturer: Magnus Richardson

Term(s): Term 2

Status for Mathematics students: List C for Mathematics

Commitment: 30 one-hour lectures

Assessment: 3 hour exam.

Prerequisites: Calculus and standard methods for the solution of differential equations. Basic knowledge of stochastic calculus (Langevin, Fokker-Planck and master equations) and probability theory would be an advantage

Leads To:

Location and times

When and where for year 2016/2017
Academic weeks 15-24

Mondays: 11am in B3.01
Wednesdays: 11am in D1.07
Thursdays: 11am in MS.04

Start: Monday 9th January 2017.
End: Thursday 16th March 2017.

Exam
Duration: 3 hours. No calculators allowed.
Date: To be confirmed
A Few Basic Equations

Past paper 2012 Questions
Past paper 2013 Questions