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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 |
| | MA4A2 | Advanced PDEs | 15 | List C |
| | MA4A5 | Algebraic Geometry | 15 | List C |
| | MA4C0 | Differential Geometry | 15 | List C |
| | MA4E0 | Lie Groups | 15 | List C |
| | MA4F7 | Brownian Motion | 15 | List C |
| | MA4H0 | Applied Dynamical Systems | 15 | List C |
| | MA4H7 | Atmospheric Dynamics | 15 | List C |
| | MA4H8 | Ring Theory | 15 | List C |
| | MA4J3 | Graph Theory | 15 | List C |
| | MA4J5 | Structures of Complex Systems | 15 | List C |
| | MA4L6 | Analytic Number 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<br>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 |
| | MA448 | Hyperbolic Geometry | 15 | List C |
| | MA453 | Lie Algebras | 15 | List C |
| | MA475 | Riemann Surfaces | 15 | List C |
| | MA482 | Stochastic Analysis | 15 | List C |
| | MA4A7 | Quantum Mechanics: Basic Principles and Probabilistic Methods | 15 | List C |
| | MA4E7 | Population Dynamics: Ecology and Epidemiology | 15 | List C |
| | MA4G6 | Calculus of Variations | 15 | List C |
| | MA4H4 | Geometric Group Theory | 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 |
| | MA4J6 | Mathematics and Biophysics of Cell Dynamics | 15 | List C |
| | MA4L7 | Algebraic Curves | 15 | List C |
| | MA5Q3 | Topics in Complexity Science | 18 | List D |

## 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 and GSD)

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 (this module is run by Global Sustainable Development from 2018 on).

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 (as an Unusual Option) 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. We used to restrict maths students to 24 (12) if there was a choice, but we no longer do this.

**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.

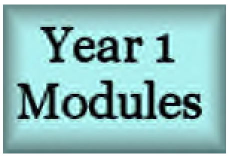
Information on modules can be found at

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

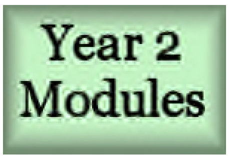
## Objectives

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**

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## 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**:

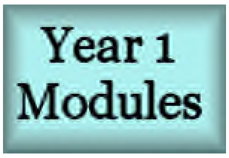
By the end of the module the student should be able to:

- 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

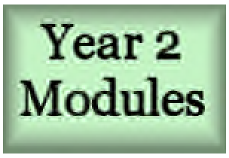
**Books**:
Isaacs, *Character Theory of Finite Groups*
Curtis and Reiner, *Methods of Representation Theory, with Applications to Finite Groups and Orders*, Vols. 1 and 2

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

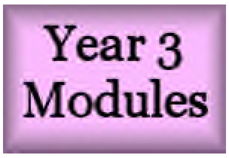
## Additional Resources



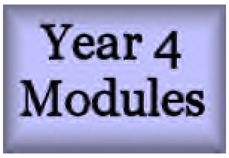

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



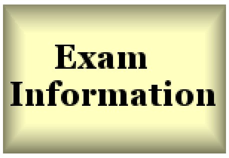

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## 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.

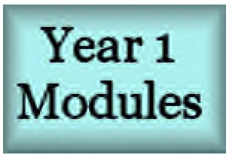
*Stokes phenomenon*: examples, asymptotics in sectors of a complex plane, an application - asymptotic of Airy function.
*Multivalued analytic functions*: analytic continuation, multivalued functions, introduction to Riemann surfaces.
*Formal convergence*: space of formal series, formal convergence, an 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.

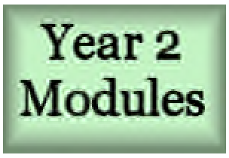
**Objectives:**
At the end of the module the student should be familiar with the methods involving analysis of asymptotic series and to acquire basic techniques in studying asymptotic problems. The student should be able to perform analysis of divergent series and to be able to correctly interpret them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

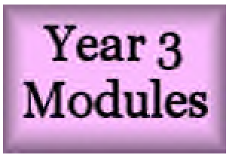
## Additional Resources



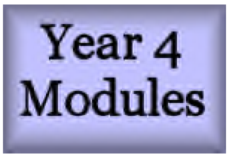
**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



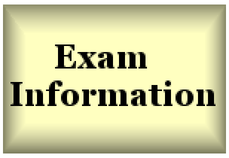
**Year 2 regs and modules**
**G100 G103 GL11 G1NC**



**Year 3 regs and modules**
**G100 G103**



**Year 4 regs and modules**
**G103**



**Past Exams**
**Core module averages**

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## 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.

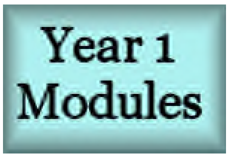
**Objectives:**
By the end of the module, students will:

- 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).

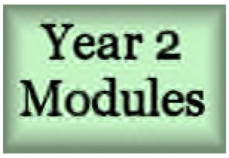
**Books:**

- 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**




**Year 2 regs and modules**
**G100 G103 GL11 G1NC**

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## MA4G6 Calculus of Variations

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

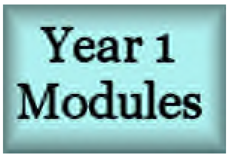
**Objectives:**
By the end of the module the student should be able to:

- 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.

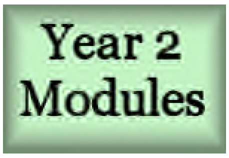
**Books:**
B. Dacorogna: *Introduction to the Calculus of Variations*. Imperial College Press 2004.
B. Dacorogna: *Direct Methods in the Calculus of Variations*. 2nd edition. Springer, 2008.
L. C. Evans: *Partial Differential Equations*. 2nd edition. AMS, 2010 (some chapters).
I. Fonseca and G. Leoni: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

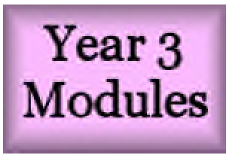
Archived Pages: 2014 2016



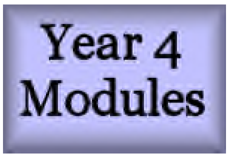

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**




**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

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## MA4J7 Cohomology and Poincaré Duality

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j7)
**Lecturer:** Dr. Saul Schleimer

**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

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

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## 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

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## 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. "$L^\infty$" 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.

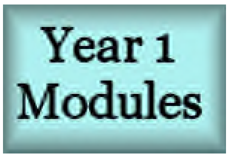
**Literature:**
The course will be based on two sets of lectures notes; details of how to access these are given under Additional Resources.
The following books may also be of interest:

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

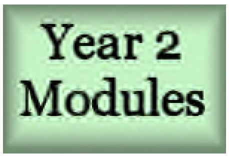
Le Maître, O. P.; Knio, O. M. *Spectral methods for uncertainty quantification. With applications to computational fluid dynamics.* Scientific Computation. Springer, New York, 2010. xvi+536 pp. ISBN: 978-90-481-3519-6

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

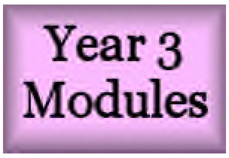
## Additional Resources



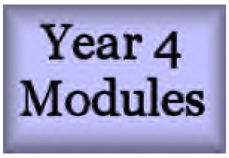

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



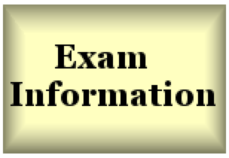

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## 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.

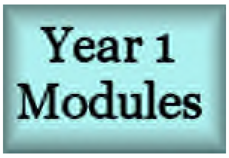
List A (These books contain material directly relevant to the module):-

- 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)

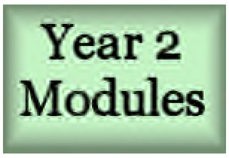
List B (The following texts contain relevant and more advanced material):-

- 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




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




**Year 2 regs and modules**
**G100 G103 GL11 G1NC**

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## 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**

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## 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.

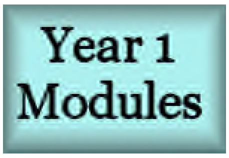
**Aims:**
The principle aim is firstly to introduce basic stochastic models of collective phenomena arising from the interactions of a large number of identical components, called interacting particle systems. The module will then introduce several key topics which are currently at the forefront of mathematical 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**

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## 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

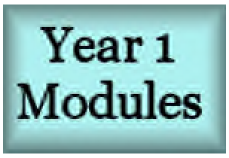
equations, including a statement of the relevant well-posedness theorems and a discussion of their relevance. We will take a 'field theory' approach to the subject, emphasising the deep connection between Lorentzian geometry and hyperbolic PDE. In contrast to the course PX436 General Relativity offered 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:

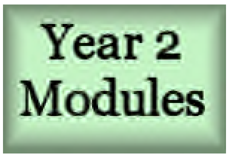
- Understand how the Minkowski geometry and Lorentz group arise from considerations of signal propagation for the scalar wave equation.
- Understand the basics of Lorentzian geometry: the metric; causal classification of vectors; connection and curvature; hypersurface geometry; conformal compacti cations; 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.

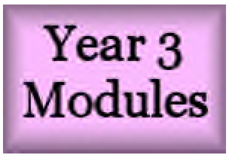
## Additional Resources



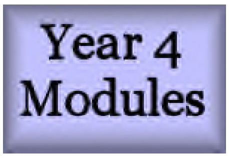

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



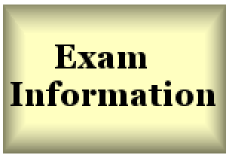

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## 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.

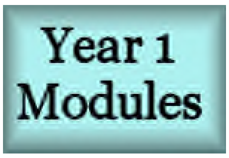
**Aims:**
The module will form a fourth year option on the MMath Degree. Data Assimilation is concerned with the principled integration of data and dynamial models to produce enhanced predictive capability. As such it finds wide-ranging applications in areas such as weather forecasting, oil reservoir 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:

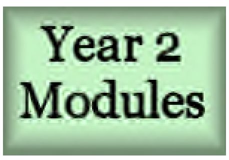
- Stochastic dynamical systems
- Long-time behaviour of dynamical systems
- Bayesian probability
- Metrics on probability measures
- Monte Carlo Markov Chain
- Optimization
- Control
- Matlab programming

**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




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




**Year 2 regs and modules**
**G100 G103 GL11 G1NC**

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## 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....)

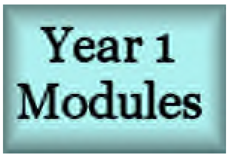
- Appreciate universality of the fluid dynamics processes in diverse applications, from quantum fluids to astrophysical systems.

- 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.

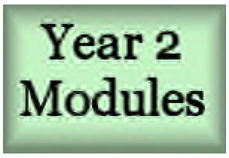
**Books:**

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

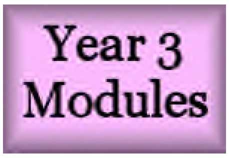
## Additional Resources



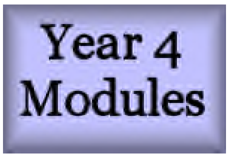

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



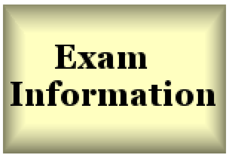

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## MA4L1 Mathematical Modelling in Biology and Medicine

(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 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**

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## MA4L2 Statistical Mechanics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l2)
**Lecturer:** Professor Roman Kotecky

**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

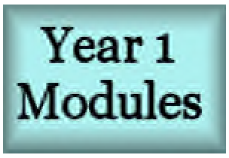
http://www.unige.ch/math/folks/velenik/smbook/index.html

Interested students can also look into:

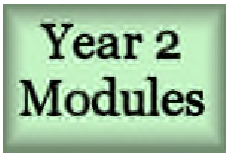
David Ruelle, Statistical Mechanics: Rigorous Results, World Scientific, 1999.

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

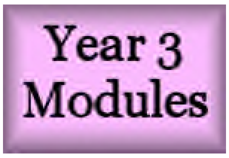
## Additional Resources




**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**

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## 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).

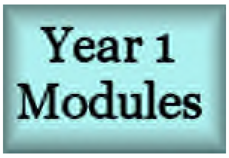
Other relevant books and lecture notes:

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

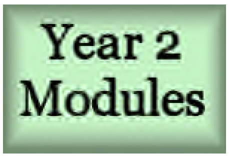
[b] Stefan Adams, Lectures on mathematical statistical mechanics, Communications of the Dublin Institute for Advanced Studies Series A (Theoretical Physics), No. 30 , available online http://www2.warwick.ac.uk/fac/sci/maths/people/staff/stefan adams/lecturenotestvi/cdias-adams-30.pdf

[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

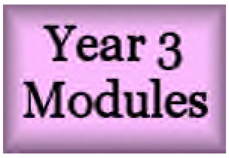
## Additional Resources



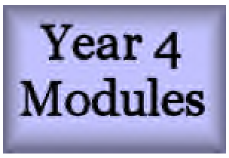

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**




**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**

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# 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

Archived Pages: 2017

Year 1 Modules

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 Modules

Year 2 regs and modules
G100 G103 GL11 G1NC

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## MA4L6 Analytic Number Theory

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

**Term(s):** Term 1

**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, including uniform convergence, the Identity Theorem from complex analysis, and especially Cauchy's Residue Theorem (e.g. the modules MA244 Analysis III and MA3B8 Complex Analysis). There are no real number theory prerequisites, but things like the Chinese Remainder Theorem and the structure of the multiplicative group mod q (as in e.g. MA249 Algebra II and MA257 Introduction to Number Theory) will be useful in a few places.

Although there are not many prerequisites in terms of content, the course will have a serious "analytic" flavour of estimating objects and handling error terms. The most important thing is to be comfortable with this style of mathematics, which might be familiar from previous courses in analysis, measure theory or probability.

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**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 $\chi$ 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.

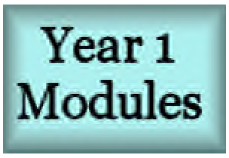
**Objectives:**
By the end of the module the student should be able to:

- 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

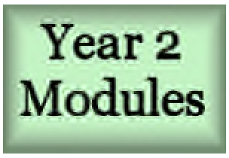
**Books:**

- 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

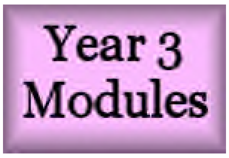
## Additional Resources



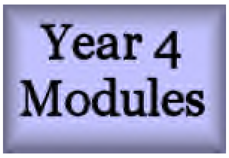

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



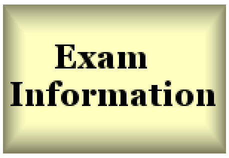

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## MA4L7 Algebraic Curves

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4l7)

**Lecturer:** Professor Miles Reid

**Term(s):** Term 2

**Status for Mathematics students:** List C

**Commitment:** 30 Lectures

**Assessment:** 85% exam, 15% assessed worksheets

**Prerequisites:** The module is intended as an entry-level introduction to the ideas of algebraic geometry. The student may have picked up part or all of the prerequisites from different sections of these Warwick modules: MA3D5 Galois Theory, MA3G6 Commutative Algebra or MA3A6 Algebraic Number Theory.

Some familiarity with basic ideas of commutative algebra is a prerequisite. More specifically, the main technical items are localisation (partial rings of fraction of an integral domain), local rings and integral closure. These ideas are similar to those that apply to rings of integers in a number field. The proof of RR develops characterisations of free modules over a polynomial ring such as $k[x, y]$, from first principles.

**Content:**

The module covers basic questions on algebraic curves. The first sections establishes the class of nonsingular projective algebraic curves in algebraic geometry as an object of study, and, for comparison and motivation, the parallel world of compact Riemann surfaces. After these preliminaries, most of the rest of the course focuses on the Riemann--Roch space $\mathcal{L}(C, D)$, the vector space of meromorphic functions on a compact Riemann surface or a nonsingular projective algebraic curve with poles bounded by a divisor $D$ - roughly speaking, allowing more poles gives more meromorphic functions.

The statement of the Riemann-Roch theorem

$$\dim \mathcal{L}(C, D) \geq 1 - g + \deg D.$$

It comes with sufficient conditions for equality. The main thrust of the result is to provide rational functions that allows us to embed $C$ into projective space $\mathbb{P}^n$. The formula involves an invariant called the genus $g(C)$ of the curve. In intuitive topological terms, we think of it as the "number of holes". However, it has many quite different characterisations in analysis and in algebraic geometry, and is calculated in many different ways. The logical relations between these treatments is a little complicated. A middle section of the course emphasizes the meaning and purpose of the theorem (independent of its proof), and give important examples of its applications.

The proof of RR is based on commutative algebra. Algebraic varieties have many different types of rings associated with them, including affine coordinate rings, homogeneous coordinate rings, their integral closures, and their localisations such as the DVRs that correspond to points of a nonsingular curve. Footnote to the course notes include (as nonexaminable material) references to high-brow ideas such as coherent sheaves and their cohomology and Serre--Grothendieck duality.

**Learning Outcomes:**

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

- Demonstrate understanding of the basic concepts, theorems and calculations related to projective curves defined by homogeneous polynomials of low degree.
- Demonstrate understanding of the basic concepts, theorems and calculations that relate the zeroes and poles of rational functions with the general theory of discrete valuation rings and divisors on projective curves.
- Demonstrate knowledge and understanding of the statement of the Riemann-Roch theorem and an understanding of some of its applications.
- Demonstrate understanding of the proof of the Riemann-Roch theorem.

**Books:**

Frances Kirwan, *Complex algebraic curves*, LMS student notes

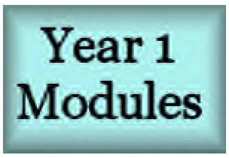
William Fulton, *Algebraic Curves: An Introduction to Algebraic Geometry* online at www.math.lsa.umich.edu/~wfulton/CurveBook.pdf

I.R. Shafarevich, *Basic Algebraic Geometry* (especially Part 1, Chapter 3, Section 3.7)

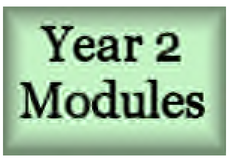
Robin Hartshorne, *Algebraic Geometry*, (Chapter 4 only)

The lecturer's notes will be made available during the course.

## Additional resources




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




**Year 2 regs and modules**
**G100 G103 GL11 G1NC**

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## 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:**

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## 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

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
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G103
Exam Information
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## 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

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## 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.

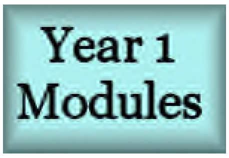
**Assessment:**
Not available

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

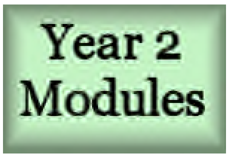
**Content:**
Gaussian measures on infinite-dimensional spaces.
Chaining arguments.
Non-Gaussian measures.
Introduction to Bayesian inversion.
Priors as random functions.
Posterior distribution.
Well-Posedness and approximation of the posterior.
Posterior-preserving stochastic dynamics (SPDEs and MCMC).

**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.

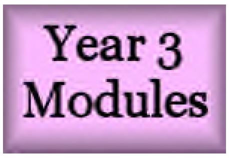
## Additional Resources



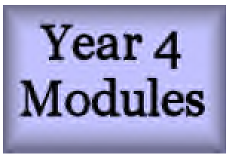
Year 1 regs and modules
G100 G103 GL11 G1NC



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

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# 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**
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**Exam Information**

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# 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

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## 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

Archived Pages: Pre-2011 2012 2013 2016 2017

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**
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### 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

Archived Pages: 2013 2014 2015 2017

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**
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## MA427 Ergodic Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma427)
**Lecturer:** Professor Ian Melbourne

**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 $2\pi$.
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)

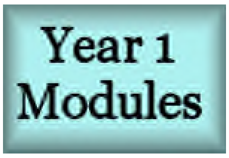
A. Katok & B. Hasselblatt, *Introduction to the modern theory of dynamical systems*, C.U.P., 1995.

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

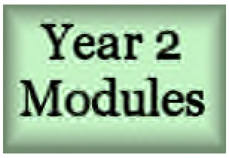
P. Walters, *An introduction to ergodic theory*, Springer, 1982.

## Additional Resources

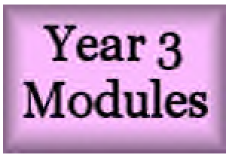
Archived Pages: 2012 2013 2014 2015 2016 2017



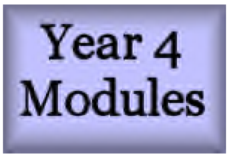

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**




**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**

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## MA433 Fourier Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma433)
**Lecturer:** Professor Ian Melbourne

**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

Archived Pages: 2014 2015 2016 2017

Year 1 Modules

**Year 1 regs and modules**

**G100 G103 GL11 G1NC**

Year 2 Modules

**Year 2 regs and modules**

**G100 G103 GL11 G1NC**

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## 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

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## MA448 Hyperbolic Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma448)
**Lecturer:** Dr. Salim Ghazouani

**Term(s):** Term 2

**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

Archived Pages: Pre-2011 2011 2012 2014

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

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**Core module averages**

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## MA453 Lie Algebras

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

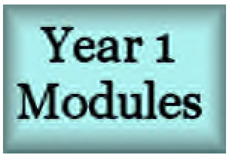
J.E. Humphreys, *Introduction to Lie algebras and representation theory*, Springer, 1979

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

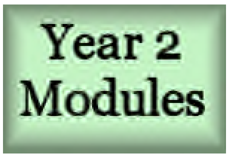
N. Jacobson, *Lie algebras*, Dover, 1979

## Additional Resources

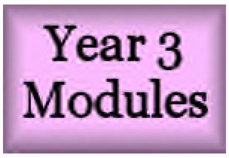
Archived Pages: Pre-2011 2012 2015 2016



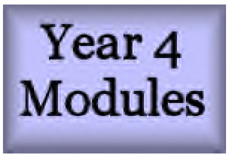

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



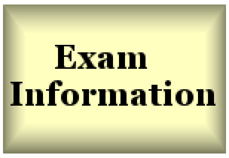

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## 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:**

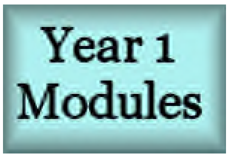
Lee, J .M. *Introduction to Smooth Manifolds*, Springer-Verlag;

**Additional texts:**

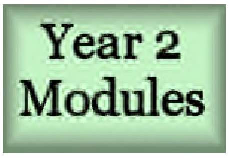
Warner, F. Foundations of differentiable manifolds and Lie groups, Springer-Verlag;

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

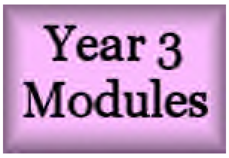
## Additional Resources



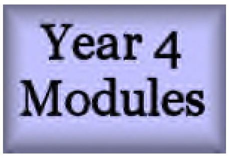

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**




**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

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## 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

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## 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

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## 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

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## 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

Archived Pages: 2012 2014

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## MA482 Stochastic Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma482)
**Lecturer:** Dr. Roger Tribe

**Term(s):** Term 2

**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 stochastic integration, and basic tools in stochastic analysis including Ito's formula. We will also introduce lots of examples of stochastic differential equations.

**Books**:
Laurence Evans: An introduction to Stochastic Differential Equations.
Bernt Oksendall: Stochastic Differential Equations.

## Additional Resources

Archived Pages: 2015 2017

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## MA4A2 Advanced Partial Differential Equations

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4a2)
**Lecturers:** Professor Peter Topping

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 100% Final Exam.

**Prerequisites:** Strongly recommended to have taken MA3G7 Functional Analysis I and MA359 Measure Theory. Ideally one would take MA3G1 Theory of PDEs.

**Leads To:** MA4G6 Calculus of Variations and MA592 Topics in PDE. Essential for research in much of geometry, analysis, probability and applied mathematics etc.

**Content**: Partial differential equations have always been fundamental to applied mathematics, and arise throughout the sciences, particularly in physics. More recently they have become fundamental to pure mathematics and have been at the core of many of the biggest breakthroughs in geometry and topology in particular. This course covers some of the main material behind the most common 'elliptic' PDE. In particular, we'll understand how analysis techniques help find solutions to second order PDE of this type, and determine their behaviour. Along the way we will develop a detailed understanding of Sobolev spaces.

This course is most suitable for people who have liked the analysis courses in earlier years. It will be useful for many who intend to do a PhD, and essential for others. There are not too many prerequisites, although you will need some functional analysis, and some facts from Measure Theory will be recalled and used (particularly the theory of Lp spaces, maybe Fubini's theorem and the Dominated Convergence theorem etc.). It would make sense to combine with "MA3G1 Theory of PDEs", in particular the parts about Laplace's equation, in order to see the relevant context for this course, although this is not essential.

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

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## 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.

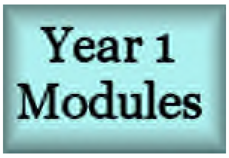
In the lectures, we will introduce the category of (quasi-projective) varieties, morphisms and rational maps between them, and then proceed to a study of some of the most basic geometric attributes of varieties: dimension, tangent spaces, regular and singular points, degree. Moreover, we will present 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**:

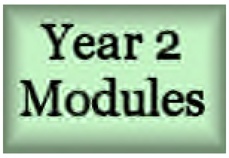

- Atiyah M.& Macdonald I. G., Introduction to commutative algebra, Addison-Wesley, Reading MA (1969)
- Harris, J., Algebraic Geometry, A First Course, Graduate Texts in Mathematics 133, Springer-Verlag (1992)
- Mumford, D., Algebraic Geometry I: Complex Projective Varieties, Classics in Mathematics, 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

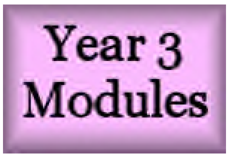

Archived Pages: 2011 2013 2014 2015 2016 2017



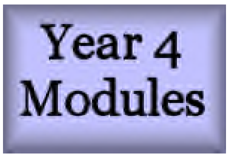

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



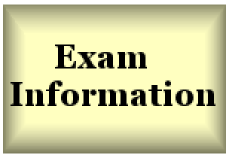

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**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## MA4A7 Quantum Mechanics: Basic Principles and Probabilistic Methods

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4a7)
**Lecturer:** Professor Daniel Ueltschi

**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

Archived Pages: 2011 2013 2016 2017

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**

## MA4C0 Differential Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4c0)
**Lecturers:** Dr. Mario Micallef

**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

Archived Pages: 2012 2015 2017

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## 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

Archived Pages: 2011 2012 2013 2014 2016 2017

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## MA4E7 Population Dynamics: Ecology & Epidemiology

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

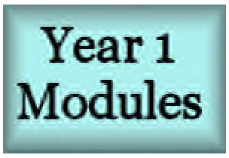
S.P. Ellner and J. Guckenheimer *Dynamic Models in Biology*, Princeton University Press, 2006 (ISBN 0691125899)

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

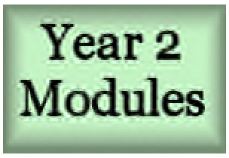
M.J. Keeling and P. Rohani *Modeling Infectious Diseases in Humans and Animals*, Princeton University Press, 2007 (ISBN 0691116172)

## Additional Resources

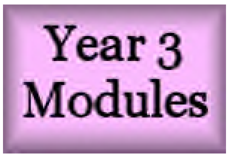
Archived Pages: Pre-2011 2011 2012 2013 2014 2015 2016 2017



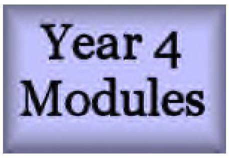

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



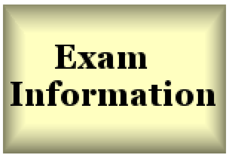

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## 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.

**Lecturer:** Dr. Stefan Grosskinsky

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 Lectures

**Assessment:** 85% by 3 hour exam, 15% by assessments.

**Prerequisites:** Atleast one of: ST318 Probability Theory, MA359 Measure Theory

**Content**: In 1827 the Botanist Robert Brown reported that pollen suspended in water exhibit random erratic movement. This 'physical' Brownian motion can be understood via the kinetic theory of heat as a result of collisions with molecules due to thermal motion. The phenomenon has later been related in Physics to the diffusion equation, which led Albert Einstein in 1905 to postulate certain properties for the motion of an idealized 'Brownian particle' with vanishing mass:

- the path $t \mapsto B(t)$ of the particle should be continuous,
- the displacements $B(t+\Delta t) - B(t)$ should be independent of the past motion, and have a Gaussian distribution with mean 0 and variance proportional to $\Delta t$.

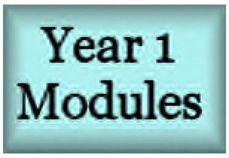
In 1923 'mathematical' Brownian motion was introduced by the Mathematician Norbert Wiener, who showed how to construct a random function $B(t)$ with those properties. This mathematical object (also called the Wiener process) is the subject of this module.
Over the last century, Brownian motion has turned out to be a very versatile tool for theory and applications with interesting connections to various areas of mathematics, including harmonic analysis, solutions to PDEs and fractals. It is also the main building block for the theory of stochastic calculus (see MA482 in term 2), and has played an important role in the development of financial mathematics. Even though it is almost 100 years old, Brownian motion lies at the heart of deep links between probability theory and analysis, leading to new discoveries still today.

Topics discussed in this module include:

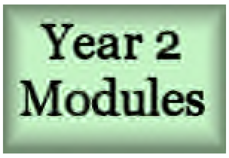
- Construction of Brownian motion/Wiener process
- fractal properties of the path, which is continuous but still a rough, non-smooth function
- connection to the Dirichlet problem, harmonic functions and PDEs
- the martingale property of Brownian motion and some aspects of stochastic calculus
- description in terms of generators and semigroups
- description as a Gaussian process, an important class of models in machine learning
- some generalizations, including sticky Brownian motion and local times

**Books:**
Peter Mörters and Yuval Peres, *Brownian Motion*, Cambridge University Press, 2010
Thomas M. Liggett, *Continuous Time Markov Processes - An Introduction*, AMS Graduate studies in Mathematics 113, 2010

## Additional Resources




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




**Year 2 regs and modules**
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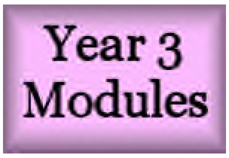
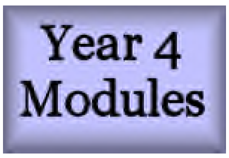
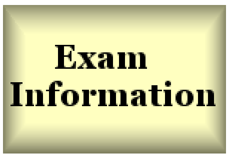



**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## 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**

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**

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## 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
Past paper 2014 Questions
Past paper 2015 Questions
Past paper 2016 Questions

## Course details

Abstract
Mathematical Primer

**Week 1 - 9th January - Basic electrophysiology**

Intracellular voltage, capacitance, ionic currents, equilibrium potentials, Nernst relation, Goldman current, GHK equation, ohmic currents, resting potential, voltage equation, response to injected current waveforms, measures of capacitance and input resistance.
Lecture Notes - Questions - Answers

**Week 2 - 16th January - Synaptic drive**

Excitatory and inhibitory classes of synapses, AMPA, NMDA and GABA types, stochastic channel dynamics, vesicle-release statistics, PSCs and PSPs, synaptic depression.
Lecture Notes - Questions - Answers

**Week 3 - 23rd January - Cable theory for passive dendrites**

Derivation of the cable equation. Open and closed cables. The Rall soma-dendrite model. Calculation of total input conductance of complex dendritic trees. Decay of transients. Velocity of signals in passive structures.
Lecture Notes - Questions - Answers

**Week 4 - 30th January - Subthreshold voltage-gated channels**

Derivation of channel activation kinetics. Phase-plane analysis of the two-variable non-linear model. Positive feedback and bistability. Negative feedback and damped oscillations. Linearisation of the two-variable equation. Eigenvalues and phase diagram of stability.
Lecture Notes - Questions - Answers

**Week 5 - 6th February - Models of spiking neurons**

Hodgkin-Huxley spike-generating currents, anatomy of an action potential, two-variable reductions, excitability and spontaneous oscillations, theta/quadratic model, Fitzhugh-Nagumo model, Type I and Type II neurons.
Lecture Notes - Questions - Answers

**Week 6 - 13th February - Integrate-and-fire models**

Leaky, Exponential and Non-Leaky Integrate-and-Fire models, Type I and Type II integrate-and-fire models, bistability, spike-frequency adaptation.
Lecture Notes - Questions - Answers

**Week 7 - 20th February - Synaptic fluctuations**

Poissonian pulse arrival, Gaussian white noise models of conductance fluctuations, filtered conductance, voltage response to synaptic fluctuations, reduced response and shortened time constant in presence of synaptic input, voltage fluctuations, mean and variance.
Lecture Notes - Questions - Answers

**Week 8 - 27th February - Populations of neurons**

Fokker-Planck equation and current equation for a leaky IF neuron, derivation of the steady-state subthreshold voltage mean and variance, boundary conditions for the threshold case, integral form for the steady-state firing rate, the firing rate in various limits.
Lecture Notes - Questions - Answers

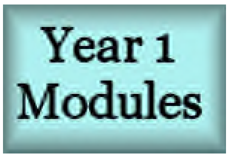
**Week 9 - 6th March - Networks of connected neurons**

Coupled single-population networks, mean-field and self-consistent solutions for the steady state, bistable excitatory networks and short-term memory, emergence of oscillations in inhibitory networks with delay, propagation of fronts of activity in neural tissue.
Lecture Notes - there are no questions this week

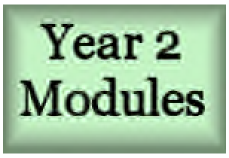
**Week 10 - 13th March**

Revision and exam questions.

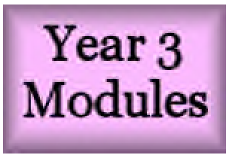
## Additional Resources



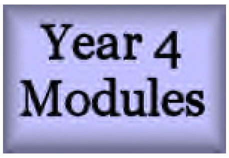

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



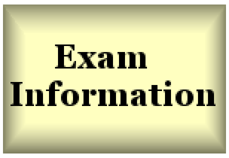

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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# MA4G7 Computational Linear Algebra and Optimisation

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4g7)

**Not Running in 2015/16**

**Status for Mathematics students:** List C for MMath. Also listed under Scientific Comupting as CY902

**Commitment:** 3 one hour lectures per week (one of which will be in the computing lab)

**Assessment:** 2 hour exam (70%), assignments (30%)

**Prerequisites:** A good knowledge of a scientific programming language such as C or Fortran is essential. No scripting languages such as matlab or python are permitted. Knowledge of both linear algebra and vector calculus is essential

**Leads To:**

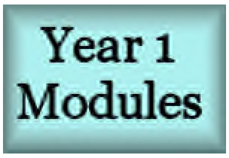
**Content**: See module page on CSC site.

**Books**:

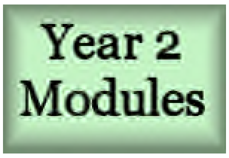
Lloyd Trefethen and David Bau, *Numerical Linear Algebra*, SIAM, 1997

J. Nocedal and S. Wright, *Numerical Optimization*, Springer Verlag 1999

## Additional Resources




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




**Year 2 regs and modules**
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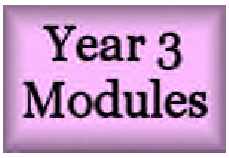
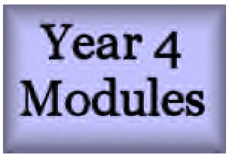
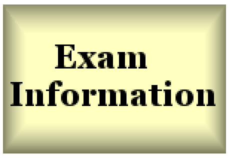



**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## MA4H0 Applied Dynamical Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4h0)
**Lecturer:** Claude Baesens

**Term(s):** Term 1

**Status for Mathematics students:** List C for Math.

**Commitment:** 30 lectures

**Assessment:** 3 hour examination 100%.

**Prerequisites:** There will be no specific prerequisites for the course, although a background in ODES and dynamics, such as MA254 Theory of ODEs, is highly recommended. This material will be reviewed at the beginning and so the main requirement will be a willingness to learn quickly!

**Leads To:**

**Content**: This course will introduce and develop the notions underlying the geometric theory of dynamical systems and ordinary differential equations. Particular attention will be paid to ideas and techniques that are motivated by applications in a range of the physical, biological and chemical sciences. In particular, motivating examples will be taken from chemical reaction network theory, climate models, fluid motion, celestial mechanics and neuronal dynamics.

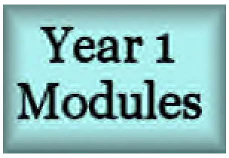
The module will be structured around the following topics:

1. Review of basic theory: flows, notions of stability, linearization, phase portraits, etc.
2. `Solvable' systems: integrability and gradient structure, applications in celestial mechanics and chemical reaction networks.
3. Invariant manifold theorems: stable, unstable and center manifolds.

4. Bifurcation theory from a geometric perspective.
5. Compactification techniques: flow at infinity, blow-up, collision manifolds.
6. Chaotic dynamics: horsehoes, Melnikov method and discussion of strange attractors.
7. Singular perturbation theory: averaging and normally hyperbolic manifolds.

## Additional Resources

Archived Pages: Pre-2011 2017




**Year 1 regs and modules**
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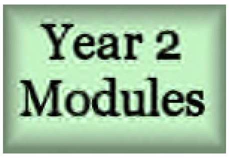
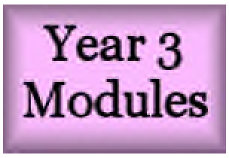
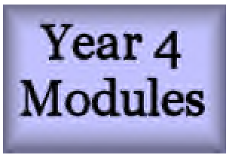


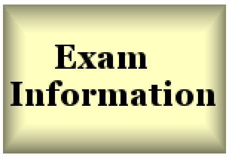

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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# MA4H4 Geometric Group Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4h4)
**Lecturer:** Brian Bowditch

**Term(s):** Term 2

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3 hour written examination (100%)

**Prerequisites:** MA222 Metric Spaces (strongly recommended), MA243 Geometry (recommended) MA3F1 Introduction to topology (recommended). Some connections with MA448 Hyperbolic Geometry.

**Leads To:**

**Content**: This will be an introduction to the basic ideas of geometric group theory. The main aim of subject is to apply geometric constructions to understand finitely generated groups. Although many of the ideas can be traced back a century or more, the modern subject has its origins in the 1980s and has rapidly grown into a major field in its own right. It draws on ideas from many subjects, though two particular sources of inspiration are low dimensional topology and hyperbolic geometry. A significant insight is that ``most'' finitely presented groups are ``hyperbolic'' in a broad sense. This has many profound applications. Some familiarity with group presentations will be useful. Beyond that, geometric or topological background is probably more relevant than algebraic background.

Learning outcomes: An understanding of the main notions of quasi-isometry, quasi-isometry invariants, and hyperbolic groups. To be able to apply these in particular examples.

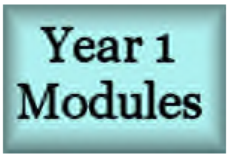
**Books**:

P. de la Harpe, *Topics in geometric group theory* : Chicago lectures in mathematics, University of Chicago Press (2000).

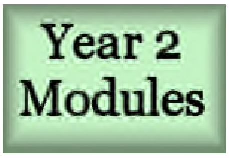
M. Bridson, A. Haefliger, *Metric spaces of non-positive curvature* : Grundlehren der Math. Wiss. No. 319, Springer (1999).

B. H. Bowditch, *A course on geometric group theory* : MSJ Memoirs, Vol 16, Mathematical Society of Japan (2006).

## Additional Resources




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




**Year 2 regs and modules**
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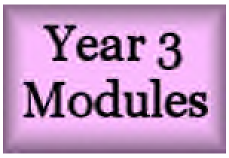
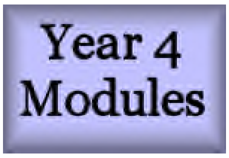
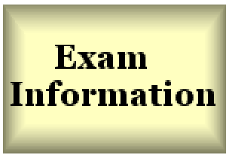



**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## MA4H7 Atmospheric Dynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4h7)
**Lecturer:** Robert Kerr

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3 hour exam (100%)

**Prerequisites:**

Maths/Physics students are required to have two of the following: MA231 Vector Analysis, PX253 PDEs, PX244 Introduction to Fluids

Mathematics students are required to have exposure to physical conservation laws such as momentum and energy and the differential equations that describe them. This means fluids or physics courses from the Warwick Physics department, MA3D1, or A-level Physics or Mechanics A.

**Leads To:**

**Content**: Topics would include:

Vertical motion and the role of moisture:

- Atmospheric stability: Dry and saturated adiabatic lapse rates
- Water vapour: Relative humidity, evaporation and condensation

Mechanics in a rotating frame (linear theory):

- Pressure gradients and their origins.
- Coriolis force, geostrophic wind.
- Stability and waves in a rotating frame.
- Stability and waves due to stratification.

Circulation on a global scale (nonlinear theory):

- Prevailing winds, jet streams, synoptic scale motion.
- Air masses, fronts, cyclones and accompanying weather patterns

Mesoscale and microscale motion:

- The planetary boundary layer.
- Ekman layers.
- Thunderstorm initiation.

**Books**:

J.C. McWilliams, *Fundamentals of Geophysical Fluid Dynamics*, CUP (2006).

B. Cushman-Roisoin, *Introduction to Geophysical Fluid Dynamics*, Prentice-Hall (1994).

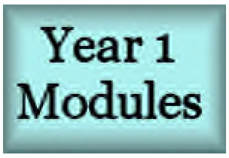
Additional resources:

John M. Wallace and Peter V. Hobbs, *Atmospheric science: an introductory survey* (2nd ed), Academic Press, 2006.

Roland Stull, *Meteorology For Scientists And Engineers: A Technical Companion Book To C. Donald Ahrens' Meteorology Today*.

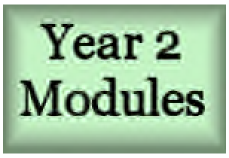
## Additional Resources

Archived Pages: 2011 2016 2017



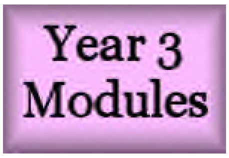

**Year 1 regs and modules**

**G100 G103 GL11 G1NC**



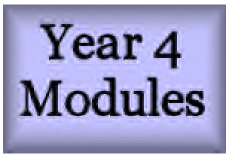

**Year 2 regs and modules**

**G100 G103 GL11 G1NC**




**Year 3 regs and modules**

**G100 G103**




**Year 4 regs and modules**

**G103**

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## MA4H8 Ring Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4h8)

**Lecturer:** Charudatta Hajarnavis

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 Lectures

**Assessment:** 3 hour exam (100%). The examination paper will contain five questions of equal credit. Four questions are to be answered.

**Prerequisites:** Familiarity with basic concepts in rings and modules. e.g. from the MA3G6 Commutative algebra course (see Additional Resources below)

**Content**: The course will be based on the lecture notes:

Both commutative and non-commutative rings will be studied. Our main aim is to develop the theory required to prove a theorem of Auslander and Buchsbaum that a (commutative) regular local ring is a unique factorisation domain. All known proofs of this theorem require methods form homological algebra. Thus we shall study properties of Noetherian rings and modules, look at projective resolutions of a module, define the global dimension of a ring and see how it relates to its Krull dimension.

**Books:** (For background reading and further study only):
M. Atiyah and I. Macdonald, Introduction to Commutative Algebra (QA 251.3.A8)
I. Kaplansky, Commutative rings (QA 251.3.K2)
J. Rotman, An Introduction to Homological Algebra (QA169.R667)
O. Zariski and P. Samuel, Commutative Algebra, vols. I & II (QA 251.3.Z2)

## Additional Resources

Archived Pages: 2016 2017

# MA4H9 Modular Forms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4h9)

**Not running in 2017/18.**

**Lecturer:** Guhanvenkat Harikumar

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 lectures, plus a willingness to work hard at the homework.

**Assessment:** 85% by 3-hour examination, 15% assessed work.

**Prerequisites:** MA231 Vector Analysis. Additionally, MA3B8 Complex Analysis is highly recommended although not strictly required. Please talk to me if you have not yet taken MA3B8 and still want to take this course.

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

**Content**: The course's core topics are the following:

1. The modular group and the upper half-plane.
2. Modular forms of level 1 and the valence formula.
3. Eisenstein series, Ramanujan's Delta function.
4. Congruence subgroups and fundamental domains. Modular forms of higher level.
5. Hecke operators.
6. The Petersson scalar product. Old and new forms.
7. Statement of multiplicity one theorems.
8. The *L*-function of a modular form.
9. Modular symbols

**Books**:

F. Diamond and J. Shurman, A First Course in Modular Forms, Graduate Texts in Mathematics 228, Springer-Verlag, 2005. (Covers everything in the course and a great deal more, with an emphasis on introducing the concepts that occur in Wiles' work.)

J.-P. Serre, A Course in Arithmetic, Graduate Texts in Mathematics 7, Springer-Verlag, 1973. (Chapter VII is a short but beautifully written account of the first part of the course. Good introductory reading.)

W. Stein, Modular Forms, a Computational Approach, Graduate Studies in Mathematics, American Mathematical Society, 2007. (Emphasis on computations using the open source software package Sage.)

## 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

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## MA4J0 Advanced Real Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j0)
**Lecturer:** Vedran Sohinger

**Term(s):** Term 2

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3 hour exam (100%).

**Prerequisites:** MA3G7 Functional Analysis I & MA359 Measure Theory. Desirable: MA3G8 Functional Analysis II, MA433 Fourier Analysis

**Content**: The module builds upon modules from the second and third year like Metric Spaces, Measure Theory and Functional Analysis I to present the fundamental tools in Harmonic Analysis and some applications, primarily in Partial Differential Equations. Some of the main aims include:

- Setting up a rigorous calculus of rough objects, such as distributions.
- Studying the boundedness of singular integrals and their applications.
- Understanding the scaling properties of inequalities.
- Defining Sobolev spaces using the Fourier Transform and the connections between the decay of the Fourier Transform and the regularity of functions.

**Outline**:

- Distributions on Euclidean space.
- Tempered distributions and Fourier transforms.
- Singular integral operators and Calderon-Zygmund theory.
- Theory of Fourier multipliers.
- Littlewood-Paley theory.

**Books**:

- Friedlander, G. and Joshi, M. : Introduction to the theory of distributions, 2nd edition, Cambridge University Press, 1998.

- Duoandikoetxea, J. : Fourier Analysis - American Mathematical Society, Graduate Studies in Mathematics, 2001.

- Muscalu C. and Schlag, W. : Classical and Multilinear Harmonic Analysis, Cambridge Studies in advanced Mathematics, 2013.

- 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, 1970.

## Additional Resources

Archived Pages: 2012 2015 2016 2017

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## MA4J1 Continuum Mechanics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j1)

**Not Running in 2015/16**

**Lecturer:**

**Term(s):**

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3 hour written examination (100%)

**Prerequisites:** A basic knowledge of linear algebra, multivariable calculus, differential equations and physics.

**Leads To:**

**Content**: The modeling and simulation of fluids and solids with significant coupling and thermal effects is an important area of study in applied mathematics and engineering. Necessary for such studies is a fundamental understanding of the basic principles of continuum mechanics and thermodynamics. This course, which will closely follow the text "A first course in continuum mechanics'' by Andrew Stuart, is a clear introduction to these principles.

The outline will be as follows: we will begin with a review of tensor algebra and calculus, followed by mass and force concepts, kinematics, and then balance laws. We will then proceed to derive some commonly used models governing isothermal fluids and solids, consisting of systems of partial differential equations (PDEs). If time permits we will also explore the thermal case.

**Book**:

Oscar Gonzalez, Andrew Stuart, *A first course in continuum mechanics*, Cambridge University Press, 2008.

## Additional Resources

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## MA4J2 Three-Manifolds

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j2)

**Not Running in 2015/16**

**Lecturer:**

**Term(s):**

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

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

**Prerequisites:** MA222 Metric Spaces and MA3F1 Introduction to Topology

**Leads To:**

**Content:**
1) Surfaces, handlebodies, I-bundles, polyhedral
2) Hauptvermutung, Heegaard splittings, $S^3$, $T^3$, PHS
3) Reducibility, Alexander's Theorem, knot complements, submanifolds of $R^3$
4) Fundamental group, incompressible surfaces, surface bundles
5) Tori and JSJ decomposition, circle bundles
6) Seifert fibered spaces
7) Loop theorem
8) Normal surfaces
9) Sphere theorem
10) Discussion of geometrization conjecture

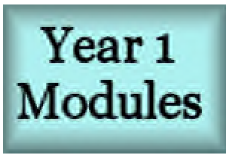
Other possible topics:
Poincare conjecture, Fox's reimbedding theorem, space forms spherical, euclidean, hyperbolic, eg dodecahedral space, Thurston's eight geometries, Dehn fillings topologically, algebraically, geometrically, eg fillings of the trefoil, figure eight, non-Haken manifolds, three views of PHS (following Gordon).

**Aims:** An introduction to the geometry and topology of three-dimensional manifolds, a natural extension of MA3F1 Introduction to Topology

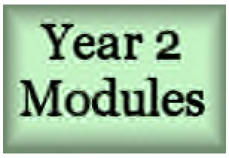
**Objectives:** By the end of the module the student should be:
Familiar with the basic examples (S3, ∏3, knot components...)
Able to compute ∏, (M3) from a variety of presentations of M.
Familiar with the sphere and torus decomposition.
Able to state the loop theorem and use it (e.g. to prove that knot components are aspherical).

**Books:**
*Three-dimensional Topology* by Andrew J Casson
*The Theory of Normal Surfaces* by Cameron Gordon
*Notes on Basic 3-manifold Topology* by Allen Hatcher
*3-manifolds* by John Hempel
*Classical Tessellations and Three-manifolds* by José María Montesinos

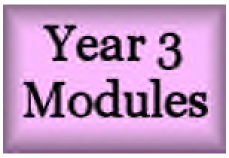
## Additional Resources



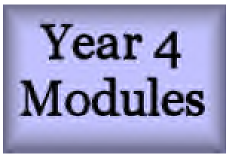

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



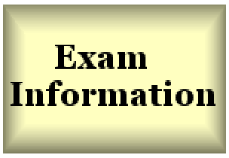

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## MA4J3 Graph Theory

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j3)
**Lecturer:** Vadim Lozin

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3 hour examination (100%)

**Prerequisites:** Familiarity with MA241 Combinatorics and MA252 Combinatorial Optimisation will be useful

**Leads To:**

**Content:**

Graph theory is a rapidly developing branch of mathematics that finds applications in other areas of mathematics as well as in other fields such as computer science, bioinformatics, statistical physics, chemistry, sociology, etc. In this module we will focus on results from structural graph theory. The module should provide an overview of main techniques with their potential applications. It will include a brief introduction to the basic concepts of graph theory and it will then be structured around the following topics:

Structural graph theory:

- Graph decompositions
- Graph parameters

Extremal graph theory:

- Ramsey's Theorem with variations
- Properties of almost all graphs

Partial orders on graphs:

- Minor-closed, monotone and hereditary properties
- Well-quasi-ordering and infinte antichains

**Aims:**

To introduce students to advanced methods from structural graph theory.

**Objectives:**

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

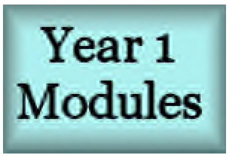
- State basic results covered by the module
- Understand covered concepts from graph theory
- Use presented graph theory methods in other areas of mathematics
- Apply basic graph decomposition techniques

**Books:**

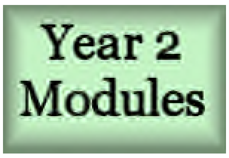
Bollobás, Béla (2004), *Extremal Graph Theory*, New York: Dover Publications, ISBN 978-0-486-43596-1
Diestel, Reinhard (2005), *Graph Theory* (3rd ed.), Berlin, New York: Springer-Verlag, ISBN 978-3-540-26183-4

## Additional Resources

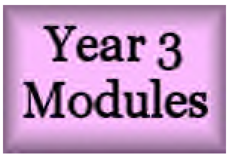
Archived Pages: 2012 2014 2015 2016




**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**

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## MA4J4 Quadratic Forms

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j4)

**Not Running in 2015/16**

**Lecturer:**

**Term(s):**

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3-hour examination (100%)

**Prerequisites:** MA251 Algebra I, MA249 Algebra II,
Desirable: MA3D5 Galois Theory, MA377 Rings and Modules

**Leads To:** PhD studies in Number Theory, Algebraic Geometry and Algebraic K-theory

**Content:**
Quadratic and symmetric bilinear forms over fields
The Witt group W(F) of a field F, chain lemma, cancellation and presentation of W(F)
Classification of quadratic forms over Q, R, finite fields and algebraically closed fields
Stable classification of symmetric bilinear forms over the integers
Formally real fields, signatures, sums of squares, torsion in W(F), transfer
Extension to Dedekind domains, Milnor's exact sequence

**Aims:**
Quadratic forms are homogeneous polynomials of degree 2 in several variables. They appear in many parts of mathematics where one reduces the classification of certain objects to the classification of quadratic forms. This happens for instance in algebra (quaternion algebras), in manifold theory (cohomology intersection form), in Lie theory (Killing form), in lattice theory (e.g., sphere packing problems), in number theory (sums of squares formulas, quadratic reciprocity) etc. The aim of this module is to understand the classification of quadratic forms over fields (e.g., field of rational numbers, finite fields) and certain rings (e.g., the integers) and to understand the relationship between properties of quadratic forms and properties of the fields in question.

**Objectives:** By the end of the module the student should be able to:
Understand the use of Witt groups in the classification of quadratic forms
Compute Witt groups in easy examples
Decide whether two given quadratic forms (over Q, R, F_q etc) are equivalent
Relate properties of fields to properties of quadratic forms and vice versa

**Books:**
Kazimierz Szymiczek, *Bilinear Algebra: An Introduction to the Algebraic Theory of Quadratic Forms*. 1997. xii+486 pp. ISBN: 90-5699-076-4
(Elementary text with lots of exercises, covers part of the module)

John Milnor, Dale Husemoller, *Symmetric Bilinear Forms*. 1973. viii+147 pp
(Great text, covers everything in the module but no exercises)

T Y Lam, *Introduction to Quadratic Forms over Fields*. 2005. xxii+550 pp. ISBN: 0-8218-1095-2
(Covers everything in the module and much more with lots of exercises)

## Additional Resources

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## MA4J5 Structures of Complex Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j5)
**Lecturer:** Markus Kirkilionis

**Term(s):** Term 1

**Status for Mathematics students:** List C

**Commitment:** 30 lectures

**Assessment:** 3 hour examination (80%), project (20%)

**Prerequisites:** There are no formal pre-requisites, but the following background will be assumed:
Familiarity with basic programming and programming languages, e.g. MA117 Programming for Scientists; Knowledge of basic stochastic processes, e.g. ST202 Stochastic Processes; Some basic statistics and differential equations e.g. ST111/112 Probability A and B, MA131 Differential Equations.

**Leads To:**

**Content:**
Part A: Complex Structures

Graphs, the language of relations:
• Introduction to graph theory.
• Degree distributions, their characteristics, examples from real world complex systems (social science, infrastructure, economy, biology, internet).
• Introduction to algebraic and computational graph theory.

Evolving graph structures:
• Stochastic processes of changing graph topologies.
• Models and applications in social science, infrastructure, economy and biology.
• Branching structures and evolutionary theory.

Graphs with states describing complex systems dynamics:
• Stochastic processes defined on vertex and edge states.
• Models and applications in social science and game theory, simple opinion dynamics.
• Opinion dynamics continued.

Graph applications:
• Graphs and statistics in social science.
• Graphs describing complex food webs.
• Graphs and traffic theory.

Extension of graph structures:
• The general need to describe more complex structures, examples, introduction to design.
• Hypergraphs and applications.
• Algebraic topology and complex structures.

Part B: Complex Dynamics:

Agent-based modelling:
• Introduction to agent-based modelling.
• Examples from social theory.
• Agent-based modelling in economy.

Stochastic processes and agent-based modelling:
• Markov-chains and the master equation.
• Time-scale separation.
• The continuum limit (and 'inversely' references to numerical analysis lectures)

Spatial deterministic models:
• Reaction-diffusion equations as limit equations of stochastic spatial interaction.
• Basic morphogenesis.
• The growth of cities and landscape patterns.

Evolutionary theory I:
• Models of evolution.
• Examples of complex evolving systems, biology and language.
• Examples of complex evolving systems, game theory.

Evolutionary theory II:
• Basic genetic algorithms.
• Basic adaptive dynamics.
• Discussion and outlook.

**Aims:**
1. To introduce mathematical structures and methods used to describe, investigate and understand complex systems.
2. To give the main examples of complex systems encountered in the real world.
3. To characterize complex systems as many component interacting systems able to adapt, and possibly able to evolve.
4. To explore and discuss what kind of mathematical techniques should be developed further to understand complex systems better.

**Objectives:** By the end of the module the student should be able to:
Know basic examples of and important problems related to complex systems.
Choose a set of mathematical methods appropriate to tackle and investigate complex systems.
Develop research interest or practical skills to solve real-world problems related to complex systems.
Know some ideas how mathematical techniques to investigate complex systems should or could be developed further.

**Books:** There are currently no specialized text books in this area available. But all the standard textbooks related to the prerequisite modules indicated are relevant.

## Additional Resources

Archived Pages: 2011

Year 1 Modules

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

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## MA4J6 Mathematics and Biophysics of Cell Dynamics

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma4j6)
**Lecturer:** Nigel Burroughs

**Term:** Term 2

**Status for Mathematics students:** List C

**Commitment:** 30 lectures and weekly assignments

**Assessment:** 3 hour examination (100%)

**Prerequisites:**
Previous experience with at least a couple of Dynamical Systems, PDEs, probability theory/stochastic processes, continuum mechanics and physical principles such as elasticity and energy (thermodynamics) would be beneficial; students from Mathematics or Physics with backgrounds covering some of these areas should also find the course accessible. Given the diversity of techniques used in the course, do not worry if you haven't got them all. MA256 Introduction to Systems Biology or MA390 Topics in Mathematical Biology provide some useful background in modelling, Probability A/B (ST111/2), or ST202 Stochastic Processes provide background for the probabilistic aspects of the course, and MA250 Introduction to partial differential equations provides some background in PDEs. Programming: A small number of the examples will involve a programming component, so MatLab, or another high-level language would be useful.

**Leads To:**

**Content:**

1. Spatial systems and organisation principles. Cell adhesion, protein patterns and diffusion driven instability.

2. Molecule diffusion and search times. Diffusion along DNA (1D), in membranes (2D). Molecule tracking.

3. Polymerisation underpinning motion. Work and catastrophes.

4. Molecular motors.

5. Cell movement. Actin gels and pushing beads.

6. Cell division.

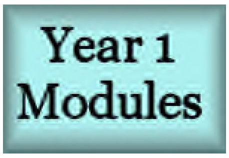
**Aims:**
How cells manage to do seeming intelligent things and respond appropriately to stimulus has generated scientific and philosophical debate for centuries given that they are just a 'bag' of chemicals. This course will attempt to offer some answers using state-of-the-art mathematical/physics models of fundamental cell behaviour from both bacteria and mammals. A number of key models have emerged over the last decade dealing with spatial-temporal

dynamics in cells, in particular cell movement, but also in developing crucial understanding of the basic architecture governing dynamic processes such as division. We will also explore a number of biological phenomena to illustrate fundamental biological principles and mechanisms, including for example molecular polymerisation to perform work. This course will take a mathematical modelling viewpoint, developing both modelling techniques but also essentials of model analysis. We will draw on a large body of mathematical areas; including dynamical systems approaches (20%), probabilistic modelling (60%) and mechanics (20%); indicated percentages are approximate and may vary from year to year. Note that the models can very quickly become complex so we will draw on a wide variety of techniques to best address the issues.

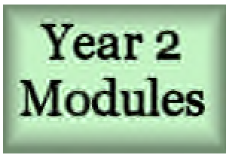
**Objectives:**
By the end of the module the student should be able to:
Develop spatial-temporal models of biological phenomena from basic principles
Understand the basic organisation and physical principles governing cell dynamics and structure
Determine dynamic capabilities of simple (stochastic) models of biological polymers (actin, tubulin)
Construct and solve optimisation problems in biological systems, e.g. for a diffusing protein to find a target binding site
Reproduce models and fundamental results for a number of cell behaviours (division, actin gels)

**Books:**
There are currently no specialized text books in this area available.

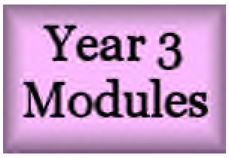
## Additional Resources



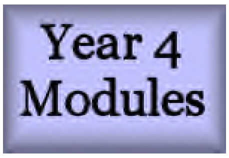

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**



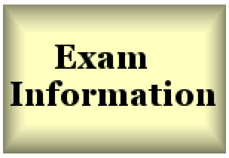

**Year 2 regs and modules**
**G100 G103 GL11 G1NC**




**Year 3 regs and modules**
**G100 G103**




**Year 4 regs and modules**
**G103**




**Past Exams**
**Core module averages**

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## MA595 Topics in Stochastic Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma595)

**Not Running in 2015/16**

**Lecturer:**

**Term(s):**

**Status for Mathematics students:** List D

**Commitment:** 30 lectures

**Assessment:** 3 hour exam 100%

**Prerequisites:** Knowledge of basic stochastic calculus including stochastic differential equations driven by Brownian motion will be assumed. Measure theory and functional analysis are basic tools and familiarity with basic concepts of differentiable manifolds is likely to be needed. Useful preparatory courses include: MA482 Stochastic Analysis, MA460 Differential Geometry.

**Leads To:**

**Content:** The natural state space for stochastic differential equations is a smooth manifold. Even if that manifold is a Euclidean space, if the equation has a more interesting structure than that of just additive noise it induces differential geometric structures which help to identify the behaviour of the solutions (the ``volatility'' can often determine a Riemannian metric for example, whose curvature affects the long time behaviour of solutions). On the other hand the solution to the equation can be considered as a map from path space on some $R^m$, i.e, Wiener space, to the space of the manifold, and this can be analysed by techniques of infinite dimensional calculus, in particular those known as Malliavin Calculus.

The precise content of the course will be decided after consulting those who expect to come to the lectures. If you are intending to come it might help if you could contact me sometime in Term 1. Of course if you have not done so you will be very welcome to come! but you will then have much less influence on the content.

MA 460 looks as if it will be a near perfect course introducing much of the differential geometry which arises in the theory. The first part, at least, is strongly recommended for anyone who wishes to continue in this area either as a researcher or as a practitioner.

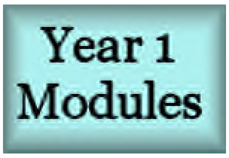
**Aims:**

**Objectives:**

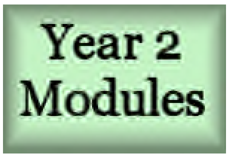
**Books:** The following contain useful material for the course:

Rogers, L. C. G.; Williams, David; *Diffusions, Markov processes, and martingales. Vol. 2. It™ calculus.* Reprint of the second (1994) edition. Cambridge Mathematical Library. Cambridge University Press, Cambridge, 2000. xiv+480 pp. ISBN: 0-521-77593-0 60J60
Elworthy, David; *Geometric aspects of diffusions on manifolds. École d'Eté de Probabilités de Saint-Flour XV-XVII,* 1985-87, 277-425, Lecture Notes in Math., 1362, Springer, Berlin, 1988.
Bell, Denis R; *The Malliavin calculus.* Reprint of the 1987 edition. Dover Publications, Inc., Mineola, NY, 2006.
Hsu, Elton P. *Stochastic analysis on manifolds.* Graduate Studies in Mathematics, 38. American Mathematical Society, Providence, RI, 2002.

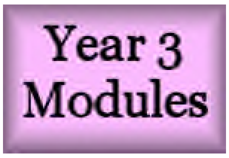
## Additional Resources



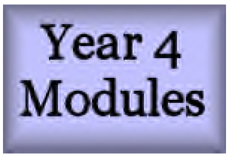

**Year 1 regs and modules**
**G100 G103 GL11 G1NC**




**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**

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## MA5Q3 Topics in Complexity Science

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma5q3)

**Lecturer:** Professor Robert Mackay

**Term(s): 2**

**Status for Mathematics students:** List D (also for MathSys, MASt, Maths & Interdiscipinary Maths MSc and MASDOC)

**Commitment:** 10 two hour lectures and 10 one hour classes

**Assessment:** 100% by essay (15-20 pages) due beginning of term 3

**Prerequisites:**

**Content:** In 2018/9 the chosen topic is Stellarator Mathematics.

A stellarator is a magnetic confinement device for plasma (ionised gas). It has some similarities to the better known tokamak but does not require its strong toroidal current, which is problematic to drive and causes bad instabilities. But it is not close to axisymmetric so its design requires much more sophisticated mathematics to confine the plasma.

The module will address:

Charged particle motion in magnetic fields from a Hamiltonian viewpoint

Adiabatic invariance of the magnetic moment and the resulting equations for guiding centre motion

Design of magnetic field to achieve integrability of the guiding centre motion (quasi-symmetry)

Vacuum fields

Magnetohydrodynamic (MHD) equilibrium

MHD equilibrium with mean flows and electrostatic fields

Interaction of two charged particles in a magnetic field

Measures of non-integrability (conditions for non-existence of invariant tori)

Guiding-centre billiards

Other topics to be added

**Aims:**

**Objectives:**

**Books:**

**Notes:** We will use differential forms, Lie derivatives etc where it makes things tidy and easier to see but will also attempt to give parallel statements in more traditional terminology (grad, div, curl, cross product). A good book for background on this in the MHD context is

Arnold VI, Khesin BA, Topological methods in hydrodynamics (Springer, 1998) [though note that in Remark 1.4 of Chapter II, the 1-form u is not defined (it is v♭), the stationary Euler equation should be L_v u = −d(p − 1/2 |v|^2) and α = p + 1/2 i_v u.]

Another which is more expository and for Hamiltonian mechanics is

Arnold VI, Mathematical methods of classical mechanics (Springer, 1978)

You can google to find more about anything you don't understand. That's how I learn these days.

## Additional Resources

Archived Pages: 2015 2017

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## MA606 Modern Analysis (Classical Real Analysis)

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma606)
**Lecturer:** David Preiss

**Term(s):** Term 1

**Status for Mathematics students:** Not available for credit

**Commitment:**

**Assessment:**

**Prerequisites:** MA4J0 Advanced Real Analysis, MA359 Measure Theory and MA222 Metric Spaces

**Leads To:**

**Content:**
This will mostly run as a reading seminar on various themes from real analysis.

## 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

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## MA608 Topics in Geometric Analysis

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma608)
**Lecturer:** Peter Topping

**Term(s):** Terms 2,3

**Status for Mathematics students:** Not available for credit

**Content:** This will run as a reading seminar. Details from Peter Topping's personal website

## 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

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MA610 Algebraic Geometry

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma610)

**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:** There will be a weekly seminar on a self-help basis starting in Term 1 organised by Miles Reid and Diane Maclagan, details will be circulated by e-mail, together with Algebraic Geometry Seminar announcements. Anyone wishing to be included on the mailing list should contact Miles Reid and Diane Maclagan.

**Assessment:**

**Prerequisites:**

**Leads To:**

## Content:

The course consists of topics in Algebraic Geometry, including foundational questions, the construction of varieties in terms of commutative algebra, the classification of varieties, orbifolds and their resolutions and other matters.

## 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

## MA4K8 MA4K9 Projects

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/ma469)
**Organisers:** Dwight Barkley, Oleg Zaboronski

**Term(s):** Terms 1-2

**Status for Mathematics students:** Core for 4th Year G103

**Assessment:** See below

For Maths-in-Action Projects: the themes are now finalised and can be found below. The procedure for assigning themes is also explained below. It is important that you spend some time exploring each theme before making your choices. Past experience shows that rushing into a choice based on title alone is a bad idea.

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The fourth-year Project module comes in two flavours:

- **MA4K9 Research (R-Projects):** Essential for students intending to pursue further mathematical studies such as a PhD or other research degree. It is also highly recommended for students going on to careers (such as quantitative analysis in finance) in which developing mathematics will be a vital skill. Finally, it is for anyone wishing to experience the joy of mathematical study at the frontiers of research.
- **MA4K8 Maths-in-Action (MiA-Projects):** These projects are primarily aimed at those who seek to further develop their communication skills in speaking and writing. The projects involve understanding deeply how mathematics underpins a particular topic in the modern world and then communicating this understanding in the form of a presentation, a written popular science article, and a written scholarly report at the MMath level.

**IMPORTANT**: **Please note the Important Dates sections below for the R-Projects and the MiA Projects. Deadlines must be strictly adhered to!**

It is your responsibility to make sure you are registered for the correct version of the project on eMR!

In addition, all MMath students **must** register their project choice by midnight on
**Sunday, 28 October 2018**.

### Project registration is open.

### Register for Research Projects here
### Register for Maths-in-Action Projects here

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## RESEARCH PROJECTS

**Aims**: The primary aim of the Research Project is to give you experience of mathematics as it is pursued close to the frontiers of research, not just as a spectator sport but as an engaging, evolving activity in which you yourself can play a part.

**Content**: Before you register for a Research Project, you must first take the following steps:

1. Find a member of staff willing to supervise you;
2. Agree on a theme suited to your mathematical background and interests, and to your supervisor's expertise;
3. Negotiate a title and brief for your project, and discuss its aims and objectives. It is normal for this to need renegotiating as the project evolves and final titles sometimes differ from the title originally registered;
4. Discuss the criteria for assessment with your supervisor. This will normally be the standard criteria listed under `Assessment' below.

**Project Supervisors and Themes:** A list of the Research project themes offered by staff members can be found on the R-Projects Resource page.

If you have your own ideas about a theme for an R-project, feel free to ask any member of staff whether they would be willing to be your supervisor, but remember, staff are under no obligation to supervise an R-project, and are, in any case, discouraged from supervising more than two a year.

**Assessment**: The Research Projects are assessed on the basis of

- A short progress report in Term 2 (5% of the module credit)
- A written dissertation (80% of the module credit)
- An oral presentation and defence of dissertation (15% of the module credit)

The *Progress Report* must be signed by your supervisor and submitted to the Undergraduate Office by **2.00 p.m on Tuesday 15 January, 2019.** The template for the report can be found on R-Projects Resource page. The short report consists of two sides of A4: one summarising progress to date and two stating the goals and target timetable for the remainder of the project. The summary of progress to date will typically consist of a list of identified sources (books, articles, etc) and specific accomplishments (material that has been read and digested, calculations that have been performed, theorems that have been proved, computer programmes that have been written, etc).

The *Dissertation* must be word-processed using Latex using the template provided on the R-Projects Resource page (unless you have specific permission from your supervisor to do otherwise). The main body of the dissertation should normally be about 30 pages (excluding the title page, table of contents and bibliography) and strictly no longer than 40 pages. If necessary, additional information may be included in the form of appendices. You must submit your dissertation to the Undergraduate Office by **2.00 p.m on Tuesday, 2 April 2019.** If your dissertation does not satisfy these requirements, it may be returned to you and a resubmission required.

The *Oral Presentation and Defence* will take place on a designated day in Term 3 (typically set between April and Summer exams). Each candidate will be expected to give a prepared talk, lasting between 20 and 25 minutes, on the theme of their dissertation. After their talk, they will submit to questioning and discussion of their work with the staff members in the audience for a further 20 minutes or so; thus, for each student, the examination should normally last no more than 45 minutes. When appropriate, we recommend that supervisors coordinate with each other to arrange the R-Project candidates into small groups (of up to four students), in cognate areas of mathematics. These supervisors and students would then attend all the talks in their group; we expect the joint presentations and defences to take about a half-day. Below we summarise the standard criteria for assessing an R-Project dissertation and oral component. Examiners may give different weighting to the criteria or add further criteria to suit the features of a specific project brief. You are strongly advised to discuss assessment with your supervisor.

**Assessment of the R-Project Dissertation**

These are the standard criteria for assessing a dissertation; marks awarded on the basis of the dissertation may be modified in the light of evidence from the oral.

- *The amount of work and effort undertaken:* This might be evidenced by the breadth and depth of your reading and research in the literature, the organisation and presentation of the material, new skills you acquired (e.g. learning to program or to use a mathematical package such as Matlab, etc.), work on examples and calculations.
- *The clarity and accuracy of the explanation and justification:* Is your exposition of the material well directed at your target audience, easy to read, and logical? Does it have a good story to tell? Are your proofs comprehensive and mathematically correct?
- *The level of the material and the depth of understanding:* Is the intellectual content deep? Have you assimilated and understood it well, and also convinced the reader of this? Does your exposition carry the stamp of your ownership of the material?
- *The quality of the scholarship:* Is your written English concise, fluent, correctly spelt and grammatical? Is the quality of the word-processing good (well laid out and free of typos)? Is the mathematics typeset well (with suitable font styles and sizes and well-displayed expressions)? Are your sources reliable, and are they regularly cited (so that the reader can clearly distinguish your own contributions) and listed in a conventional bibliography at the end? Is the material well structured and sensibly numbered for cross-referencing?
- *The degree of originality:* Originality may be shown in a number of ways, for instance: in the way the material is organised; by making new connections between existing ideas or areas of knowledge; through a new proof or a generalisation of a known result, including perhaps relaxed hypotheses or a stronger conclusion; through the creation of examples that illustrate the theory or establish its limits of validity; by creative use of the library and the resources on the Web.

**Assessment of the R-Project Oral Examination**

Your mark for the oral examination will be based on the following:

- *Your prepared talk:* Your talk should be a succinct survey of your work. Your account can be informal and personal but it should (i) show clearly that you have a good knowledge and understanding of the subject and its context and (ii) take into account to the likely knowledge of the students attending your talk. You will be able to refer to notes and use the blackboard, and it might be an advantage to have your own copy of your dissertation with you.
- *Your defence of your dissertation:* After your talk the examiners may ask you questions about the material in your dissertation and you will be expected to engage in a general discussion about such things as your motivation for choosing the topic, any difficulties you met, and your ideas for taking the work further.
- *Your background knowledge and understanding:* You will be expected to know something about the background of your theme and its place in the broader scheme of things. The oral will be used to test the thoroughness of your understanding and to identify your own personal contributions as distinct from what is already in the public domain.

**Research Project Important Dates: The dates below are strict and marks will be deducted for late submissions!**

- *Registration:* You must register your project by **Sunday, 28 October 2018** (the end of Week 4). Note, this is not the same as module registration. This is registering the project title and supervisor via the link at the top of this page.
- *Progress Report:* You must submit the signed Progress Report to the Undergraduate Office by **2.00 pm on Tuesday 15 January, 2019**. Note, this form must be signed by your supervisor, so you need to begin discussing the report before the deadline, preferably by the end of Term 1.
- *Dissertation:* You must submit **two hard copies** of your dissertation to the Undergraduate Office **and one electronic copy** via Tabula by **2.00 pm on Tuesday 2 April, 2019**. You must attach a signed cover sheet to one of the two hard copies. Cover sheets can be obtained from the UG office or here. If you are unable to submit the hard copies in person, Royal mail recorded or next day delivery is probably the best option.
https://www.royalmail.com/personal/uk-delivery/special-delivery. Please post to the Maths Undergraduate Office:
|Mathematics Institute Zeeman Building | B0.01 | University of Warwick | Coventry | CV4 7AL |
**Do not fail attach a signed cover sheet. Make sure that upload a pdf version of the dissertation via Tabula by the deadline.**
Please contact the Undergraduate Office ugmaths@warwick.ac.uk for any questions concerning the submission procedure.
- *Oral examination:* This will usually take place in Term 3 between the April and Summer exams at a time and place to be arranged by the supervisor. Students are strongly advised to keep the Wednesdays in this time frame free of other commitments.

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# MATHS-in-ACTION PROJECTS

**Aims:** The broad aims are: to develop your ability to communicate mathematics to diverse audiences and to give you a deeper appreciation of how mathematics underpins the modern world. Doing a Maths-in-Action project will teach you the art of scholarship; it will help you to acquire a variety of presentation skills and improve your scientific word-processing. Fruitful collaboration is a valuable experience and you will have the opportunity to work cooperatively on a public oral presentation.

**Content:** The Maths-in-Action Projects will show how some of the mathematics you have learnt at Warwick affects contemporary life and technology. Themes for 2018/19 are:

Theme 1: Mathematics of Bitcoin
Theme 2: Mathematics of Traffic
Theme 3: Quantum Computing
Theme 4: Mathematics of Climate
Theme 5: Biological synchronisation: flocking, swarming, and schooling
Theme 6: Cardiac Arrhythmias
Theme 7: Mathematics of Evolution

It is important that you spend some time exploring each theme before making your choices. Past experience shows that rushing into a choice based on title alone is a bad idea.

### Important! Each theme will be restricted to a limited number of takers. The system works as follows:

Theme registration opens on the first day of term. At the end of Week 1, theme assignments will be posted on the Maths-in-Action resources page. As long as no theme is fully subscribed, everyone will get their first choice. If, in Week 1 a theme is oversubscribed, then we will use the Matlab random number generator to select those getting that theme. The remainder will get their second choice.

After week 1, theme choices will be on a strict first come first served policy. Given the number of projects, the majority of students will get their first choice.

**Support:** The main support for the Maths-in-Action projects are:

- The Maths-in-Action Resources page describing how to get started and what to do next. It also is the main source of news and valuable information for the Maths-in-Action projects. You should consult this page frequently.
- A Project Guide containing advice on how to make good presentations and explaining the criteria that will be used in assessing your work.
- A Theme Guide describing each approved theme, defining the brief and listing some source materials.

(Both guides are available on the Maths-in-Action Resources page.)

In addition to the above:

- The organisers hold two open meetings for all Maths-in-Action project students in Term 1. At the meeting in Week 3 the organisers will discuss project details, offer advice and answer any questions. The meeting in Week 10 is primarily devoted to discussing progress reports and draft posters, but it is also a further opportunity to ask questions. A further opportunity for feedback and questions is provided in Term 2.
- Maths-in-Action projects are not supervised the way R-projects are. The organisers do not generally meet with students to discuss technical details of the projects. However, on occasion the organiser can discuss projects and offer advice on an individual basis. Send an email to the module organisers to start the discussion or to arrange an appointment.

**Assessment:** The Maths-in-Action Projects are assessed on:

- Scholarly Report and Viva (60% of the module credit).
- Popular Article (10% of the module credit).
- Presentation (20% of the module credit).
- Progress Report (5% of the module credit).
- Peer Assessment (5% of the module credit).

**MiA Project Important Dates: The submission deadlines below are strict and marks will be deducted for late submissions!**

Further information about various submissions and meetings (including possibly additional open meetings) will be posted on the News Items on the Maths-in-Action Resources page. You should check it regularly.

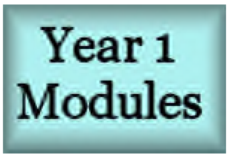
- Options Fair: **Monday, 1 October, 2018** (Week 1). The organiser will give a brief overview of the MMaths projects.
- Short open meeting for general discussion, and Q & A: **Wednesday, ~~17 October~~, 24 October 2018** (Week 4), 1:15pm - 2pm. Room MS.05.
- Registration: You must register your project by **Sunday, 28 October 2018** (the end of Week 4). Note, this is not the same as module registration.
- Meeting to discuss Progress Reports and other issues: **Wednesday, 5 December, 2018** (Week 10), 1pm - 3pm. Room MS.05.
- Progress Report: You must submit the Progress Report to the Undergraduate Office by **2.00 pm on Tuesday 15 January, 2019**.
- Meeting to provide feedback on draft posters and to answer further questions: **1:00 pm Wednesday, 23 January, 2019. Room B3.02.**
- Presentations: presentations will take place on Wednesday afternoons in Term 2. ~~(Exact dates are TBC and subject to the number of students enrolled. All students are expected to attend all presentations. Please be available all Wednesday afternoon in weeks 6 - 10 of Term 2.)~~ Presentations will take place **1pm-4pm 27 Feb, 2019. 4pm - 8pm 6 Mar, 2019, and 1pm-4pm 13 Mar, 2019**. Further details can be found on the resources page.
- Submission of Scholarly Reports and Popular Article: You must submit **two hard copies** of your Scholarly Report and **two hard copies** of your Popular Article to the Undergraduate Office **and one electronic copy of the Scholarly Report** via Tabula by **2.00 pm on Tuesday 2 April, 2019**. You must attach a signed cover sheet to one of the two hard copies of the Scholarly Report. Cover sheets can be obtained from the UG office or here. If you are unable to submit the hard copies in person, Royal mail recorded or next day delivery is probably the best option. https://www.royalmail.com/personal/uk-delivery/special-delivery. Please post to the Maths Undergraduate Office: |Mathematics Institute Zeeman Building | B0.01 | University of Warwick | Coventry | CV4 7AL |
  **Do not fail attach a signed cover sheet. Make sure that upload a pdf version of the Scholarly Report via Tabula by the deadline (you do not need to submit the popular article via Tabula).**
  Please contact the Undergraduate Office ugmaths@warwick.ac.uk for any questions concerning the submission procedure.
- Viva: These will be scheduled in Term 3 between the April and Summer exams, typically in **Weeks 3 - 5 of Term 3**.

## Additional Resources - Research Projects

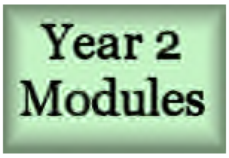
Archived Pages: 2014

## Additional Resources - Math-in-Action Projects

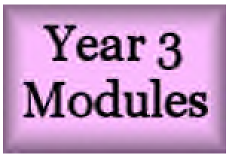
Archived Pages: 2014




**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 Modules

Year 4 regs and modules

G103

Exam Information

Past Exams

Core module averages

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## CO905 Stochastic Models of Complex Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/co905)

uk.ac.warwick.sbr.content.LinkedContentNotFoundException: The source page does not contain HTML, or has been deleted.

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

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## CO907 Quantifying Uncertainty and Correlation in Complex Systems

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/co907)

uk.ac.warwick.sbr.content.LinkedContentNotFoundException: The source page does not contain HTML, or has been deleted.

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

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## ST4 Modules

(https://warwick.ac.uk/fac/sci/maths/undergrad/ughandbook/year4/st4xx)

| Name | Last Updated |
|---|---|
| ST401: Stochastic Methods in Finance | 28/09/18 |
| ST402: Risk Theory | 02/10/18 |
| ST403: Brownian Motion | 18/01/19 |
| ST404: Applied Statistical Modelling | 07/11/18 |
| ST405: Bayesian Forecasting and Intervention with Advanced Topics | 28/09/18 |
| ST406: Applied Stochastic Processes with Advanced Topics | 28/09/18 |
| ST407: Monte Carlo Methods | 30/11/18 |
| ST409: Medical Statistics with Advanced Topics | 24/01/19 |
| ST410: Designed Experiments with Advanced Topics | 28/09/18 |
| ST411: Dynamic Stochastic Control | 28/09/18 |
| ST412: Multivariate Statistics with Advanced Topics | 26/10/18 |
| ST413: Bayesian Statistics & Decision Theory with Advanced Topics | 28/09/18 |
| ST414: Advanced Topics in Statistics | 28/09/18 |
| ST415: Statistics Masters Dissertation | 28/09/18 |
| ST416: Advanced Topics in Biostatistics | 28/09/18 |
| ST417: Topics in Applied Probability | 28/09/18 |
| ST418: Statistical Genetics with Advanced Topics | 24/01/19 |
| ST419: Advanced Topics in Data Science | 28/09/18 |

**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**

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