# Mathematics

## Prof. Anthony Ashton

Fellow, Tutor, College Associate Professor, Director of Studies in Mathematics at Homerton College, University of Cambridge

Lecturer, Department of Applied Mathematics & Theoretical Physics, University of Cambridge

13th-26th July, 2025

Anthony Ashton has been lecturing courses in the Mathematical Tripos since 2011. His teaching responsibilities fall across a broad range of subjects, from courses on Differential Equations and Probability in Part IA all the way to Analysis of PDEs in Part III. He is director of studies in mathematics at Homerton, where he oversees the progress of around 40 students each year.

His research interests focus mainly on partial differential equations (PDE). More specifically, he works on spectral approaches to elliptic boundary value problems, Lie group methods, new approaches to regularity problems in linear PDE and certain aspects of mathematical physics. He is also interested in several problems in analytic number theory relating to the Hurwitz zeta function.

Profile: https://www.homerton.cam.ac.uk/people/anthony-ashton

**Module Structure and Syllabus:**

The primary purpose of this course will be to teach students *how to count*. We will build up knowledge and understanding of elementary combinatorics and see how those ideas can be used to solve problems of probability.

| **Date** | **14th July Monday** | **15th July Tuesday** | **16th July Wednesday** | **17th July Thursday** | **18th July Friday** |
|---|---|---|---|---|---|
| | Counting & Permutations | Combinations | Pigeon hole principle | Supervision Day 1 | Algebra of sets and Inclusion-Exclusion |
| **Date** | **19th July Saturday** | **21st July Monday** | **22nd July Tuesday** | **23rd July Wednesday** | **24th July Thursday** |
| | Probability I | Probability II | Guided Presentation and Essay Writing | Supervision Day 2 | Final Presentations |

**Counting and permutations:** Discussion of foundational principles: product rule and permutations.

**Combinations.** Counting sizes of selections; binomial coefficients and combinatorial identities.

**Pigeon hole principle:** Exploration of the pigeon hole principle and its generalisations. Applications.

**Supervision Day 1:** Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

**Algebra of sets and Inclusion-Exclusion:** Basic set theory; unions and intersections of sets; Moore's laws and applications. Counting the size of a union of sets; introduction to inclusion-exclusion.

**Probability I:** Axiomatic definitions, probabilities on finite sample spaces. Examples.

**Probability II:** Independence; conditional probability; expectation.

**Guided Presentation and Essay Writing:** Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

**Supervision Day 2:** Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

**Final presentations**: You will present your research to other participants on the course and the course instructor.

**List of prerequisite knowledge:**
None.

# Mechanical and Electrical Engineering

**Dr Miles Stopher**
Director of Admissions and Affiliated Lecturer, Department of Engineering, Cambridge
Senior Lecturer, Fellow and Director of Studies in Engineering, Homerton College
Bye-Fellow in Engineering at Fitzwilliam College

13th July – 26th July, 2025

Dr Miles Stopher is a Senior Lecturer in Engineering at Homerton College and the Director of Admissions and an Affiliated Lecturer in the Department of Engineering. He is a Bye-Fellow of Fitzwilliam College, having previously been Acting Senior Tutor. He has supervised and directed studies in Engineering for 10 years, across a number of colleges at the University, including his alma mater, Jesus College. His research focuses on nuclear reactor design, with particular interest in the design of nanostructured materials for applications in extreme environments, such as the reactor core, radiation damage modelling, hydrogen embrittlement, and the engineering and safety of integral and passive small modular reactors. He lectures Nuclear Materials for Part III materials scientists at Cambridge, An Introduction to Materials Science for Engineers, and Nuclear Materials for Engineers on the MPhil in Nuclear Energy. He has also lectured on nuclear safety. Miles supervises Part IA and Part IB Mechanics, Materials and Structures to engineering undergraduates at Cambridge. Prior to his arrival at Cambridge, he worked on the design of the Royal Navy's Dreadnought-class nuclear-powered ballistic missile submarines.

Department profile: http://www.eng.cam.ac.uk/profiles/mas251

## Module Structure and Syllabus:

Engineering has many branches, but the oldest and broadest is mechanical engineering. Mechanical engineers look at the design, analysis, and manufacturing of mechanical systems and machines that keep our world moving forward. Electrical engineering was born in the 18th century, known then as "the youngest of the sciences". Electrical engineers study electricity, electronics and electromagnetism, and their application in the design, development, and testing of systems. This intensive course offers a valuable insight into what it is like to study mechanical or electrical engineering at university, covering the most prominent specialisms within the fields. Students will study the foundational concepts on which such specialisms are built and apply them to real-world problems, acquiring the skills and knowledge necessary to gain a head start in studying engineering at university.

| Date | 14th July Monday | 15th July Tuesday | 16th July Wednesday | 17th July Thursday | 18th July Friday |
|---|---|---|---|---|---|
| | Mechanical Engineering: Aircraft design | Mechanical Engineering: Engine design | Mechanical Engineering: Power plant design | Supervision Day 1: Mechanics problems | Electrical Engineering: Electronics |
| **Date** | **19th July Saturday** | **21st July Monday** | **22nd July Tuesday** | **23rd July Wednesday** | **24th July Thursday** |
| | Electrical Engineering: Renewable Energy | Electrical and Mechanical Engineering: Robotics | Guided Presentation and Essay Writing | Supervision Day 2: Electronics problems | Final Presentations |

**Mechanical Engineering, aircraft design**: Engineering has many branches, but the oldest and broadest is mechanical engineering. Mechanical engineers look at the design, analysis, and manufacturing of systems that keep our world moving forward. In the mechanical engineering section of this course, you will focus on how mechanical engineers are working towards sustainable solutions within three key industries: aerospace, energy and transport. On your first day, you will be taught the fundamentals necessary to understand aircraft design and the principles that keep them in the air. Towards the end of the day, you will gain a unique insight into the concepts proposed for aircraft and aircraft of the future.

**Mechanical Engineering, Engines:** On the second day, you are introduced to the fundamental concepts of the engine, from steam to internal combustion, covering the fundamental principles behind the engines of cars and jet planes. Towards the end of the day, you will learn about innovations in sustainable engine design, from hydrogen engines to water engines.

**Mechanical Engineering, Nuclear Reactor Design:** On your final day of teaching for the mechanical engineering section of the course, you will learn the fundamentals of power plant design. You will study the range of designs in use today, with particular focus on nuclear power, and the advanced concepts proposed for future application.

**Supervision Day 1, Mechanics Problems:** Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear during the lectures.

**Electrical Engineering, Electronics:** Electrical engineering is the study of electricity, electronics and electromagnetism, and the design of systems based on the respective principles. This section of the course will introduce three exciting industries where electrical engineers play a key role in design, development and testing: integrated circuits, power generation and robotics. On your first day**,** you will study the fundamentals of analog and digital circuits. You will learn the fundamentals of circuit design, understand the key components found in some of the common circuits you might find in your own home and how they are manufactured.

**Electrical Engineering, Renewable Energy:** On your second day of teaching, you will learn about the key types of renewable electrical power, the electrical technologies that support them, how they are incorporated into existing electrical transmission and distribution networks and the impact of government policy and economics on their viability.

**Electrical and Mechanical Engineering, Robotics:** On your final day, we will look at the multidisciplinary field of robotics. You will learn what is involved in the design, construction and use of robots from a mechanical and electrical perspective, building on your knowledge learnt across the programme. You will study the fundamentals of robotics and the technologies and techniques used to design, assemble, and control robots.

**Guided Presentation and Essay Writing:** Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

**Supervision Day 2, Electronics Problems:** Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear during the lectures.

**Final presentations**: You will present your research to other participants on the course and the course instructor.

**List of prerequisite knowledge:**

The emphasis during the course will be on the physical understanding of the principles involved. Only elementary mathematical methods will be used. The key is the engineering and not the mathematics behind it. As such, I only ask students have an appetite for learning and an inquisitiveness for engineering. Nonetheless, I've provided a few fun questions below that hopefully you enjoy tackling and can challenge your friends with.

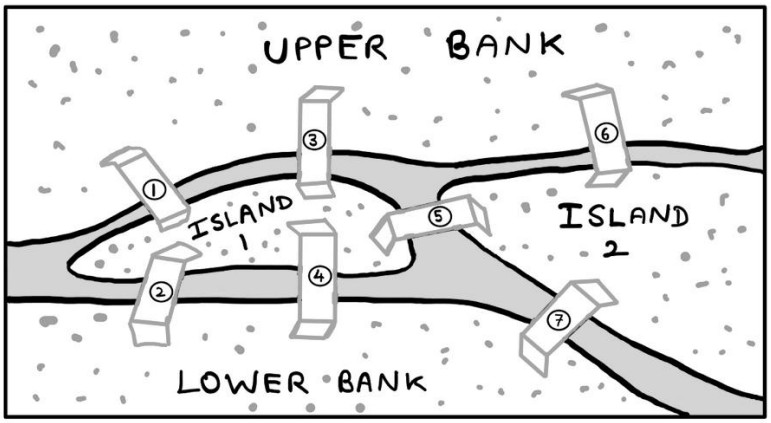
1. Eight of my pets aren't dogs, five aren't rabbits, and seven aren't cats. How many pets do I have?

2. I've forgotten the PIN to my bank card. If I enter six incorrect attempts, I will be locked out of my account: I've already used five! Only two digits are displayed after each unsuccessful attempt: "**2, 0**" means 2 digits from that guess are in the PIN, but 0 are in the right place. What should my sixth attempt be?

| | | |
|---|---|---|
| 3456 | \| | **3,0** |
| 5890 | \| | **0,0** |
| 1234 | \| | **2,0** |
| 2304 | \| | **2,1** |
| 6241 | \| | **2,2** |
| ???? | \| | **?,?** |

3. An infinite number of engineers buy pizza. The first wants half of a pizza. The second wants a quarter of a pizza. The third & fourth want an eighth and a $16^{th}$ each, and so on. How many pizzas should they order?

4. Fitzwilliam college has installed seven footbridges as shown below. Can you find a route around the college that crosses every bridge exactly once?


UPPER BANK
ISLAND 1
ISLAND 2
LOWER BANK
1
2
3
4
5
6
7

**Natural Sciences Taster Course**

Physics, Chemistry and Biology


**Dr Anke Ardern-Arentsen**

Herchel Smith Postdoctoral Fellow, Institute of Astronomy
& Research Fellow at Fitzwilliam College

**Dr Laura Frost**

Lead Veterinary Surgeon at Woodgreen, The Animal Charity,
Bye-fellow in Veterinary Medicine at Fitzwilliam College
& Director of Studies in Veterinary Medicine at Wolfson/Lucy Cavendish Colleges

**Dr Itai Massad**

Herchel Smith Postdoctoral Fellow, Department of Chemistry
& Research Fellow at Fitzwilliam College


13th-26th July, 2025

Anke Ardern-Arentsen is a researcher working at the Institute of Astronomy, University of Cambridge, where she studies the history of our home galaxy, the Milky Way. She is especially interested in what the oldest surviving stars can teach us about the early Universe. She teaches supervisions for third-year Astronomy students, co-teaches an astronomy module for the Data Intensive Science MPhil and supervises research projects at the University of Cambridge.

Departmental profile: https://www.ast.cam.ac.uk/people/anke.ardern-arentsen

Laura Frost qualified as a vet from Cambridge vet school in 2009 and initially worked in general practice while studying for a surgical certificate. She now works as a surgeon at Woodgreen, a large rehoming charity dealing with dogs, cats, rabbits, ferrets and other small mammals. She lectures as part of the preclinical vet course and teaching surgery to final year students and recent graduate vets. In her spare time, she rehabilitates wild hedgehogs ready for release back into the wild.

College profile: https://www.wolfson.cam.ac.uk/people/ms-laura-frost

Itai Massad is a researcher in the Department of Chemistry, where his research in the field of supramolecular chemistry explores the design and preparation of supramolecular cages – well-defined three-dimensional assemblies that can trap small molecules within their structures. Itai has extensive experience in teaching organic chemistry from introductory to graduate level.

Departmental profile: https://www.ch.cam.ac.uk/person/im580

**Module Structure and Syllabus:**

In this taster programme, you will get to explore three fields within the natural sciences. In the physics/astronomy module, we will revise and study the relevance of many areas in physics for the fascinating field of astronomy, explore the history of the Universe and learn about stars and their planets. In the biology module we will look at comparative anatomy, study hormones and metabolism in humans, domestic pets and wild animals (including hibernation) and build an understanding of how wounds and bones heal including practicing some practical skills like how to close a wound. In the organic chemistry module, we will learn to understand and predict the structure of organic (and inorganic) molecules and explore modern analytical techniques for determining molecular structure. Modules will be a mixture of lectures and practical elements.

| **Date** | **14th July Monday** | **15th July Tuesday** | **16th July Wednesday** | **17th July Thursday** | **18th July Friday** |
|---|---|---|---|---|---|
| | Physics for astronomy<br><br>Dr Ardern-Arentsen | The history of the Universe<br><br>Dr Ardern-Arentsen | Comparative anatomy<br><br>Dr Frost MRCVS | Comparative metabolism<br><br>Dr Frost MRCVS | How things heal<br><br>Dr Frost MRCVS |
| **Date** | **19th July Saturday** | **21st July Monday** | **22nd July Tuesday** | **23rd July Wednesday** | **24th July Thursday** |
| | Molecular structures<br><br>Dr Massad | Isomerism and resonance<br><br>Dr Massad | NMR spectroscopy<br><br>Dr Massad | Stars and exoplanets<br><br>Dr Ardern-Arentsen | Final Presentations |

**Physics for astronomy:** in this session we will cover important physics concepts for astronomy, such as motion and gravity, the electromagnetic spectrum, optics and nuclear physics.

**The history of the Universe:** this session will show how the laws of physics and the ingredients of the Universe led to a place fit for life, from the formation of the first stars, galaxies and chemical elements to the present day.

**Comparative anatomy:** 'Humans, mammals and others' - Looking at the anatomy of teeth, the skeleton, lungs/gills and digestive systems.

**Comparative metabolism:** 'From hormones to hibernation' How hormones vary across humans and the animal kingdom including common conditions. How does hibernation work?

**How things heal:** Looking at wound healing including suture patterns and how bones heal (including how surgeons can fix them). Practical elements.

**Molecular structures:** this session will focus on predicting and drawing molecular structures. We will cover the concepts of valence, Lewis structures and VSEPR theory.

**Isomerism and resonance:** an overview of different types of isomerism, their fundamental properties and how these relate to chemical and physical behaviour.

**NMR spectroscopy:** this session will cover nuclear magnetic resonance spectroscopy and its applications.

**Stars and exoplanets:** in this session, we will study the properties of stars and their life cycles and learn why stars are crucial for life, and we will cover how we know that most stars have planets and what we can know about them.

**Final presentations**: You will present your research to other participants on the course and the course instructor.

**List of prerequisite knowledge:**

Some knowledge of basic physics and chemistry would be useful, as well as a familiarity with using (simple) equations.

**Test your knowledge of the prerequisites! Can you answer the questions below?**

1. Using Newton's second law, determine the force required to accelerate an average adult human being at 2 $m/s^2$.
2. What are the three-dimensional shapes of $H_2O$ and $CO_2$? Why do they differ?

**Recommended reading list (optional):**

Any book on physics and chemistry for high school.