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Course Regulations for Year 2

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/)

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MATHEMATICS BSC. G100

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

Students must take the 6 core modules (total 66 CATS), plus options. List A modules have a high mathematical content. The Core modules are: MA259 Multivariable Calculus, MA244 Analysis III, MA251 Algebra I, MA249 Algebra II, MA260 Norms, Metrics and Topologies, MA213 Second Year Essay.

Please note that if you wish to transfer to the G103 degree either in your second year, or later in your third year, you must have fulfilled the conditions for that degree this year (see below).

MASTER OF MATHEMATICS MMATH G103

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

The first two years are in common with the BSc Mathematics degree course G100 except that in Year 2 students must take at least 90 CATS credits from the core and List A combined.

To remain on the G103 course at the second year exam board students must have achieved a weighted average on their best 90 CATS of maths modules (Core and List A modules starting with an MA2 code) of a good 2.1 standard, or if fewer than 90 CATS of MA2 modules are taken (due to List A Stats modules) we calculate the average over all registered MA2 modules. The department strictly interprets this to mean 65.0% or above. Experience has shown that students who do not achieve this threshold struggle with the four year degree, and by being transferred to the BSc. have a better chance of achieving a good 2.1 or first class degree and can plan their future better. For students who take 90 CATS of Core and List A, but fewer than 90 CATS of MA2 modules, we would take the average over the MA2 modules that have been taken, and then look at the overall mark profile, including the other List A modules taken, to make a progression decision on a case by case basis.

Please note:4th year MMath students are not be able to take second year modules except as unusual options. It is highly unlikely that MA2 modules would be allowed as unusual so choose your modules this year to take this into account.

MATHEMATICS WITH BUSINESS STUDIES G1NC

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

Students must take the 6 core modules for G100 students (total 66 CATS), plus one of the List B Warwick Business School modules below (coded IBxxx). To transfer to the Business School at the end of the second year students must get at least 50% in one of these modules, gain an overall honours mark (40% end of year) and be successfully interviewed by WBS.

MATHEMATICS AND ECONOMICS GL11

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

Year 2 core consists of 60 CATS of Mathematics and 60 CATS of Economics. The Economics modules are EC204 Economics 2 (30 CATS), plus either EC226 Econometrics 1 (30 CATS) or EC220/221 Mathematical Economics 1a and 1b (30 CATS). The Mathematics modules are MA251 Algebra I, MA244 Analysis III, MA259 Multivariable Calculus, MA260 Norms, Metrics and Topologies, plus 12 CATS from option list A/Core for the second year of the Mathematics BSc (G100). Students taking EC226 as a core module should consider, as recommended options, ST202 Stochastic Processes and/or ST213 Mathematics of Random Events. Students taking EC220/1 as a core module should consider MA209 Variational Principles.

Note, in year 3 GL11 students transfer to the Economics department where overcatting is not permitted and level 1 modules are also not allowed as options.

For a full list of available modules see the relevant course regulation page.

Maths Modules

Note: The Term 1 modules MA259 Multivariable Calculus, MA241 Combinatorics, MA243 Geometry, MA244 Analysis III and MA251 Algebra I are all examined in the April exam period directly after the Easter vacation.
For students who commenced studies **before the 2021/22 academic year**, in order to progress to the 3rd year you must pass at least 60 CATS of modules in your second year and have an end of year average over 40%. You can still proceed whilst failing (some) core modules.
For students commencing studies as first years **in the academic year 2021/22 or later**, in order to progress to the 3rd year you must pass at least 90 CATS of modules in your second year and have an end of year average over 40%.

Term	Code	Module	CATS	List GL11	List Others
Term 1	MA241	Combinatorics	12	List A	List A

	MA243	Geometry	12	List A	List A
	MA244	Analysis III	12	Core	Core
	MA251	Algebra I: Advanced Linear Algebra	12	Core	Core
	MA259	Multivariable Calculus	12	Core	Core
	MA2K3	Consolidation (by invitation)	6	Unusual	Unusual
Terms 1 & 2	MA213	Second Year Essay	6	List A	Core
Term 2	MA117	Programming for Scientists	12	List B	List B
	MA249	Algebra II: Groups and Rings	12	List A	Core
	MA250	Introduction to Partial Differential Equations	12	List A	List A
	MA252	Combinatorial Optimization	12	List A	List A
	MA254	Theory of ODEs	12	List A	List A
	MA257	Introduction to Number Theory	12	List A	List A
	MA260	Norms, Metrics and Topologies	12	Core	Core
	MA261	Differential Equations: Modelling and Numerics	12	List A	List A
	MA269	Asymptotics and Integral Transforms	12	List A	List A
Term 3	MA209	Variational Principles	6	List A	List A
	MA256	Introduction to Mathematical Biology	6	List A	List A

Maths Modules for External Students

These modules are not available to Maths students.

Term	Code	Module	CATS
Term 1	MA258	Mathematical Analysis III	12
Term 2	MA222	Metric Spaces	12

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 GD305 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:

Term	Code	Module	CATS	List
Term 1	IL005	Applied Imagination	12/15	Unusual
	GD305	Challenges of Climate Change	15	Unusual
Term 2	IL008	Reinventing Education	12/15	Unusual
	IL031	Serious Tabletop Game Design and Development	12/15	Unusual
	IL016	The Science of Music	7.5/15	Unusual
	IL023	Genetics: Science and Society	12/15	Unusual

Statistics Modules

Students who have successfully completed the first year in Maths and have taken statistics options in their first year may apply to the Department of Statistics for transfer to the joint degree. Alternatively, transfer may be made at the beginning of the third year if the appropriate second year modules have been taken. Further information may be obtained from the Department of Statistics.

Term	Code	Module	CATS	List
Term 1	ST222	Games, Decisions and Behaviour	12	List B
	ST220	Introduction to Mathematical Statistics	12	List A
Term 2	ST202	Stochastic Processes	12	List A

Economics Modules

The Economics 2nd and 3rd Year Handbook is available on request from the Economics Department and contains details of their modules and prerequisites, including information on which will actually run during the year. This information is also available from the Economics web pages.

See the Economics Handbooks for information on the Joint degree in Mathematics and Economics.

Once you have consulted the Economics handbook, the Economics department should be consulted if you have questions about the joint degree, or about economics options for the maths degrees.

Term	Code	Module	CATS	List GL11	List Others
Term 1	EC220	Mathematical Economics 1A	15	Op Core	List B but must have taken EC106 or EC107
Term 2	EC221	Mathematical Economics 1B	15	Op Core	List B but must have taken EC106 or EC107
Terms 1,2,3	EC204	Economics 2	30	Core	N/A
	EC226	Econometrics 1	30	Op Core	N/A

Computer Science

Term	Code	Module	CATS	List
Term 1	CS260	Algorithms	15	List B
Term 2	CS262	Logic and Verification	15	List B
	CS254	Algorithmic Graph Theory	15	List B

Physics

Students from the Department of Mathematics may take any combination of the modules listed below. All exams are one hour per 6 CATS. Please contact the Physics department to answer any queries concerning their second year modules.

Module Seminars for Physics Options: Certain physics modules are supported by module seminars which start one week after the start of the module. These are timetabled locally and details will be announced at the start of each module.

Term	Code	Module	CATS	List
Term 1	PX267	Hamiltonian Mechanics	7.5	List B
	PX281	Computational Physics	15	List B
Terms 1 & 2	PX262	Quantum mechanics and its Applications	15	List B
	PX280	Environmental Physics	15	List B

	PX276	Methods of Mathematical Physics	7.5	List B
	PX282	Stars and the Solar System	15	List B
Term 2	PX264	Physics of Fluids	7.5	List B
Terms 2 & 3	PX263	Electromagnetic Theory and Optics	7.5	List B

Philosophy Modules

Students following modules in Philosophy should register for them as normal on the module registration system, but are also encouraged to check with the Philosophy department to ensure that the module still has places available in case it is oversubscribed.

Term	Code	Module	CATS	List
Term 1	PH210	Logic II: Metatheory	15	List B
	PH373	The Philosophy of Time	15	List B
Terms 1 & 2	PH201	History of Modern Philosophy	30	List B
Term 2	PH251	Metaphysics	15	List B
	PH340	Logic III: Incompleteness and Undecidability	15	List B

Warwick Business School

Students intending to transfer at the end of the second year to the joint degree *Mathematics and Business Studies* run by the Warwick Business School should note at the end of the second year students must get at least 50% in any IB coded module, gain an overall honours mark (40% Seymour) and be interviewed by WBS. See the information for all WBS modules.

Note that for any WBS module you MUST register on both the University registration system (eVision) and the WBS system (MyWBS), **with the same CATS weighting**. Failure to do this may mean that you will not be permitted to continue on the module and be removed from it.

You will need to register on myWBS in the Spring of the previous academic year to ensure you have secured your place on the modules. NOTE that from next year IB132 and IB133 will be available to maths students, **but will have different module codes** for second year students (which have not been finalised yet).

PLEASE NOTE 2: From 2020/21 all 2nd year WBS modules will only be available at 15 CATS not 12.

Term	Code	Module	CATS	List
Term 1	IB133	Foundations of Accounting	15	List B
	IB207	Mathematical Programming II	12	List B
Term 2	IB132	Foundations of Finance	15	List B
	IB320	Simulation	15	List B
	IB2C9	Principles of Entrepreneurship	15	List B

Centre for Education Studies

Note: we advise students to take this module in their second year rather than third since it involves teaching practice over the Easter vacation which may interfere with revision for final year modules examined immediately after that vacation.

Term	Code	Module	CATS	List
Term 2	EP304	Introduction to Secondary Maths Teaching	15	List B
	EP304	Introduction to Secondary Maths Education	30	List B

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.

Plan ahead! 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 second year the students will have

- covered the foundational core;
- had the opportunity to follow options which build on their core knowledge;
- acquired sufficient knowledge and understanding to be in a position to make an informed choice of options in their final years;
- (joint degrees) acquired their core mathematical knowledge and been prepared, through their choice of options, for their final year in the department of their second specialism.

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
Core module averages

MA269 Asymptotics and Integral Transforms

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma269/)
Lecturer: Ed Brambley

Term(s): Term 2

Status for Mathematics students:

Commitment: 30 Lectures

Assessment: 100% by 2 hour examination

Formal registration prerequisites: None

Assumed knowledge:

- MA133 Differential Equations: Methods for solving ODEs (particularly 2nd order linear ODEs)
- MA244 Analysis III: Complex differentiability, and complex contour integration (including calculating residues)
- MA259 Multivariable Calculus: Classification of minima, maxima, and saddles

Useful background:

- MA134 Geometry and Motion: Provides background and intuition for some of the example models used in this course.

Synergies: Since this is a new course, no other courses depend on this one (yet), but knowledge from this course helps with the understanding of the following courses:

- MA250 Introduction to Partial Differential Equations: Fourier transforms can be used to solve many linear PDEs on infinite domains, including all the ones covered in MA250
- MA254 Theory of ODEs: Asymptotics can be seen as a generalization of the concept of linearization near critical points covered in this course
- MA261 Differential Equations: Modelling and Numerics: Asymptotics are used to simplify complex mathematical models, and numerical Fourier transforms are extensively used to speed up numerics
- MA3B8 Complex Analysis: Experience of using complex contour integration will help prepare for the more rigorous treatment in Complex Analysis
- MA3D1 Fluid Dynamics: Many of the techniques and concepts covered in this course are used in fluid dynamics, including both asymptotics and Fourier transforms, and several examples in this course originate in fluid dynamics
- MA3G1 Theory of Partial Differential Equations: Many of the techniques covered here can be used to solve, or understand the solutions of, many forms of PDEs

Aims: A two-part course covering an introduction to asymptotics, and an introduction to integral transforms, focusing on their properties and their applications, with proofs to come in later courses (although these may be hinted at by the lecturer). The course covers standard techniques that are of widespread use throughout applied mathematics, physics, and engineering.

Content: We will cover the following topics:

Asymptotics:

- Formal definition of an asymptotic series, with examples (e.g. erf(z)). Discussion of the origins of small parameters (e.g. dimensionless parameters, stability analysis)
- Asymptotics of algebraic equations, with examples (e.g. solutions of nearly-linear quadratic equations)
- Asymptotics of integrals, with examples (e.g. Stirling's formula, computing oscillatory integrals)
- Asymptotics of differential equations, with examples (e.g. boundary layers).

Integral Transforms:

- Definition of an Integral Transform, with examples including Fourier (superposition of musical notes) and Radon (CAT scans) transforms
- Fourier Transforms, and their applications to linear ODEs and PDEs, with examples including waves in a waveguide
- Laplace transforms, and their use in solving initial-value problems for ODEs
- A brief tour of other integral transforms, including Mellin, Z, and Radon transforms

If time permits, we may also touch on Green’s Functions, Discrete Fourier Transforms or Half-Range Fourier Transforms.

Objectives:

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

- Understand the formal definition of asymptotic series and their uses
- Be able to identify both regular and singular perturbations
- Use various techniques to construct asymptotic series
- Be aware of a range of integral transforms and their interpretations
- Be able to calculate Fourier and Laplace transforms and understand their similarities and differences

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
Core module averages

MA2K3 Consolidation

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma2k3/)
Lecturer: Mark Cummings

Term(s): Term 1

Status for Mathematics students: By invitation only

Commitment:

Assessment: 100% Assignments

Formal registration prerequisites: None

Assumed knowledge: None

Useful background: None

Synergies: Covers first year material useful for second year core modules, in particular:

- MA244 Analysis III
- MA251 Algebra I
- MA259 Multivariable Calculus

Content: The tutor selects problems related to first year modules where the student's record indicates that further study is desirable. Each week, the student receive an assignment of written work to be handed in. At the following tutorial, the student and the tutor discuss the student's answers and related material.

Aims:

- To provide individual attention for students recommended by the First Year Exam Board to improve prospects of a good honours degree.
- To improve understanding of the material from the first year, focusing primarily on the topics that a student struggled with first time around.

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

MA209 Variational Principles

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma209/)
Lecturer: Mario Micallef

Term(s): Term 3

Status for Mathematics students: List A for Maths

NOTE: To avoid clashes with April exams this module starts in the 2nd week of Term 3 and is lectured 4 times a week. It overlaps with the 3rd/4th year examination periods in April and May so these students should be aware that they may miss examinable material.

Commitment: 15 lectures

Assessment: 100% 1 hour examination

Formal registration prerequisites: None

Assumed knowledge: Solving ODEs including separation of variables and linear constant coefficient ODEs (this material is covered in both MA133 Differential Equations and MA113 Differential Equations A), MA259 Multivariable Calculus (and, by implication, the prerequisites for this module), MA244 Analysis III or MA258 Mathematical Analysis III

Useful background: Newton's laws of motion, scalar potential of electrostatic field or gravitational field. However, this is a mathematics module and a physics background will not be required

Synergies: Variational problems arise whenever some quantity is to be optimised. This quantity can come from geometry (length, area), physics (energy), biology, economics. So all modules in which optimisation is considered are related to this module. Examples of such modules include:

- PX267 Hamiltonian Mechanics
- MA250 Introduction to Partial Differential Equations
- MA4G6 Calculus of Variations
- MA4L9 Variational Analysis and Evolution Equations

Content: This module consists of a study of the mathematical techniques of variational methods, with applications to problems in physics and geometry. Critical point theory for functionals in finite dimensions is developed and extended to variational problems. The basic problem in the calculus of variations for continuous systems is to minimise an integral of the form

$$I(y) = \int_a^b f(x, y, y_x)\, dx$$

on a suitable set of differentiable functions y: $[a, b] \to \mathbb{R}$ where y_x denotes the derivative of y with respect to x. The Euler-Lagrange theory for this problem is developed and applied to dynamical systems (Hamiltonian mechanics and the least action principle), shortest time (path of light rays and Fermat's principle), shortest length and smallest area problems in geometry. The theory is extended to constrained variational problems using Lagrange multipliers.

Aims: To introduce the calculus of variations and to see how central it is to the formulation and understanding of physical laws and to problems in geometry.

Objectives: At the conclusion of the course you should be able to set up and solve minimisation problems with and without constraints, to derive Euler-Lagrange equations and appreciate how the laws of mechanics and geometrical problems involving least length and least area fit into this framework.

Books:

A useful and comprehensive introduction is:

R Weinstock, *Calculus of Variations with Applications to Physics and Engineering*, Dover, 1974.

Other useful texts are:

F Hildebrand, *Methods of Applied Mathematics* (2nd ed), Prentice Hall, 1965.

IM Gelfand & SV Fomin. *Calculus of Variations*, Prentice Hall, 1963.

The module will not, however, closely follow the syllabus of any book.

Additional Resources

MA257 Introduction to Number Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma257/)

Lecturer: Sam Chow

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: 85% 2 hour examination, 15% homework assignments

Formal registration prerequisites: None

Assumed knowledge:

- MA136 Introduction to Abstract Algebra: Rings, subrings, ideals, integral domains, fields
- MA132 Foundations or MA138 Sets and Numbers: Congruence modulo n, prime factorisation, Euclidean algorithm, gcd and lcm, Bezout Lemma

Useful background: Interest in Number Theory is essential

Synergies:

- MA249 Algebra II: Groups and Rings: Ring theoretic part Algebra II and Introduction to Number Theory have much in common

Leads to: The following modules have this module listed as **assumed knowledge or useful background:**

- MA3G6 Commutative Algebra
- MA3A6 Algebraic Number Theory
- MA4H9 Modular Forms
- MA4L6 Analytic Number Theory
- MA426 Elliptic Curves

Content:

- Factorisation, divisibility, Euclidean Algorithm, Chinese Remainder Theorem
- Congruences. Structure on Z/mZ and its multiplicative group. Theorems of Fermat and Euler. Primitive roots
- Quadratic reciprocity, Diophantine equations
- Elementary factorization algorithms
- Introduction to Cryptography
- p-adic numbers, Hasse Principle

- Geometry of numbers, sum of two and four squares

Aims: To introduce students to elementary number theory and provide a firm foundation for later number theory and algebra modules

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

- Work with prime factorisations of integers
- Solve congruence conditions on integers
- Determine whether an integer is a quadratic residue modulo another integer
- Apply p-adic and geometry of numbers methods to solve some Diophantine equations
- Follow advanced courses on number theory in the third and fourth year

Books:
H. Davenport, *The Higher Arithmetic*, Cambridge University Press

G. H. Hardy and E. M. Wright, *An Introduction to the Theory of Numbers*, Oxford University Press, 1979

K. Ireland and M. Rosen, *A Classical Introduction to Modern Number Theory*, Springer-Verlag, 1990

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
Core module averages

MA257 Forum

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma257/forum/)

Search this forum

2 followers

1. introductory message

1 post, started by John Cremona, 15:57, Fri 2 Jan 2015

MA213 Second Year Essay

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma213/)
Organiser: Helena Verrill

Term(s): Terms 1 & 2

Status for Mathematics students: Core for all Maths students except GL11 (for whom it is List A)

Commitment: Independent study with guidance from Personal Tutor

Assessment: Essay 80%, Presentation 20%

Organisation: You can choose your own topic in consultation with your tutor (who must approve it) or base an essay on one of the Maths at Work topics after attending the talks.

Students may, and are strongly advised to, submit a draft of their essay to their tutor by the end of the first week of Term 2. You are expected to have consulted the web pages in the additional resources page on essay writing prior to submission of the draft. The tutor will provide written comments and discuss the draft, normally by Week 4 of Term 2.

Students have to give a 15-minute oral presentation of the essay to their tutor and a small group of other second year students, normally in week 9 of Term 2. This presentation is a compulsory requirement and 20% of the essay mark is allocated to the quality of the presentation. Students should seek advice, e.g. from their tutor, on how to convey the content of their essay within such a short period of time; they must not get bogged down in technicalities but they should not be vague.

Aims:

1. To provide an opportunity for students to learn some mathematics directly from books and other sources.
2. To develop written and oral exposition skills.

Objectives:

1. To learn how to write mathematics well.
2. To practice presenting mathematics orally to a group.
3. To develop research skills, including planning, use of library and the internet.

Deadline The essays should be submitted electronically online through Moodle by 12:00 noon on Thursday 29th April 2021. *This deadline is enforced* by the mechanism described in the Course Handbook section on Assessment.

It is the students' responsibility to choose their essay topic, to prepare the draft on time, to seek advice where necessary, to prepare the presentation on time and to submit the final version of the essay on time.

The essay will be marked by your tutor and a second marker. Your tutor will also award the mark for the oral presentation. Instructions about the essay and information on the marking scheme will be given out by the end of Term 1. Students are advised to read the instructions carefully, since failure to follow one of the University Regulations (on plagiarism, for example) could result in a mark of zero.

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
Core module averages

MA241 Combinatorics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma241/)
Lecturer: Robert Silversmith

Term(s): Term 1

Status for Mathematics students: List A for Mathematics

Commitment: 30 lectures

Assessment: 10% by 4 fortnightly assignments during the term, 90% by a two-hour written examination

Formal registration prerequisites: None

Assumed knowledge: The module starts from first principles and requires only interest in Mathematics and some level of mathematical maturity

Useful background:

- MA106 Linear Algebra or
- CS137 Discrete Mathematics and its Applications 2

Synergies:

- MA252 Combinatorial Optimization

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA252 Combinatorial Optimization
- MA3J2 Combinatorics II
- MA4L2 Statistical Mechanics
- MA4J3 Graph Theory
- MA4M4 Topics in Complexity Science
- MA4J5 Structures of Complex Systems

Content:

I Enumerative Combinatorics:

- Basic counting (Lists with and without repetitions, Binomial coefficients and the Binomial Theorem)
- Applications of the Binomial Theorem (Multinomial Theorem, Multiset formula, Principle of inclusion/exclusion)
- Linear recurrence relations and the Fibonacci numbers
- Generating functions and the Catalan numbers
- Permutations, Partitions and the Stirling and Bell numbers

II Graph Theory:

- Basic concepts (isomorphism, connectivity, Euler circuits)
- Trees (basic properties of trees, spanning trees, counting trees)
- Planarity (Euler's formula, Kuratowski's theorem, the Four Colour Problem)
- Matching Theory (Hall's Theorem and Systems of Distinct Representatives)
- Elements of Ramsey Theory

III Boolean Functions

Books:

Edward E. Bender and S. Gill Williamson, *Foundations of Combinatorics with Applications*, Dover Publications, 2006. Available online at the author's website: http://www.math.ucsd.edu/~ebender/CombText/

John M. Harris, Jeffry L. Hirst and Michael J. Mossinghoff, *Combinatorics and Graph Theory*, Springer-Verlag, 2000.

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

MA243 Geometry

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma243/)
Lecturer: Helena Verrill

Term(s): Term 1

Status for Mathematics students: List A for Mathematics

Commitment: 30 lectures plus weekly worksheets

Assessment: The weekly worksheets carry 15% assessed credit; the remaining 85% credit by 2-hour examination

Formal registration prerequisites: None

Assumed knowledge: Basics of linear algebras:

MA106 Linear Algebra:

- Vector spaces
- Bases and dimension
- Linear maps
- Rank and nullity
- Represent linear maps by matrices
- Euclidean inner product
- Eigenvalues and eigenvectors

Useful background: Familiarity with the basic language of geometry:

MA134 Geometry and Motion:

- Euclidean distance and norm
- Parametrised curves

Synergies: The following modules go well together with Geometry:

- MA251 Algebra 1: Advanced Linear Algebra
- MA3D9 Geometry of Curves and Surfaces

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3J2 Combinatorics II
- MA3F1 Introduction to Topology
- MA448 Hyperbolic Geometry
- MA4H4 Geometric Group Theory
- MA4A5 Algebraic Geometry

Content: Geometry is the attempt to understand and describe the world around us and all that is in it; it is the central activity in many branches of mathematics and physics, and offers a whole range of views on the nature and meaning of the universe.

Klein's Erlangen program describes geometry as the study of properties invariant under a group of transformations. Affine and projective geometries consider properties such as collinearity of points, and the typical group is the full $n \times n$ matrix group. Metric geometries, such as Euclidean geometry and hyperbolic geometry (the non-Euclidean geometry of Gauss, Lobachevsky and Bolyai) include the property of distance between two points, and the typical group is the group of rigid motions (isometries or congruences) of 3-space. The study of the group of motions throws light on the chosen model of the world.

Aims: To introduce students to various interesting geometries via explicit examples; to emphasize the importance of the algebraic concept of group in the geometric framework; to illustrate the historical development of a mathematical subject by the discussion of parallelism.

Objectives: Students at the end of the module should be able to give a full analysis of Euclidean geometry; discuss the geometry of the sphere and the hyperbolic plane; compare the different geometries in terms of their metric properties, trigonometry and parallels; concentrate on the abstract properties of lines and their incidence relation, leading to the idea of affine and projective geometry.

Books:

M Reid and B Szendröi, Geometry and Topology, CUP, 2005

J G Ratcliffe, Foundations of Hyperbolic Manifolds, Springer, 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

Year 4 regs and modules
G103

Exam information
Core module averages

MA244 Analysis III

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma244/)
Lecturer: Oleg Zaboronski

Term(s): Term 1

Status for Mathematics students: Core for Maths

Commitment: 30 one-hour lectures plus three assignments

Assessment: 85% by 2-hour examination, 15% coursework

This module will be examined in the first week of Term 3

Formal registration prerequisites: None

Assumed knowledge: Notions of convergence, and basic results for sequences, series, differentiation and integration from introductory analysis modules like MA131 Analysis (or MA137 Mathematical Analysis for non-maths students); knowledge of vector spaces from MA106 Linear Algebra

Useful knowledge: Basic results about curves and surfaces and vectorfields from MA134 Geometry and Motion

Synergies: The module fits with MA259 Multivariable Calculus

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA260 Norms, Metrics and Topologies
- MA222 Metric Spaces

- MA250 Introduction to Partial Differential Equations
- MA269 Asymptotics and Integral Transforms
- MA209 Variational Principles
- MA3H0 Numerical Analysis and PDEs
- MA3D9 Geometry of Curves and Surfaces
- MA3B8 Complex Analysis
- MA3H7 Control Theory
- MA3G1 Theory of Partial Differential Equations
- MA3K0 High Dimensional Probability
- MA3G7 Functional Analysis I
- MA359 Measure Theory
- MA4L6 Analytic Number Theory

Content: This covers three topics:

- Riemann integration
- Convergence of sequences and series of functions
- Introduction to complex valued functions

The idea behind integration is to compute the area under a curve. The fundamental theorem of calculus gives the precise relation between integration and differentiation. However, integration involves taking a limit, and the deeper properties of integration require a precise and careful analysis of this limiting process. This module proves that every continuous function can be integrated, and proves the fundamental theorem of calculus. It also discusses how integration can be applied to define some of the basic functions of analysis and to establish their fundamental properties.

Many functions can be written as limits of sequences of simpler functions (or as sums of series): thus a power series is a limit of polynomials, and a Fourier series is the sum of a trigonometric series with coefficients given by certain integrals. The second part of the module develops methods for deciding when a function defined as the limit of a sequence of other functions is continuous, differentiable, integrable, and for differentiating and integrating this limit. Norms are used at several stages and finally applied to show that a Differential Equation has a solution.

The final part of module focuses on complex valued functions, starting with the notion of complex differentiability. The module extends the results from Analysis II on power series to the complex case. The final section focuses on contour integrals, where a complex valued function is integrated along a curve. Cauchy's integral formula will be developed and a series of applications presented (to compute integrals of real valued functions, Liouville's Theorem and the Fundamental Theorem of Algebra).

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

- Develop a good working knowledge of the construction of the Riemann integral
- Understand the fundamental properties of the integral; main ones include: any continuous function can be integrated on a bounded interval and the Fundamental Theorem of Calculus (and its applications)
- Understand uniform and pointwise convergence of functions together with properties of the limit function
- Study the continuity, differentiability and integral of the limit of a uniformly convergent sequence of functions
- Study complex differentiability (Cauchy-Riemann equations) and complex power series
- Study contour integrals: Cauchy's integral formulas and applications.

Books:

There is no recommended textbook for the course. A complete set of lecture notes will be provided.

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

MA249 Algebra II: Groups and Rings

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma249/)
Lecturer: Nicholas Jackson

Term(s): Term 2

Status for Mathematics students: Core for Year 2 mathematics students. It could be suitable as a usual or unusual option for non-maths students

Commitment: 30 lectures

Assessment: 85% 2 hour June examination, 15% Assignments

Formal registration prerequisites: None

Assumed knowledge:

MA132 Foundations or MA138 Sets and Numbers:

- Number theory: congruence modulo-n, prime factorisation, Euclidean algorithm, gcd and lcm
- Sets and functions: basic set theory, injective and surjective functions, relations
- Polynomials: multiplication and division, Euclidean algorithm, Remainder Theorem, algebraic and transcendental numbers

Useful background:

MA136 Introduction to Abstract Algebra:

- Group theory: definitions of groups, subgroups, homomorphisms. Key examples (numbers, permutations, dihedral and other symmetry groups), Lagrange's Theorem, Normal subgroups and quotient groups
- Ring theory: definitions of rings, subrings, integral domains, fields. Key examples (Z, Q, R, C, Z_n, matrix rings, polynomial rings). (This material will be covered again, but prior knowledge will be helpful.)

MA251 Algebra I:

- Classification of finitely generated Abelian groups

Synergies: The following modules goes well with Algebra II:

- MA243 Geometry
- MA257 Introduction to Number Theory

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3E1 Groups and Representations
- MA3G6 Commutative Algebra
- MA3J9 Historical Challenges in Mathematics
- MA377 Rings and Modules
- MA3F1 Introduction to Topology
- MA3K4 Introduction to Group Theory

- MA3J3 Bifurcations, Catastrophes and Symmetry
- MA3D5 Galois Theory
- MA3H6 Algebraic Topology
- MA3J2 Combinatorics II
- MA3A6 Algebraic Number Theory
- MA4L6 Analytic Number Theory
- MA4H4 Geometric Group Theory
- MA426 Elliptic Curves
- MA473 Reflection Groups
- MA453 Lie Algebras
- MA4J8 Commutative Algebra II

Content: This is an introductory abstract algebra module. As the title suggests, the two main objects of study are groups and rings. You already know that a group is a set with one binary operation. Examples include groups of permutations and groups of non-singular matrices. Rings are sets with two binary operations, addition and multiplication. The most notable example is the set of integers with addition and multiplication, but you will also be familiar already with rings of polynomials. We will develop the theories of groups and rings.

Some of the results proved in MA251 Algebra I: Advanced Linear Algebra for abelian groups are true for groups in general. These include Lagrange's Theorem, which says that the order of a subgroup of a finite group divides the order of the group. We defined quotient groups G/H for abelian groups in Algebra I, but for general groups these can only be defined for certain special types of subgroups *H* of *G*, known as normal subgroups. We can then prove the isomorphism theorems for groups in general. An analogous situation occurs in rings. For certain substructures *I* of rings *R*, known as ideals, we can define the quotient ring R/I, and again we get corresponding isomorphism theorems.

Other results to be discussed include the Orbit-Stabiliser Theorem for groups acting as permutations of finite sets, the Chinese Remainder Theorem, and Gauss' theorem on unique factorisation in polynomial rings.

Aims: To study abstract algebraic structures, their examples and applications.

Objectives: By the end of the module the student should know several fundamental results about groups and rings as well as be able to manipulate with them.

Books:

Niels Lauritzen, *Concrete Abstract Algebra*, Cambridge University Press

M A Armstrong, *Groups and Symmetry*, Springer

John B Fraleigh, *A First Course in Abstract Algebra*, Pearson

Joseph Gallian, *Contemporary Abstract Algebra*, Chapman Hall

John M Howie, *Fields and Galois Theory*, Springer

Nicholas Jackson, *A Course in Abstract Algebra*, Oxford University Press (forthcoming, draft sections available on request)

Recommended Syllabus

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

MA250 Introduction to Partial Differential Equations

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma250/)
Lecturer: Bjorn Stinner

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 lectures

Assessment: 85% 2 hour final exam, 15% Coursework

Formal registration prerequisites: None

Assumed knowledge: We will use facts and techniques of the following topics, knowledge of which may have been obtained in the modules stated below or otherwise: Solutions to linear first and second order ODEs, separation of variables techniques - MA113 Differential Equations A or MA133 Differential Equations. Differentiation along a curve, Leibniz' rule and the divergence theorem MA134 Geometry and Motion. The spaces of (multiply) continuously differentiable functions and uniform convergence MA244 Analysis III or MA258 Mathematical Analysis III. Diagonalisation of symmetric matrices MA251 Algebra 1: Advanced Linear Algebra.

Useful background: MA259 Multivariable Calculus provides more depth on the topics covered by MA134 Geometry and Motion. More generally, good working knowledge of partial derivatives and calculus for functions of multiple variables is beneficial.

Synergies: MA209 Calculus of Variations addresses a way how differential equations can be derived. Sometimes, solving partial differential equations comes down to having to solve ordinary differential equations, and then computational techniques as discussed in MA261 Differential Equations: Modelling and Numerics can prove useful. Eigenvalue problems for second order ordinary differential equations are investigated in MA254 Theory of ODEs in more depth. There are many applications of partial differential equations, for example, those discussed in PX263 Electromagnetic Theory and Optics and PX264 Physics of Fluids.

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3D1 Fluid Dynamics
- MA3J4 Mathematical Modelling with PDE
- MA3G1 Theory of Partial Differential Equations
- MA390 Topics in Mathematical Biology
- MA3H0 Numerical Analysis and PDEs
- MA4M2 Mathematics of Inverse Problems
- MA4L0 Advanced Topics in Fluids
- MA482 Stochastic Analysis

Content: The theory of partial differential equations (PDE) is important both in pure and applied mathematics. On the one hand they are used to mathematically formulate many phenomena from the natural sciences (electromagnetism, Maxwell's equations) or social sciences (financial markets, Black-Scholes model). On the other hand since the pioneering work on surfaces and manifolds by Gauss and Riemann partial differential equations have been at the centre of many important developments on other areas of mathematics (geometry, Poincare-conjecture).

Subject of the module are four significant partial differential equations (PDEs) which feature as basic components in many applications: The transport equation, the wave equation, the heat equation, and the Laplace equation. We will discuss the qualitative behaviour of solutions and, thus, be able to classify the most important partial differential equations into elliptic, parabolic, and hyperbolic type. Possible initial and boundary conditions and their impact on the solutions will be investigated. Solution techniques comprise the method of characteristics, Green's functions, and Fourier series.

Aims: To introduce the basic phenomenology of partial differential equations and their solutions. To construct solutions using classical methods.

Objectives: At the end, you will be familiar with the notion of well-posed PDE problems and have an idea what kind of initial or boundary conditions may be imposed for this purpose. You will have studied some techniques which enable you to solve some simple PDE problems. You will also understand that properties of solutions to PDEs sensitively depend on the its type.

Books:
A script based on the lecturer's notes will be provided. For further reading you may find the following books useful (sections of relevance will be pointed out in the script or in the lectures):

S Salsa, *Partial Differential Equations in Action, From Modelling to Theory*. Springer (2008)
A Tveito and R Winther, *Introduction to Partial Differential Equations, A Computational Approach*. Springer TAM 29 (2005)
W Strauss, *Partial Differential Equations, An Introduction*. John Wiley (1992)
JD Logan, *Applied Partial Differential Equations*. 2nd edt. Springer (2004)
MP Coleman, *An Introduction to Partial Differential Equations with MATLAB*. Chapman and Hall (2005)
M Renardy and RC Rogers, *An Introduction to Partial Differential Equations*, Springer TAM 13 (2004)
LC Evans, *Partial Differential Equations*. 2nd edt. American Mathematical Society GMS 19 (2010)

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
Core module averages

MA251 Algebra 1: Advanced Linear Algebra

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma251/)
Lecturer: Christian Boehning

Term(s): Term 1

Status for Mathematics students: Core for Maths

Commitment: 30 one-hour lectures plus three assignments

Assessment: 85% by 2-hour examination, 15% coursework

Formal registration prerequisites: None

Assumed knowledge: Knowledge of Vector spaces and matrices from MA106 Linear Algebra. In particular, understanding change of basis matrices, eigenvalues and eigenvectors, elementary row and column operations and diagonalisation of matrices

Useful background: Group theory from MA136 Introduction to Abstract Algebra especially abelian groups

Synergies: The following modules go well with this module: MA249 Algebra 2: Groups and Rings

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA249 Algebra II: Groups and Rings
- MA250 Introduction to Partial Differential Equations
- MA254 Theory of ODEs

- MA3E1 Groups and Representations
- MA3H6 Algebraic Topology
- MA3J9 Historical Challenges in Mathematics
- MA3G6 Commutative Algebra
- MA3A6 Algebraic Number Theory
- MA377 Rings and Modules
- MA3F1 Introduction to Topology
- MA3K4 Introduction to Group Theory
- MA398 Matrix Analysis and Algorithms
- MA4C0 Differential Geometry
- MA453 Lie Algebras
- MA4H4 Geometric Group Theory
- MA4H0 Applied Dynamical Systems
- MA473 Reflection Groups

Content: This module is a continuation of MA106 Linear Algebra. In that course we studied conditions under which a matrix is similar to a diagonal matrix, but we did not develop methods for testing whether two general matrices are similar. Our first aim is to fill this gap for matrices over C. Not all matrices are similar to a diagonal matrix, but they are all similar to one in Jordan canonical form; that is, to a matrix which is almost diagonal, but may have some entries equal to 1 on the superdiagonal.

We next study quadratic forms. A *quadratic form* is a homogeneous quadratic expression $\sum \ a_{ij}x_ix_j$ in several variables. Quadratic forms occur in geometry as the equation of a quadratic cone, or as the leading term of the equation of a plane conic or a quadric hypersurface. By a change of coordinates, we can always write $q(x)$ in the *diagonal form* $\sum \ a_ix_i^2$. . For a quadratic form over R, the number of positive or negative diagonal coefficients $a_i$is an invariant of the quadratic form which is very important in applications.

Finally, we study matrices over the integers Z, and investigate what happens when we restrict methods of linear algebra, such as elementary row and column operations, to operations over Z. This leads, perhaps unexpectedly, to a complete classification of finitely generated abelian groups.

Aims: To develop further and to continue the study of linear algebra, which was begun in Year 1.

To point out and briefly discuss applications of the techniques developed to other branches of mathematics, physics, etc.

Objectives: By the end of the module students should be familiar with: the theory and computation of the the Jordan canonical form of matrices and linear maps; bilinear forms, quadratic forms, and choosing canonical bases for these; the theory and computation of the Smith normal form for matrices over the integers and its application to finitely generated abelian groups.

Books:

P M Cohn, *Algebra, Vol. 1*, Wiley

I N Herstein, *Topics in Algebra*, Wiley.

Neither is essential, but are a good idea if you are intending to study further algebra modules.

Recommended Syllabus

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

MA252 Combinatorial Optimisation

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma252/)
Lecturer: Diane Maclagan

Term(s): Term 2

Status for Mathematics students: List A for Mathematics

Commitment: 30 lectures.

Assessment: 100% 2 hour exam

Formal registration prerequisites: None

Assumed knowledge: None

Useful background:

- MA241 Combinatorics
- CS137 Discrete Mathematics & its Applications 2
- CS260 Algorithms

Synergies: This module complements the following:

- MA241 Combinatorics
- MA4J3 Graph Theory

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA4M4 Topics in Complexity Science
- MA4J5 Structures of Complex Systems

Content: The focus of combinatorial optimisation is on finding the "optimal" object (i.e. an object that maximises or minimises a particular function) from a finite set of mathematical objects. Problems of this type arise frequently in real world settings and throughout pure and applied mathematics, operations research and theoretical computer science. Typically, it is impractical to apply an exhaustive search as the number of possible solutions grows rapidly with the "size" of the input to the problem. The aim of combinatorial optimisation is to find more clever methods (i.e. algorithms) for exploring the solution space.

This module provides an introduction to combinatorial optimisation. Our main focus is on several fundamental problems arising in graph theory and algorithms developed to solve them. These include problems related to shortest paths, minimum weight spanning trees, matchings, network flows, cliques, colourings and matroids. We will also discuss "intractible" (e.g. NP-hard) problems.

Main Reference:

- B. Korte and J. Vygen, *Combinatorial Optimization: Theory and Algorithms*, Springer, 6th Edition, 2018. E-book available through the Warwick Library; click the link.

Other Resources:

- A. Bondy and U. S. R. Murty, *Graph Theory with Applications*, Elsevier, 1976. Available through the link.
- W.J. Cook, William H. Cunningham, W. R. Pulleybank, and A. Schrijver, *Combinatorial Optimization*, Wiley-Interscience Series in Discrete Mathematics, 1998.
- C.H. Papadimitriou and K. Steiglitz *Combinatorial Optimization: Algorithms and Complexity* *Optimization: Algorithms and Complexity*, Dover Publications, 1998.

Additional Resources

MA254 Theory of ODEs

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma254/)

Lecturer: James Robinson

Term(s): Term 2

Status for Mathematics students: List A

Commitment: 30 one hour lectures

Assessment: 100% 2 hour examination

Formal registration prerequisites: None

Assumed knowledge:

- MA131 Analysis or MA137 Mathematical Analysis
- MA133 Differential Equations or MA113 Differential Equations A
- MA106 Linear Algebra - Eigenvectors and eigenvalues of real matrices
- MA134 Geometry & Motion - Parametrisation of curves and geometry of level sets
- MA251 Algebra I - Jordan Canonical Form (this will also be reviewed briefly in the two-dimensional case)

Useful background: Some ideas introduced in MA259 Multivariable Calculus (open and closed sets, compactness) and expanded on in MA260 Norms, Metrics, & Topologies or MA222 Metric Spaces will be used throughout, although a review of the main concepts will be available. ["Assumed knowledge of which you will be reminded."] The module will make use of other parts of MA260 Norms, Metrics, & Topologies or MA222 Metric Spaces too, but as this is running concurrently the required concepts will be introduced during the module.

Synergies:

- MA261 Differential Equations: Modelling and Numerics
- MA250 Introduction to PDEs
- MA209 Variational Principles

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3J4 Mathematical Modelling with PDE
- MA3H5 Manifolds
- MA3H7 Control Theory
- MA390 Topics in Mathematical Biology
- MA3J3 Bifurcations, Catastrophes and Symmetry
- MA4J1 Continuum Mechanics

- MA4C0 Differential Geometry
- MA4E0 Lie Groups
- MA4H0 Applied Dynamical Systems
- MA4M1 Epidemiology by Example

Content: Many fundamental problems in the applied sciences reduce to understanding solutions of ordinary differential equations (ODEs). Examples include: the laws of Newtonian mechanics, predator-prey models in Biology, and non-linear oscillations in electrical circuits, to name only a few. These equations are often too complicated to solve exactly, so one tries to understand *qualitative* features of solutions.

Some questions we will address in this course include:

When do solutions of ODEs exist and when are they unique? What is the long time behaviour of solutions and can they "blow-up" in finite time? These questions culminate in the famous Picard-Lindelof theorem on existence and uniqueness of solutions of ODEs.

The main part of the course will focus on phase space methods. This is a beautiful geometrical approach which often enables one to understand the behaviour of solutions near critical points - often exactly the regions one is interested in. Different trajectories will be classified and we will develop techniques to answer important questions on the stability properties (or lack thereof) of given solutions.

We will eventually apply these powerful methods to particular examples of practical importance, including the Lotka-Volterra model for the competition between two species and to the Van der Pol and Lienard systems of electrical circuits.

The course will end with a discussion of the Sturm-Liouville theory for solving boundary value problems.

Aims: To extend the knowledge of first year ODEs with a mixture of applications, modelling and theory to prepare for more advanced modules later on in the course.

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

- Determine the fundamental properties of solutions to certain classes of ODEs, such as existence and uniqueness of solutions
- Sketch the phase portrait of 2-dimensional systems of ODEs and classify critical points and trajectories
- Classify various types of orbits and possible behaviour of general non-linear ODEs
- Understand the behaviour of solutions near a critical point and how to apply linearization techniques to a non-linear problem
- Apply these methods to certain physical or biological systems

Books:
(Complete Lecture Notes will be made available)

Ordinary Differential Equations and Dynamical Systems, **Gerald Teschl**, [Available online]
Elementary Differential Equations and Boundary Value Problems, **Boyce DiPrima** 1997
Differential Equations, Dynamical Systems, and an Introduction to Chaos, **Hirsch, Smale** 2003
Nonlinear Systems, **Drazin** 1992

Additional Resources

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

MA256 Introduction to Mathematical Biology

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma256/)
Lecturer: Emma Davis

Term(s): Term 3

Status for Mathematics students: List A

Commitment: 15 one hour lectures

Assessment: 100% 2 hour examination

Formal registration prerequisites: None

Assumed knowledge: Students should have a good knowledge of differential equations and stochastic modelling. The following modules will provide a good background to this module:

- MA133 Differential Equations or MA113 Differential Equations A
- ST111 Probability A
- ST112 Probability B

Useful background: A good understanding of mathematical models of biological systems will help students to follow the material in this course. The book listed below by Keeling and Rohani "Modelling Infectious Diseases in Humans and Animals" will provide an excellent background to solving differential equations of biological systems.

Synergies: The following year 2 modules will go well with this module:

- MA254 Theory of ODEs
- MA261 Differential Equations: Modelling and Numerics

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA390 Topics in Mathematical Biology
- MA4E7 Population Dynamics: Ecology & Epidemiology
- MA4M1 Epidemiology by Example

Course content:

1. General introduction to the course

2. Introduction to Systems Biology

3. Introduction to Epidemiology

Aims:
Introduction to Mathematical Biology and Systems Biology. Modelling techniques (based on core module material).

Objectives:

- To develop simple models of biological phenomena from basic principles
- To analyse simple models of biological phenomena using mathematics to deduce biologically significant results
- To reproduce models and fundamental results for a range of biological systems
- To have a basic understanding of the biology of the biological systems introduced

Books:
H. Van den Berg, *Mathematical Models of Biological Systems*, Oxford Biology, 2011
James D. Murray, *Mathematical Biology: I. An Introduction*. Springer 2007
Christopher Fall, Eric Marland, John Wagner, John Tyson, *Computational Cell Biology*, Springer 2002
L. Edelstein Keshet, *Mathematical Models in Biology*, SIAM Classics in Applied Mathematics 46, 2005
Keeling, M.J. and Rohani, P. Modeling Infectious Diseases in Humans and Animals, Princeton University Press, 2007
Anderson, R. and May, R. Infectious Diseases of Humans, Oxford University Press, 1992
Glendinning, P. Stability, Instability and Chaos, Cambridge Texts in Applied Mathematics, 1994

Additional Resources

MA259 Multivariable Calculus

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma259/)
Lecturer: Mario Micallef

Term(s): Term 1

Status for Mathematics students: Core

Commitment: 30 one-hour lectures plus three assignments

Assessment: 85% 2-hour examination, 15% coursework

Formal registration prerequisites: None

Assumed knowledge:

- MA131 Analysis I & II or MA137 Mathematical Analysis: epsilon-delta definition of continuity and continuous limits, properties of continuous functions, definition of derivative, Mean Value Theorem, Taylor's theorem with remainder, supremum and infimum.
- MA106 Linear Algebra: Rank-Nullity Theorem and its geometric interpretation, dependence of matrix representation of a linear map with respect to a choice of bases, determinant.
- MA134 Geometry and Motion: partial derivatives, multiple integrals, parameterisation of curves and surfaces, arclength and area, line and surface integrals, vector fields.

A much more detailed list of prerequisites will be posted on the module's webpage a couple of weeks before the beginning of term.

Useful knowledge: Plotting graphs and contour plots of simple functions of two variables; the use of appropriate mathematical software for this purpose is encouraged.

Synergies:

- MA244 Analysis III - particularly the Complex Analysis section
- MA251 Algebra I: Advanced Linear Algebra - particularly bilinear forms and orthogonal matrices
- MA250 Introduction to Partial Differential Equations
- MA260 Norms, Metrics and Topologies or MA222 Metric Spaces
- MA209 Variational Principles
- MA3D9 Geometry of Curves and Surfaces
- MA3H5 Manifolds as well as all PDEs and fluids modules

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA222 Metric Spaces

- MA260 Norms, Metrics and Topologies
- MA250 Introduction to Partial Differential Equations
- MA254 Theory of ODEs
- MA261 Differential Equations: Modelling and Numerics
- MA269 Asymptotics and Integral Transforms
- MA209 Variational Principles
- MA3H0 Numerical Analysis and PDEs
- MA3J3 Bifurcations, Catastrophes and Symmetry
- MA3D9 Geometry of Curves and Surfaces
- MA3G8 Functional Analysis II
- MA3K0 High Dimensional Probability
- MA398 Matrix Analysis and Algorithms
- MA3H5 Manifolds
- MA3K1 Mathematics of Machine Learning
- MA3D1 Fluid Dynamics
- MA3B8 Complex Analysis
- MA3G1 Theory of Partial Differential Equations
- MA3H7 Control Theory
- MA448 Hyperbolic Geometry
- MA4J1 Continuum Mechanics
- MA4C0 Differential Geometry
- MA4H0 Applied Dynamical Systems
- MA424 Dynamical Systems
- MA4A2 Advanced Partial Differential Equations

Content:

- Continuous Vector-Valued Functions
- Some Linear Algebra
- Differentiable Functions
- Inverse Function Theorem and Implicit Function Theorem
- Vector Fields, Green's Theorem in the Plane and the Divergence Theorem in $\mathbb{R}^3$
- Maxima, minima and saddles

Learning Outcomes:

- Demonstrate understanding of the basic concepts, theorems and calculations of multivariate analysis
- Demonstrate understanding of the Implicit and Inverse Function Theorems and their applications
- Demonstrate understanding of vector fields and Green's Theorem and the Divergence Theorem
- Demonstrate the ability to analyse and classify critical points using Taylor expansions

Books:

1. R. Abraham, J. E. Marsden, T. Ratiu. Manifolds, *Tensor Analysis, and Applications*. Springer, second edition, 1988.
2. T. M. Apostol. *Mathematical Analysis*. Addison-Wesley Publishing Co., Reading, Mass.-London-Don Mills, Ont., second edition, 1974.
3. R. Coleman. *Calculus on Normed Vector Spaces*, Springer 2012. [available online via Warwick's library]
4. J. J. Duistermaat, J. A. C. Kolk. *Multidimensional Real Analysis I : Differentiation*, CUP, 2004 [available online via Warwick's library].
5. T. W. Körner. *A Companion to Analysis: A Second First and First Second Course in Analysis*, volume 62 of Graduate Studies in Mathematics. American Mathematical Society, Providence, RI, 2004.
6. J. E. Marsden and A. Tromba. *Vector Calculus*. Macmillan Higher Education, sixth edition, 2011.

Additional Resources

MA260 Norms, Metrics and Topologies

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma260/)

Lecturer: Rohini Ramadas

Term(s): Term 2

Status for Mathematics students: Core

Commitment: 30 lectures

Assessment: 100% 2-hour June examination

Formal registration prerequisites: None

Assumed knowledge:

MA131 Analysis I & II or MA137 Mathematical Analysis I & II:

- Sequences
- Convergence
- Cauchy sequences
- Series
- Continuous functions
- Differentiable functions

MA132 Foundations or MA138 Sets and Numbers:

- Set theory
- Proofs
- Cardinality

MA244 Analysis III or MA258 Mathematical Analysis III:

- Pointwise and uniform convergence of sequences of functions

Useful background:

MA259 Multivariable Calculus:

- Open and closed sets in R^n

Synergies: The following module goes well together with Norms, Metrics & Topologies:

MA243 Geometry

Leads to: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA254 Theory of ODEs
- MA3D9 Geometry of Curves and Surfaces
- MA3B8 Complex Analysis
- MA3G6 Commutative Algebra
- MA3G7 Functional Analysis I
- MA3G8 Functional Analysis II
- MA3H6 Algebraic Topology
- MA3D4 Fractal Geometry
- MA359 Measure Theory
- MA3J2 Combinatorics II
- MA3H5 Manifolds
- MA3G1 Theory of Partial Differential Equations
- MA3K1 Mathematics of Machine Learning
- MA3F1 Introduction to Topology
- MA3H3 Set Theory
- MA448 Hyperbolic Geometry
- MA4E0 Lie Groups
- MA4C0 Differential Geometry
- MA427 Ergodic Theory
- MA4M3 Local Fields
- MA4H4 Geometric Group Theory
- MA424 Dynamical Systems

Content: To introduce the notions of Normed Space, Metric Space and Topological Space, and the fundamental properties of Compactness, Connectedness and Completeness that they may possess. Students will gain knowledge of definitions, theorems and calculations in

- Normed, Metric and Topological spaces
- Open and closed sets and their relation to continuity
- Notions of Compactness and relations to continuous maps
- Notions of Connectedness and relations to continuous maps
- Notions of Completeness and relations to previous topics in the module.

The module comprises the following chapters:

- Normed Spaces
- Metric Spaces
- Open and closed sets
- Continuity
- Topological spaces
- Compactness
- Connectedness
- Completeness

Learning Outcomes:

- Demonstrate understanding of the basic concepts, theorems and calculations of Normed, Metric and Topological Spaces.
- Demonstrate understanding of the open-set definition of continuity and its relation to previous notions of continuity, and applications to open or closed sets.

- Demonstrate understanding of the basic concepts, theorems and calculations of the concepts of Compactness, Connectedness and Completeness (CCC).
- Demonstrate understanding of the connections that arise between CCC, their relations under continuous maps, and simple applications.

Books:

1. W A Sutherland, *Introduction to Metric and Topological Spaces*, OUP.
2. B. Mendelson (1991) *Introduction to Topology.* Dover.

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
Core module averages

MA261 Differential Equations: Modelling and Numerics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma261/)
Lecturer: Andreas Dedner

Term(s): Term 2

Status for Mathematics students:

Commitment: 10 x 3 hour lectures + 9 x 1 hour support classes

Assessment: 100% Coursework. Part of this course work will require some programming using Python

Formal registration prerequisites: None

Assumed knowledge:

- Basic knowledge on solving differential equations and the structure of solutions for systems of ODEs and DEs as provided e.g. by MA133 Differential Equations or MA113 Differential Equations A
- Programming in Python as provided e.g. by MA124 Maths by Computer
- Concepts like Taylor expansion and continuity of multivariable functions as discussed in MA259 Multivariable Calculus

Useful background: Good working knowledge in linear algebra and analysis

Synergies:

- MA117 Programming for Scientists
- MA269 Asymptotics and Integral Transforms
- MA256 Introduction to Systems Biology
- MA209 Variational Principles

Leads To: The following modules have this module listed as **assumed knowledge** or **useful background:**

- MA3J4 Mathematical Modelling with PDE

- MA398 Matrix Analysis and Algorithms
- MA3K1 Mathematics of Machine Learning
- MA3H0 Numerical Analysis and PDEs
- MA4M1 Epidemiology by Example

Content: Mathematics arises all around us not only is nature but also in social structures. A fundamental notion is that of Mathematical Modelling in which natural questions are turned into mathematical problems. Two types of mathematical models are (i) those arising from the application of physical laws and (ii) those arising from the analysis of data. In this module we expose some fundamental aspects of mathematical modelling involving ordinary differential equations. For example, fundamental principles in science like conservation laws and force balances lead to initial value problems. These principles can also be extended in epidemiology for the modelling of the transmission of diseases.

Mathematical models, in general, are too complex to solve explicitly, so that approximation methods and computation are essential tools. Consequently, this module also investigates different methods for approximating the solution to ODEs. Of particular interest and value are their mathematical properties, particularly in respecting properties of the underlying model.

Topics include:

- Demonstration of fundamental principles in deriving models (reaction kinetics and Hamiltonian principle, and fundamental role of dimensional analysis perturbation theory to simplify complex models
- Approximation by discretisation (Runge-Kutta and multistep), and the tools needed to analyse there
- Analysis of discretisation (stability and convergence)
- Examples of the use of these tools in applications.

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

- Understand the central concepts of mathematical modelling
- Be able to derive and analyse fundamental numerical methods
- Implement and test numerical methods using a scripting language

Books:

- F. F. Griffiths and D. J. Higham, *Numerical Methods for Ordinary Differential Equations: Initial Value Problems*, Springer (2010)
- Witlski, M. Brown, *Methods of Mathematical Modelling: Continous System and Differential Equations*, Springer (2015)
- R. L. Burden and J. D Faires, *Numerical Analysis, 8th edition*, Brooks-Cole Publishing (2004)

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
Core module averages

MA255 Virtual Mathematics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ma255/)

Not Running in 2015/16

Lecturer:

Term(s):

Status for Mathematics students: Unsual for second years (restricted numbers), a small number of third years may also be allowed to take this for credit.

Commitment: Weekly seminars in Term 1 (one two hour seminar, and one one hour practical session per week) in the newly refurbished Ramphal rooms, weekly meetings in Term 2 to discuss projects, other ad-hoc online communications.

Assessment: 100% assessed through tasks and assignments in Term 1 (50%) and final project due in end of Term 2 (50%).

Prerequisites: First year core modules. Would possibly complement (but not essential to be taking) IE3E1 Introduction to Secondary School Teaching. Could also be tied in with MA213 Second Year Essay.

Requirements: Access to a decent laptop is strongly encouraged and will be assumed for the seminars, but lack of one will not be a barrier to enrolment or participation. Any software required will be free.

Enrolment: Registration on the module will be subject to successful completion of a short exercise. There will be an organisational meeting for everyone interested in Week 1, registration will be confirmed (or otherwise) by the end of that week.

The module starts proper in Week 2, but there will be an organisational meeting at 10am on Tuesday 1st October in R1.15. Anyone wishing to take this module must attend that session or email the lecturer to explain why they can't make it.

Week 2 onwards the sessions are Tuesdays 9:00-11:00 in R1.15 and Fridays 12:00-13:00 in R0.12 (Ramphal Building)

Content: This module is designed to be an innovative, hands-on exploration of effective ways to disseminate mathematics through the web, the topics below will not necessarily be covered in the same order as presented, but give an idea of the topics to be discussed. Students taking this module will need to be prepared to contribute fully to the two hour seminars, and to be confident to share ideas with other students on the module through online media. Part of the final credit will be based on this participation. The final project, worth 50% of the overall mark, will be worked on during Term 2 and will be an online standalone presentation/tutorial aimed at either undergraduates, gifted children or a "public understanding of science" offering.

A large part of the module is learning and exploring basic web based solutions in a collabrative environment so this module is not very suitable for people with, for example. advanced experience of web page design.

Mac/Linux users welcome, although Windows will be the OS of choice due to University systems.

Students will be expected to keep a personal blog on the module webpage to reflect and discuss ideas with other students, and contribute to an ongoing Wiki sharing good (and bad) case studies as the module progresses. In-class tasks which will count towards the final credit will largely be group based so a willingness to collaborate on timed tasks (and have fun doing it) is essential!

Topics to be covered/explored will include:

- Knowing your audience
- Simple web page design using HTML
- The University's "SiteBuilder" interface (web pages, quizzes etc.) and Moodle
- Putting maths into web pages: (very) basic LaTeX and how to display maths on the web
- Blogs, Wikis and Forums: pros and cons
- Podcasts and screen captures
- Mathematics in Virtual Worlds

The module is likely to be hard work, but last year it was also a lot of fun! For 2012/13 the module recieved some funding and support from IATL, the University's Institute for Advanced Teaching and Learning.

Additional Resources

User pages

Archived pages: 2012

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
Core module averages

FI101 Discovering Cinema

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/fi101/)

uk.ac.warwick.sbr.content.ContentDeniedException: Access denied for the source page.

EC204 Economics 2

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ec204/)

363 total students

40 total lecture hours

16 total seminars

56 total contact hours

30 CATS - Department of Economics

Principal Aims

From this module students can develop a deeper understanding of economic concepts introduced in analysis. It will also introduce to new concepts in both micro and macroeconomic analysis and in the analysis of public policy issues such as market failure and counter-inflation policy.

Principal Learning Outcomes

Subject knowledge and understanding:...demonstrate knowledge of macroeconomic policies and understand the role of theory in analysing their effectiveness. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, Reading, Exercise question sheets, Seminar discussions, Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Subject knowledge and understanding:... abstract and simplify economic problems through the application of theoretical models.

Key Skills:... communicate knowledge and understanding of economics in written, spoken, graphical and in mathematical forms. The teaching and learning methods that enable students to achieve this learning outcome are: Exercise question sheets, Assessed Essays and Seminar discussions. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Subject knowledge and understanding:...apply rigorous knowledge of theoretical models which underlie economic analysis. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, Reading, Exercise question sheets, Seminar discussions, Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Subject knowledge and understanding:...understand the uses, applications and limitations of theoretical models. The teaching and learning methods that enable students to achieve this learning outcome are: Exercise question sheets, Seminar discussions, Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Subject knowledge and understanding:...demonstrate knowledge of microeconomic policies. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, Reading, Exercise question sheets, Seminar discussions, Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Cognitive Skills:...analyse competing models and hypotheses in a critical way. The teaching and learning methods that enable students to achieve this learning outcome are: Exercise question sheets, Readings and Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative) Essay (summative), Summer Examination (summative).

Key Skills:...present the output of their own work to an audience. The teaching and learning methods that enable students to achieve this learning outcome are: Seminar discussions and Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative)

Key Skills:...conduct individual and collaborative research into an Economic topic, using world wide web and library resources. The teaching and learning methods that enable students to achieve this learning outcome are: Exercise question sheets, seminar discussions and Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative)

Cognitive Skills:...analyse and formulate models for understanding and solving problems. The teaching and learning methods that enable students to achieve this learning outcome are: Exercise question sheets, Assessed Essays and Seminar discussions. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays, Group Projects (formative), Summer Examination.

Subject-Specific/Professional Skills:...select and apply appropriate economic models and techniques to particular problems especially those of a policy nature. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, Reading, Exercise question sheets, Assessed Essays and Seminar discussions. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Subject-Specific/Professional Skills:...produce concise and analytical reports relating to economic problems and issues. The teaching and learning methods that enable students to achieve this learning outcome are: Assessed Essays and Seminar presentations. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Subject knowledge and understanding:...understand key concepts and principles in intermediate microeconomics and macroeconomics. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, Reading, Exercise question sheets, Seminar discussions, Assessed Essays. The assessment methods that measure the achievement of this learning outcome are: Exercise question sheet answers (formative), Essays (summative), Summer Examination (summative).

Syllabus

The module will typically cover some of the following topics:

Microeconomics: consumer theory, preferences, indifference curves, budget constraints, optimisation, revealed preference, Hicksian and Slutsky analysis. Choice under uncertainty: expected value and expected utility, insurance, asymmetric information including moral hazard and adverse selection. The analysis of general equilibrium and welfare economics. Consideration of the economics of public policy issues such as externalities and public goods. Game theoretic approaches to oligopoly, entry and other strategic areas in industrial and business economics. Macroeconomics The unemployment-inflation relationship. The effect of monetary policy. Expectations, financial markets and the Macroeconomy. Political business cycles. The Time inconsistency problem. The open economy.

Context

Core Module	V7MR - Year 2, V7ML - Year 2, V7MP - Year 2, LM1D (LLD2) - Year 2, GL11 - Year 2, L1L8 - Year 2, R9L1 - Year 2, R3L4 - Year 2, R4L1 - Year 2, R2L4 - Year 2, R1L4 - Year 2
Optional Module	LA99 - Year 2
Pre or Co-requisites	EC106 (for MORSE students) or EC107 or EC108 and EC109 For WBS students EC131 and EC229 plus passes in IB121 and IB122 *Summary:* *Modules: EC106-24 or EC107-30 or (EC108-30 and EC109-30) or (EC131-15 and EC229-12 and EC229-15 and IB121-15 and IB122-15)*
Restrictions	May not be combined with modules
Part-year Availability for Visiting Students	Available in the Autumn term only (1 x 2000 word essay – 12 CATS) and in the Spring term only (1 x 2000 word essay – 12 CATS) and in the Autumn and Spring terms together (2 x 2000 word essays - 24 CATS)

Assessment

Assessment Method	Coursework (40%) + Online Examination (60%)
Coursework Details	4 x quizzes (2.5% each) (10%), Essay 1 (10%), Essay 2 (10%), Online Examination (60%), Participation in and engagement with Support and Feedback classes (10%)
Exam Timing	Summer

Exam Rubric

Time Allowed: 3 Hours

Read all instructions carefully- and read through the entire paper at least once before you start entering your answers.

There are THREE Sections in this paper. Answer ALL FOUR questions from Section A (50 marks total), ONE question from Section B (25 marks total) and ONE question from Section C (25 marks total).

Approved pocket calculators are allowed.

You should not submit answers to more than the required number of questions. If you do, we will mark the questions in the order that they appear, up to the required number of questions in each section.

Previous exam papers can be found in the University's past papers archive. Please note that previous exam papers may not have operated under the same exam rubric or assessment weightings as those for the current academic year. The content of past papers may also be different.

Reading Lists

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
Core module averages

EC220 & 221 Mathematical Economics I

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ec220/)

273 total students

20 total lecture hours

5 total seminars

25 total contact hours

12/15 CATS - Department of Economics

Principal Aims

Mathematical Economics 1A, "Game Theory," is an introduction to the rigorous mathematical study of strategic interactions. Students will learn how game theorists model such interactions, and how those models can be analyzed. By the end of the module, they will have developed a formidable toolbox of game-theoretic techniques, and will be familiar with a variety of applications of these techniques to real-world situations, both economic and otherwise.

Principal Learning Outcomes

12 CATS

Subject Specific and Professional Skills:...demonstrate understanding of the tools of game theory, and the ability to apply them to wide classes of problems. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, seminars, guided reading and independent study. The summative assessment methods that measure the achievement of this learning outcome are: examination

15 CATS

Subject Specific and Professional Skills:...demonstrate understanding of the tools of game theory, and the ability to apply them to wide classes of problems. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, seminars, guided reading and independent study. The summative assessment methods that measure the achievement of this learning outcome are: Tests and examination

Syllabus

12 CATS

The module will typically cover the following topics: Games in strategic form: Nash equilibrium and its applications to voting games, oligopoly, provision of public goods .Games in extensive form: sub game perfect equilibrium and its applications to voting games, repeated games. Static games with incomplete information: Bayesian equilibrium and its applications to auctions, contracts and mechanism design. Dynamic games of incomplete information: Perfect Bayesian equilibrium, Sequential equilibrium and its application to signalling games. Bargaining theory: Nash bargaining, non-cooperative bargaining with alternating offers and applications to economic markets. Evolutionary Game Theory Evolutionary game theory.

15 CATS

The module will typically cover the following topics:Games in strategic form: Nash equilibrium and its applications to voting games, oligopoly, provision of public goods.Games in extensive form: sub game perfect equilibrium and its applications to voting games, repeated games.Static games with incomplete information: Bayesian equilibrium and its applications to auctions, contracts and mechanism design.Dynamic games of incomplete information: Perfect Bayesian equilibrium, Sequential equilibrium and its application to signalling games.Bargaining theory: Nash bargaining, non-cooperative bargaining with alternating offers and applications to economic markets.Evolutionary Game Theory

Context

Core Module	Y602 - Year 2, G300 - Year 2
Optional Core Module	GL11 - Year 2, GL12 - Year 2
Optional Module	L100 - Year 2, L1P5 - Year 1, L1PA - Year 1, LM1D (LLD2) - Year 2, V7MP - Year 2, V7MP - Year 3, V7MR - Year 2, V7MR - Year 3, V7MM - Year 4, V7ML - Year 2, G100 - Year 2, G100 - Year 3, G103 - Year 2, G103 - Year 3, R9L1 - Year 4, R3L4 - Year 4, R4L1 - Year 4, R2L4 - Year 4, R1L4 - Year 4, L1L8 - Year 2, L1L8 - Year 3, LA99 - Year 2, LA99 - Year 3
Pre or Co-requisites	12 CATS - EC106 for MORSE students *Summary:* *Modules: EC106-24* 15 CATS - EC106 or EC107 for GL11 and other Maths students *Summary:* *Modules: EC106-24 or EC107-30 or EC109-30 or EC137-15 or (EC121-12 and EC122-12 and EC125-6) or (EC123-12 and EC124-12 and EC125-6)*
Part-year Availability for Visiting Students	12 CATS - Not available on a part-year basis 15 CATS - Available in the Autumn term only (1 x test – 12 CATS)

Assessment

Assessment Method	12 CATS - Online Examination (100%) 15 CATS - Coursework (20%) + Online Examination (80%)
Coursework Details	12 CATS: Online Examination (100%) 15 CATS: Online Examination (80%), Test 1 (20%)
Exam Timing	Summer

Exam Rubric

Time Allowed: 2 Hours

Read all instructions carefully- and read through the entire paper at least once before you start entering your answers.

There is ONE section in this paper. Answer TWO questions ONLY (50 marks each).

Approved pocket calculators are allowed.

You should not submit answers to more than the required number of questions. If you do, we will mark the questions in the order that they appear, up to the required number of questions in each section.

Previous exam papers can be found in the University's past papers archive. Please note that previous exam papers may not have operated under the same exam rubric or assessment weightings as those for the current academic year. The content of past papers may also be different.

Reading Lists

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
Core module averages

EC220 & 221 Mathematical Economics I

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ec221/)

273 total students

20 total lecture hours

5 total seminars

25 total contact hours

12/15 CATS - Department of Economics

Principal Aims

Mathematical Economics 1A, "Game Theory," is an introduction to the rigorous mathematical study of strategic interactions. Students will learn how game theorists model such interactions, and how those models can be analyzed. By the end of the module, they will have developed a formidable toolbox of game-theoretic techniques, and will be familiar with a variety of applications of these techniques to real-world situations, both economic and otherwise.

Principal Learning Outcomes

12 CATS

Subject Specific and Professional Skills:...demonstrate understanding of the tools of game theory, and the ability to apply them to wide classes of problems. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, seminars, guided reading and independent study. The summative assessment methods that measure the achievement of this learning outcome are: examination

15 CATS

Subject Specific and Professional Skills:...demonstrate understanding of the tools of game theory, and the ability to apply them to wide classes of problems. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures, seminars, guided reading and independent study. The summative assessment methods that measure the achievement of this learning outcome are: Tests and examination

Syllabus

12 CATS

The module will typically cover the following topics: Games in strategic form: Nash equilibrium and its applications to voting games, oligopoly, provision of public goods .Games in extensive form: sub game perfect equilibrium and its applications to voting games, repeated games. Static games with incomplete information: Bayesian equilibrium and its applications to auctions, contracts and mechanism design. Dynamic games of incomplete information: Perfect Bayesian equilibrium, Sequential equilibrium and its application to signalling games. Bargaining theory: Nash bargaining, non-cooperative bargaining with alternating offers and applications to economic markets. Evolutionary Game Theory Evolutionary game theory.

15 CATS

The module will typically cover the following topics:Games in strategic form: Nash equilibrium and its applications to voting games, oligopoly, provision of public goods.Games in extensive form: sub game perfect equilibrium and its applications to voting games, repeated games.Static games with incomplete information: Bayesian equilibrium and its applications to auctions, contracts and mechanism design.Dynamic games of incomplete information: Perfect Bayesian equilibrium, Sequential equilibrium and its application to signalling games.Bargaining theory: Nash bargaining, non-cooperative bargaining with alternating offers and applications to economic markets.Evolutionary Game Theory

Context

Core Module	Y602 - Year 2, G300 - Year 2
Optional Core Module	GL11 - Year 2, GL12 - Year 2
Optional Module	L100 - Year 2, L1P5 - Year 1, L1PA - Year 1, LM1D (LLD2) - Year 2, V7MP - Year 2, V7MP - Year 3, V7MR - Year 2, V7MR - Year 3, V7MM - Year 4, V7ML - Year 2, G100 - Year 2, G100 - Year 3, G103 - Year 2, G103 - Year 3, R9L1 - Year 4, R3L4 - Year 4, R4L1 - Year 4, R2L4 - Year 4, R1L4 - Year 4, L1L8 - Year 2, L1L8 - Year 3, LA99 - Year 2, LA99 - Year 3
Pre or Co-requisites	12 CATS - EC106 for MORSE students *Summary:* *Modules: EC106-24* 15 CATS - EC106 or EC107 for GL11 and other Maths students *Summary:* *Modules: EC106-24 or EC107-30 or EC109-30 or EC137-15 or (EC121-12 and EC122-12 and EC125-6) or (EC123-12 and EC124-12 and EC125-6)*
Part-year Availability for Visiting Students	12 CATS - Not available on a part-year basis 15 CATS - Available in the Autumn term only (1 x test – 12 CATS)

Assessment

Assessment Method	12 CATS - Online Examination (100%) 15 CATS - Coursework (20%) + Online Examination (80%)
Coursework Details	12 CATS: Online Examination (100%) 15 CATS: Online Examination (80%), Test 1 (20%)
Exam Timing	Summer

Exam Rubric

Time Allowed: 2 Hours

Read all instructions carefully- and read through the entire paper at least once before you start entering your answers.

There is ONE section in this paper. Answer TWO questions ONLY (50 marks each).

Approved pocket calculators are allowed.

You should not submit answers to more than the required number of questions. If you do, we will mark the questions in the order that they appear, up to the required number of questions in each section.

Previous exam papers can be found in the University's past papers archive. Please note that previous exam papers may not have operated under the same exam rubric or assessment weightings as those for the current academic year. The content of past papers may also be different.

Reading Lists

Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

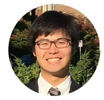
Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages

EC226 Econometrics 1

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/ec226/)

529 total students

57 total lecture hours

18 total seminars

75 total contact hours

30 CATS - Department of Economics

Principal Aims

This module provides students with a thorough understanding basic principles of econometrics. You will be exposed to a range of different econometric tools. You will gain an understanding of simple OLS, the limitations of the application of OLS, potential alternative estimators for the different type of data one might encounter including: cross-sectional data sets, time series data set and panel data sets.. You will gain skills and techniques to analyse problems from an intuitive, graphical and statistical perspective applying your knowledge to real world data.

Principal Learning Outcomes

Acquired the tools of quantitative methods necessary to study core and optional second and third year modules in economics for single honours courses in Economics. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures and classes. The summative assessment methods that measure the achievement of this learning outcome are: Test, exam, and assignment (group work).

Developed their understanding of statistical (econometric) software and economics databases. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures and classes. The summative assessment methods that measure the achievement of this learning outcome are: Tests, assignment (group work).

Further developed their communication skills in presenting and analysing data. The teaching and learning methods that enable students to achieve this learning outcome are: Classes. The summative assessment methods that measure the achievement of this learning outcome are: Tests, assignment (group work).

Developed further their techniques of statistical methods; generated a thorough understanding of the statistical techniques as well as a critical appreciation of them. The teaching and learning methods that enable students to achieve this learning outcome are: Lectures and classes. The summative assessment methods that measure the achievement of this learning outcome are: Test, exam, and assignment (group work).

Syllabus

The module will typically cover the following topics:Linear regression model. Least squares estimation. Dummy variables. Linear Restrictions. Classical Linear Regression Model Assumptions. Breakdown of CLRM assumptions. Errors in variables. Heteroscedasticity and implications for OLS. Structural change. Incorrect functional form and implications for OLS. Instrumental variable estimation. Dynamic models with lagged dependent variable. Serial

Correlation and implications for OLS. Types of autocorrelation. Nonstationarity and Cointegration. Panel data models. Limited dependent variable models.

Context

Core Module	L100 - Year 2, L116 - Year 2, L1PA - Year 1, L1P5 - Year 1, R9L1 - Year 2, R3L4 - Year 2, R4L1 - Year 2, R2L4 - Year 2, R1L4 - Year 2, V7ML - Year 2
Optional Core Module	GL11 - Year 2, GL12 - Year 2, V7MR - Year 2, LM1D (LLD2) - Year 2
Optional Module	GL12 - Year 4, V7ML - Year 2, V7ML - Year 3, V7MP - Year 2, V7MP - Year 3, V7MM - Year 4
Pre or Co-requisites	EC121 or EC123 and EC124 or IB122 for WBS students. EC106 or EC107 for GL11, MORSE and other students from Mathematics/Statistics Departments. *Summary:* *Modules: EC121-12 or (EC123-12 and EC124-12) or IB122-15 or (EC106-24 or EC107-30)*
Restrictions	May not be combined with modules
Part-year Availability for Visiting Students	Available in the Autumn term only (1 x test, 1 assignment 12 CATS) and in the Autumn and Spring term together 2 x test, 2 x assignments and problem sets 24 CATS)

Assessment

Assessment Method	Coursework (40%) + Online Examination (60%)
Coursework Details	5 x online multiple choice question tests (5%), Group Project (15%), Group work assignment (5%), Online Examination (60%), Test (15%)
Exam Timing	Summer

Exam Rubric

Time Allowed: 3 Hours, plus 15 minutes reading time.

Read all instructions carefully- and read through the entire paper at least once before you start entering your answers.

There is ONE Section in this paper. Answer ALL TEN questions (10 marks each).

Approved pocket calculators are allowed. Statistical Tables and a Formula Sheet are provided.

You should not submit answers to more than the required number of questions. If you do, we will mark the questions in the order that they appear, up to the required number of questions in each section.

Previous exam papers can be found in the University's past papers archive. Please note that previous exam papers may not have operated under the same exam rubric or assessment weightings as those for the current academic year. The content of past papers may also be different.

Reading Lists

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

CS254 Algorithmic Graph Theory

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/cs254/)

CS254-15 Algorithmic Graph Theory

Academic year	**21/22**
Department	**Computer Science**
Level	**Undergraduate Level 2**
Module leader	**Artur Czumaj**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

This module is concerned with studying properties of graphs and digraphs from an algorithmic perspective.
This module is only available to students in the second year of their degree and is not available as an unusual option to students in other years of study.

Module aims

This module is concerned with studying properties of graphs and digraphs from an algorithmic perspective. The focus is on understanding basic properties of graphs that can be used to design efficient algorithms. The problems considered will be typically motivated by algorithmic/computer science/IT applications.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

Typical topics include:
Introduction to graphs: undirected graphs, directed graphs, weighted graphs, graph representation and special classes of graphs (trees, planar graphs etc.).
Applications of graphs (in telecommunications, networking etc.).
Basic algorithmic techniques for graph problems: graph traversals (DFS and BFS), topological sorting, Eular tours.
Further algorithmic problems on graphs: minimum spanning trees, shortest path problems, matching problems.
Planar graphs and their properties. Eular's formula, planar separateor theorem and their algorithmic applications.
Further optimization problems on graphs including graph colouring and graph questions in distributed systems.
Discussing practical applications of graphs and efficient algorithms for such practical problems. Approximation algorithms and heuristic algorithms.
Applications to searching in massive graphs (e.g. page ranking); use of structural properties and algebraic properties.

Learning outcomes

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

- - Understand the basics of graphs, directed graphs, weighted graphs, and be able to relate them to practical examples.
- - Use effectively algorithmic techniques to study basic parameters and properties of graphs.
- - Design efficient algorithms for various optimisation problems on graphs.
- - Use effectively techniques from graph theory to approach practical problems in networking and telecommunication.

Indicative reading list

Please see Talis Aspire link for most up to date list.

View reading list on Talis Aspire

Subject specific skills

Acquiring basic knowledge in the new area (of algorithmic graph theory), including learning the key concepts of mathematical rigour in the analysis of graph algorithms, of the proofs of correctness of algorithms, and of the efficiency of algorithms.
An important part of the module will be to focus on mathematical properties of graphs and networks, as a tool to the design of better algorithms.

Transferable skills

Critical thinking and creativity.
Communication: presentation skills, focusing on mathematical-style presentation (students will have to prepare a short presentation describing some of the topics from the module).

CS260 Algorithms

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/cs260/)

CS260-15 Algorithms

Academic year	**21/22**
Department	**Computer Science**
Level	**Undergraduate Level 2**
Module leader	**Marcin Jurdzinski**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

Data structures and algorithms are fundamental to programming and to understand computation. The purpose of this module is to provide students with a coherent introduction to techniques for using data structures and some basic algorithms, and with the tools for applying these techniques to computational problems.

Module aims

Teaching and learning methods include lectures and reading materials which describe algorithmic techniques and applications of these techniques to specific problems. Problem sheets give students opportunities to practice problem solving.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

- Basics of algorithm analysis.

- Elementary graph algorithms.
- Greedy algorithms.
- Divide-and-conquer algorithms.
- Dynamic programming.
- Network flows.
- NP and computational intractability.

Learning outcomes

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

- Understanding a variety of techniques for designing algorithms and data structures, and ability to use them to solve problems.
- Understand a variety of data structures and be able to use them effectively to use them effectively in design and implementation of algorithms.
- Understand a variety of techniques for designing efficient algorithms, proving their correctness, and analysing their efficiency.
- Understand some fundamental algorithmic problems and algorithms for solving them.

Indicative reading list

Please see Talis Aspire link for most up to date list.

View reading list on Talis Aspire

Subject specific skills

- Designing algorithms
- Using data structures in algorithm design
- Analysing resource requirements and efficiency of algorithms
- Proving correctness of algorithms

Transferable skills

- Critical and creative thinking, problem solving
- Reading, understanding, and writing for mathematics and algorithms
- Written communication: problems, solutions, analysis

Year 1 regs and modules
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Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
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Year 4 regs and modules
G103

Exam information
Core module averages

CS262 Logic and Verification

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/cs262/)

CS262-15 Logic and Verification

Academic year	**21/22**
Department	**Computer Science**

Level	**Undergraduate Level 2**
Module leader	**Torsten Mutze**
Credit value	**15**
Module duration	**10 weeks**
Assessment	**Multiple**
Study location	**University of Warwick main campus, Coventry**

Download as PDF

Description | Study | Assessment | Availability

Introductory description

To give students an understanding of the basics of mathematical logic, and its applications to specifying and verifying computing systems.
This module is only available to students in the second year of their degree and is not available as an unusual option to students in other years of study.

Module aims

To give students an understanding of the basics of mathematical logic, and its applications to specifying and verifying computing systems. Algorithms and proof calculi for verification, as well as associated tools, will be studied. Theory and practice relating to reliability of systems form a vital part of computer science.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

- Propositional logic: proofs, semantics, normal forms, SAT solvers.
- Predicate logic: proofs, semantics.
- Specifying and modelling software.
- Verification by model checking.
- Proof calculi for program verification.

Learning outcomes

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

- Construct and reason about proofs in a variety of logics.
- Understand and compare the semantics of a variety of logics.
- Apply logic to specify and verify computing systems.
- Understand basic algorithms for formal verification.
- Use formal verification tools.

Indicative reading list

Please see Talis Aspire link for most up to date list.

View reading list on Talis Aspire

Subject specific skills

- Formal reasoning about computer systems, languages and proofs
- Using software systems for formal verification and logic programming

Transferable skills

- Capturing statements in natural language as formal mathematical statements
- Understand the limits of computation/proofs

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Year 4 regs and modules
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Exam information
Core module averages

PX262 Quantum Mechanics and its Applications

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px262/)

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Year 1 regs and modules
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Year 2 regs and modules
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Year 4 regs and modules
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Exam information
Core module averages

PX263 Electromagnetic Theory and Optics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px263/)

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Year 1 regs and modules
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Year 2 regs and modules
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Exam information
Core module averages

PX264 Physics of Fluids

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px264/)

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Year 1 regs and modules
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Year 4 regs and modules
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Exam information
Core module averages

PX266 Geophysics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px266/)

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Year 1 regs and modules
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Year 2 regs and modules
G100 G103 GL11 G1NC

Year 3 regs and modules
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Year 4 regs and modules
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Exam information
Core module averages

PX267 Hamiltonian Mechanics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px267/)

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Year 1 regs and modules
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G100 G103

Year 4 regs and modules
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Exam information
Core module averages

PX268 Stars

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px268/)

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Year 1 regs and modules
G100 G103 GL11 G1NC

Year 2 regs and modules
G100 G103 GL11 G1NC

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G100 G103

Year 4 regs and modules
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Exam information
Core module averages

PX269 Galaxies

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px269/)

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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
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Exam information
Core module averages

PX272 Global Warming

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px272/)
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Year 1 regs and modules
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Year 2 regs and modules
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Exam information
Core module averages

PX276 Methods of Mathematical Physics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px276/)
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Year 1 regs and modules
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Year 4 regs and modules
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Exam information
Core module averages

PX277 Computational Physics

(https://warwick.ac.uk/fac/sci/maths/currentstudents/ughandbook/year2/px277/)
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Year 1 regs and modules
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Year 2 regs and modules
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Year 3 regs and modules
G100 G103

Year 4 regs and modules
G103

Exam information
Core module averages