Examiners' Report: Final Honour School of Mathematics Part B Trinity Term 2023

October 27, 2023

Part I

A. STATISTICS

- **Numbers and percentages in each class.**

  See Table 1.

	Numbers					Percentages %				
	2023	(2022)	(2021)	(2020)	(2019)	2023	(2022)	(2021)	(2020)	(2019)
I	54	(55)	(51)	(73)	(59)	36.24	(41.04)	(39.84)	(46.5)	(39.07)
II.1	72	(53)	(58)	(66)	(67)	48.32	(39.55)	(45.31)	(42.04)	(44.37)
II.2	18	(24)	(18)	(13)	(20)	12.08	(17.91)	(14.06)	(8.28)	(13.25)
III	4	(2)	(1)	(4)	(4)	2.68	(1.49)	(0.78)	(2.55)	(2.65)
P	1	(0)	(1)	(0)	(0)	0.67	(0)	(0.64)	(0)	(0)
F	0	(0)	(0)	(1)	(0)	0	(0)	(0.66)	(0)	(0)
Total	149	(134)	(157)	(151)	(152)	100	(100)	(100)	(100)	(100)

Table 1: Numbers and percentages in each class

- **Numbers of vivas and effects of vivas on classes of result.**

  As in previous years there were no vivas conducted for the FHS of Mathematics Part B.

- **Marking of scripts.**

  BEE Extended Essays, BSP Mathematical Modelling and Numerical Computation Structured Projects and coursework submitted for the History of Mathematics course were double marked.

  The remaining scripts were all single marked according to a preagreed marking scheme which was strictly adhered to. For details of the extensive checking process, see Part II, Section A.

  For information on steps taken in response to the Marking and Assessments Boycott (MAB) please see Part I, Section B.

- **Numbers taking each paper.**

  See Table 5 on page 9.

B. Strike Action

The marking of Part B examinations was not affected by the marking and assessment boycott (MAB). Replacement assessors were recruited for two BEE Extended Essay projects. All replacement assessors were experienced markers with a suitable level of expertise in the subject matter.

C. Changes in examining methods and procedures currently under discussion or contemplated for the future

None.

D. Notice of examination conventions for candidates

The Notice to Candidates Offering Coursework was issued on the 3 March 2023. The first Notice to Candidates was issued on 15 March 2023 and the second notice on 28 April 2023.

All notices and the examination conventions for 2023 are online at http://www.maths.ox.ac.uk/members/students/undergraduate-courses/examinations-assessments.

Part II

A. General Comments on the Examination

The examiners would like to record their heartfelt thanks to all those who helped in the preparation, administering, and assessing of this year's examinations. The chair would like to thank Haleigh Bellamy, Clare Sheppard, Charlotte Turner-Smith, Waldemar Schlackow, Matt Brechin and the rest of the academic administration team for their support of the Part B examinations.

In addition the internal examiners would like to express their gratitude to Professor John Hunton and Professor Anne Skeldon for carrying out their duties as external examiners in such a constructive and supportive way during the year and for their thoughtful contributions during the final examiners' meetings.

The whole examination process went very smoothly this year. No paper required significant rescaling, unlike in 2022.

Standard of performance

The standard of performance was broadly in line with recent years. In setting the USMs, we took note of

- the Examiners' Report on the 2022 Part B examination, and in particular recommendations made by last year's examiners, and the Examiners' Report on the 2022 Part A examination, in which the 2023 Part B cohort were awarded their USMs for Part A;
- the guidelines provided by the Mathematics Teaching Committee, including its recommendations on the proportion of candidates that might be expected in each class.

Setting and checking of papers and marks processing

The internal examiners initially divided between them responsibility for the units of assessment (that is, the exam papers and projects).

Following established practice, the questions for each paper were initially set by the course lecturer, with the lecturer of a related course involved as checker before the first draft of the questions was presented to the examiners. The course lecturers also acted as assessors, marking the questions on their course(s).

Requests to course lecturers to act as assessors, and to act as checker of the questions of fellow lecturers, were sent out early in Michaelmas Term, with instructions and guidance on the setting and checking process, including a web link to the Examination Conventions.

The internal examiners met at the beginning of Hilary Term to consider those draft papers on Michaelmas Term courses, and changes and corrections were agreed with the lecturers where necessary. Where necessary, corrections and any proposed changes were agreed with the setters. The revised draft papers were then sent to the external examiners. Feedback from external examiners was given to examiners and to the relevant assessor for response. The internal examiners at their meeting in mid Hilary Term considered the external examiners' comments and the assessor responses, making further changes as necessary before finalising the questions. The process was repeated for the Hilary Term courses, but necessarily with a much tighter schedule. Before questions were submitted to the Examination Schools, setters were required to sign off a camera-ready copy of their questions.

Exams were held in-person in the Exams Schools. Papers were collected by the Academic Administration team and made available to assessors approximately half a day following the examination. Assessors were made aware of the marking deadlines ahead of time and all scripts and completed mark sheets were returned, if not by the agreed due dates, then at least in time for the script-checking process.

A team of graduate checkers, under the supervision of Haleigh Bellamy and Charlotte Turner-Smith, sorted all the marked scripts for each paper of this examination, cross checking against the mark scheme to spot any unmarked questions or parts of questions, addition errors or incorrectly recorded marks. Also sub-totals for each part were checked against the mark scheme, noting correct addition. In this way a number of errors were corrected,and each change was signed by one of the examiners who were present throughout the process.

Throughout the examination process, candidates were treated anonymously, identified only by a randomly-assigned candidate number.

Timetable

Examinations began on Monday 29 May and ended on Friday 16 June.

Consultation with assessors on written papers

Assessors were asked to submit suggested ranges for which raw marks should map to USMs of 60 and 70 along with their mark-sheets, and almost all did so. In most cases these were in line with the assignments given by the assessors.

Determination of University Standardised Marks

The Mathematics Teaching Committee issued each examination board with broad guidelines on the proportion of candidates that might be expected in each class. This was based on the average in each class over the last four years, together with recent historic data for Part B.

We followed the Department's established practice in determining the University standardised marks (USMs) reported to candidates. Papers for which USMs are directly assigned by the markers or provided by another board of examiners are excluded from consideration. Calibration uses data on the Part A performances of candidates in Mathematics and Mathematics & Statistics (Mathematics & Computer Science and Mathematics & Philosophy students are excluded at this stage). Working with the data for this population, numbers N_1, N_2 and N_3 are first computed for each paper: N_1, N_2 and N_3 are, respectively, the number of candidates taking the paper who achieved in Part A average USMs in the ranges $[69.5, 100]$, $[59.5, 69.5)$ and $[0, 59.5)$.

The algorithm converts raw marks to USMs for each paper separately. For each paper, the algorithm sets up a map $R \to U$ (R = raw, U = USM) which is piecewise linear. The graph of the map consists of four line segments: by default these join the points $(100, 100)$, $P_1 = (C_1, 72)$, $P_2 = (C_2, 57)$, $P_3 = (C_3, 37)$, and $(0, 0)$. The values of C_1 and C_2 are set by the requirement that the number of I and II.1 candidates in Part A, as given by N_1 and N_2, is the same as the I and II.1 number of USMs achieved on the paper. The value of C_3 is set by the requirement that P_2P_3 continued would intersect the U axis at $U_0 = 10$. Here the default choice of *corners* is given by U-values of 72, 57 and 37 to avoid distorting nonlinearity at the class borderlines.

The results of the algorithm with the default settings of the parameters provide the starting point for the determination of USMs, and the Examiners may then adjust them to take account of consultations with assessors (see above) and their own judgement. The examiners have scope to make changes, either globally by changing certain parameters, or on individual papers usually by adjusting the position of the corner points P_1, P_2, P_3 by hand, so as to alter the map raw $\rightarrow$ USM, to remedy any perceived unfairness introduced by the algorithm. They also have the option to introduce additional corners. For a well-set paper taken by a large number of candidates, the algorithm yields a piecewise linear map which is fairly close to linear, usually with somewhat steeper first and last segments. If the paper is too easy or too difficult, or is taken by only a few candidates, then the algorithm can yield anomalous results—very steep first or last sections, for instance, so that a small difference in raw mark can lead to a relatively large difference in USMs. For papers with small numbers of candidates, moderation may be carried out by hand rather than by applying the algorithm.

This year a preliminary meeting of the internal examiners was held in advance of the final exam board meeting to compare the default settings produced by the algorithm alongside the reports from assessors. It was agreed that only a selection of scaling maps would be further reviewed at the final exam board, and that external examiners would be given an opportunity to review all maps prior to the meeting. Adjustments were made to the default settings as appropriate, paying particular attention to borderlines and to raw marks which were either very high or very low. Where the examiners were in doubt as to the most appropriate scaling, the preliminary scalings were held over to the final exam board meeting, where the factors considered by those in the preliminary meeting were reviewed and weighed before a final decision was made.

Table 2 on page 6 gives the final positions of the corners of the piecewise linear maps used to determine USMs.

In accordance with the agreement between the Mathematics Department and the Computer Science Department, the final USM maps were passed to the examiners in Mathematics & Computer Science. USM marks for Mathematics papers of candidates in Mathematics & Philosophy were calculated using the same final maps and passed to the examiners for that School.

Comments on use of Part A marks to set scaling boundaries

None.

Mitigating Circumstance Notice to Examiners

A subset of the examiners (the 'Mitigating Circumstances Panel') attended a pre-board meeting to band the seriousness of the individual notices to examiners. The outcome of this meeting was relayed to the Examiners at the final exam board, who gave careful regard to each case, scrutinised the relevant candidates' marks and agreed actions as appropriate.

The full board of examiners considered all of the notices in the final meeting, along with a number of MCEs carried over from Part A. The examiners considered each application alongside the candidate's marks and the recommendations proposed by the Part A 2022 Exam board.

Table 2: Position of corners of the piecewise linear maps

Paper	P_1	P_2	P_3	Additional Corners	N_1	N_2	N_3
B1.1	13.56,37	23.6,57	47,70	50,100	9	30	11
B1.2	13.5,37	23.5,57	46,72	50,100	10	28	11
B2.1	6.78,37	11.8,57	32.8,72	50,100	15	14	1
B2.2	6.43,37	11.2,57	35.2,72	50,100	16	12	2
B3.1	10.23,37	17.8,57	38.8,72	50,100	22	24	3
B3.2	13.44,37	23.4,57	41.4,72	50,102	10	11	4
B3.3	16.77,37	29.2,57	38.2,72	50,100	14	11	4
B3.4	9.31,37	16.2,57	40.2,72	50,100	18	24	3
B3.5	11.37,37	19.8,57	40.8,72	50,100	22	22	7
B4.1	10.91,37	19,57	34,72	50,100	29	25	8
B4.2	13.56,37	23.6,57	35.6,72	50,100	22	15	6
B4.3	15.8,37	20,50	35,72	50,100	8	3	3
B4.4	9.36,37	20,50	41,70	50,100	7	2	1
B5.1	16.49,37	28.7,57	45.2,72	50,100	5	17	7
B5.2	11.55,37	20,50	39.6,72	50,100	13	28	8
B5.3	11.32,37	19.7,57	36.2,72	50,100	6	15	3
B5.4	8.39,37	18,50	41.6,72	50,100	5	13	4
B5.5	10.63,37	18.5,57	41,72	50,100	6	25	10
B5.6	13.27,37	23.1,57	42.6,72	50,100	6	19	11
B6.1	13.33,37	23.2,57	42,70	50,100	7	10	1
B6.2	16.66,37	29,57	44,72	50,100	11	22	8
B6.3	16.26,37	28.3,57	41.8,72	50,100	4	3	5
B7.1	17.18,37	29.9,57	40.4,72	50,100	4	8	3
B7.2	8.16,37	14.2,57	23.2,72	50,100	7	10	5
B7.3	11.6,37	20.2,57	29.2,72	50,100	7	7	3
B8.1	6.38,37	11,50	30.6,72	50,100	28	28	9
B8.2	5.29,37	20,50	33.2,72	50,100	22	11	2
B8.3	13.5,37	23.5,57	46,72	50,100	17	30	14
B8.4	11.26,37	19,50	41,70	50,100	8	37	14
B8.5	12.18,37	21.2,57	45.2,72	50,100	12	16	6
BSP	2000,100				1	3	2
SB1	18.73,37	32.6,57	59.6,72	66,100	11	23	11
SB1	34,100				11	23	11
SB2.1	14.02,37	24.4,57	42.4,72	50,100	12	26	9
SB2.2	13.61,37	23.7,57	40.2,72	50,100	16	33	10
SB3.1	14.94,37	26,57	41,72	50,100	26	40	18
SB3.2	13.33,37	25,60	37,70	50,100	2	6	5

B. Equality and Diversity issues and breakdown of the results by gender

Table 3: Breakdown of results by gender

Class	Number								
	2023			2022			2021		
	Female	Male	Total	Female	Male	Total	Female	Male	Total
I	5	49	54	5	50	55	13	38	51
II.1	23	49	72	19	34	53	22	36	58
II.2	7	11	18	15	9	24	4	14	18
III	2	2	4	1	1	2	1	0	1
P	0	1	1	0	0	0	0	1	1
F	0	0	0	0	0	0	0	0	0
Total	37	112	149	40	93	134	40	89	129
Class	Percentage								
	2023			2022			2021		
	Female	Male	Total	Female	Male	Total	Female	Male	Total
I	13.51	43.75	36.24	12.5	53.19	41.04	32.5	42.70	39.53
II.1	62.16	43.75	48.32	47.5	36.17	39.56	55	40.45	44.96
II.2	18.92	9.82	12.08	37.5	9.57	18.32	10	15.73	13.95
III	5.41	1.79	2.68	2.5	1.06	5.88	2.5	0	0.78
P	0	0.89	0.67	0	0	0	0	1.12	0.78
F	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100

Table 4: Rank and percentage of candidates with this or greater overall USMs

Av USM	Rank	Candidates with this USM and above	%
94	1	1	0.67
88	2	2	1.34
84	3	3	2.01
83	4	4	2.68
82	5	5	3.36
81	6	9	6.04
80	10	13	8.72
79	14	16	10.74
78	17	20	13.42
77	21	22	14.77
76	23	26	17.45
75	27	30	20.13
74	31	35	23.49
73	36	39	26.17
72	40	45	30.2
71	46	49	32.89
70	50	54	36.24
69	55	61	40.94
68	62	69	46.31
67	70	77	51.68
66	78	85	57.05
65	86	94	63.09
64	95	103	69.13
63	104	111	74.5
62	112	116	77.85
61	117	123	82.55
60	124	126	84.56
59	127	130	87.25
57	131	131	87.92
56	132	137	91.95
55	138	140	93.96
53	141	142	95.3
52	143	143	95.97
51	144	144	96.64
44	145	145	97.32
42	146	146	97.99
41	147	147	98.66
40	148	148	99.33
33	149	149	100

C. Detailed numbers on candidates' performance in each part of the examination

The number of candidates taking each paper is shown in Table 5.

Table 5: Numbers taking each paper

Paper	Number of Candidates	Avg RAW	StDev RAW	Avg USM	StDev USM
B1.1	51	34.9	11.24	64.45	15.95
B1.2	51	32.69	10.89	61.88	14.59
B2.1	30	31.77	10.13	74.9	11.97
B2.2	30	30.5	9.42	71	10.57
B3.1	50	33.54	8.13	70.08	9.87
B3.2	25	36.48	7.54	70.6	11.04
B3.3	29	38.07	7.97	74.24	16.08
B3.4	44	33.5	7.17	68.82	6.43
B3.5	50	35.48	9.29	70.52	12.81
B4.1	60	31.42	8.78	71.17	12.09
B4.2	43	34	8.8	71.65	14.23
B4.3	14	33.43	7.5	70.57	11.95
B4.4	10	37.6	10.59	70.9	14.23
B5.1	24	33.12	11	58.5	15.29
B5.2	46	30.39	7.95	61.91	10.26
B5.3	25	30.12	7.21	66.12	9.5
B5.4	24	31.5	9.23	63.38	10.46
B5.5	35	27.06	8.64	60.77	11.57
B5.6	32	31.56	9.29	63.78	12.89
B6.1	21	39	9.35	73.19	14.64
B6.2	29	36.62	8.6	66.14	13.5
B6.3	9	36.44	7.23	68.33	11.16
B7.1	18	33.89	7.35	63.06	11.95
B7.2	25	19.64	6.32	64.28	12.46
B7.3	20	24.95	8.51	63.1	17.18
B8.1	55	26.13	8.58	66.93	11.65
B8.2	33	30.76	9.77	67.97	16.78
B8.3	42	35.86	11.34	65.17	17.88
B8.4	45	31.09	9.94	61.51	13.8
B8.5	30	34.33	10.11	65.47	13.77
SB1	12	35.58	12.28	67.83	4.37
SB2.1	18	33.89	9.86	63.94	12.53
SB2.2	24	33.96	7.5	65.79	11.27
SB3.1	57	34.11	8.78	65.51	13.68
BO1.1	9	-	-	73.78	6.08
BO1.1X	9	-	-	65.67	8.56
BEE	13	-	-	78.54	7.74

Individual question statistics for Mathematics candidates are shown below for those papers offered by no fewer than six candidates.

Paper B1.1: Logic

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	20.56	20.56	5.06	48	0
Q2	12.32	12.32	6.12	34	0
Q3	19.68	19.68	6.29	19	0

Paper B1.2: Set Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.71	14.71	6.57	41	0
Q2	15.85	16.49	5.1	37	2
Q3	17.14	18.92	7.21	24	4

Paper B2.1: Introduction to Representation Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	9.56 9.56		4.02	16	0
Q2	16.53 16.53		6.15	17	0
Q3	19.22 19.22		4.29	27	0

Paper B2.2: Commutative Algebra

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.69	15.69	3.82	26	0
Q2	15.24	15.24	6.12	25	0
Q3	14	14	7.78	9	0

Paper B3.1: Galois Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.5	17.51	4.59	35	1
Q2	17.9	18.32	5.6	28	1
Q3	13.86	14.89	5.02	37	5

Paper B3.2: Geometry of Surfaces

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18.32	18.76	4.98	21	1
Q2	20.46	20.46	3.67	13	0
Q3	15.47	15.75	4.58	16	1

Paper B3.3: Algebraic Curves

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	20.1	20.61	4.38	28	1
Q2	18.08	18.08	5.17	25	0
Q3	12.57	15	6.08	5	2

Paper B3.4: Algebraic Number Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.16	15.16	2.86	31	0
Q2	19.9	19.9	3.08	30	0
Q3	14.61	15.07	5.04	27	1

Paper B3.5: Topology and Groups

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.72	17.72	5.24	29	0
Q2	19.05	19.53	5.41	40	1
Q3	14.62	15.45	6.32	31	3

Paper B4.1: Functional Analysis I

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15	15.18	4.37	56	1
Q2	13.84	15.05	5.72	37	6
Q3	17.18	17.7	6.28	27	1

Paper B4.2: Functional Analysis II

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.22	17.36	6.27	25	2
Q2	17.3	17.81	6.02	26	1
Q3	16.14	16.14	4.96	35	0

Paper B4.3: Distribution Theory and Fourier Analysis: An Introduction

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.89	14.89	5.04	9	0
Q2	15.83	15.83	3.97	6	0
Q3	18.38	18.38	2.9	13	0

Paper B4.4: Fourier Analysis and PDEs

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18.63	18.63	4.96	8	0
Q2	22	22	1.41	5	0
Q3	16.25	16.71	6.78	7	1

Paper B5.1: Stochastic Modelling and Biological Processes

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	11.6	11.69	2.95	16	4
Q2	13.75	18	7.84	11	5
Q3	19.62	20.5	6.76	20	1

Paper B5.2: Applied PDEs

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	10	14.84	8.09	31	15
Q2	11.33	15.97	8.2	32	14
Q3	9.6	14.72	7.83	29	16

Paper B5.3: Viscous Flow

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.16	16.16	3.98	25	0
Q2	9.1	11.71	5.59	7	3
Q3	14.83	14.83	4.13	18	0

Paper B5.4: Waves and Compressible Flow

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.29	16.29	5.62	21	0
Q2	14.55	16	7.07	18	2
Q3	14	14	6.08	9	0

Paper B5.5: Further Mathematical Biology

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	4.5	5	2.65	10	2
Q2	10.59	11.88	4.84	25	4
Q3	17.14	17.14	5.23	35	0

Paper B5.6: Nonlinear Systems

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.86	17.36	5.71	28	1
Q2	14.38	14.38	5.71	32	0
Q3	16	16	4.32	4	0

Paper B6.1: Numerical Solution of Differential Equations I

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	20.84	20.84	5.07	19	0
Q2	19.67	19.67	4.72	6	0
Q3	17.94	17.94	5.2	17	0

Paper B6.2: Numerical Solution of Differential Equations II

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.22	15.81	6.04	26	1
Q2	20.89	20.89	4.57	27	0
Q3	15.14	17.4	5.4	5	2

Paper B6.3: Integer Programming

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.25	15.25	6.7	4	0
Q2	20.33	20.33	4.03	6	0
Q3	17.11	18.13	4.34	8	1

Paper B7.1: Classical Mechanics

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.88	15.8	4	15	1
Q2	16.6	16.6	4.93	10	0
Q3	18.82	18.82	2.89	11	0

Paper B7.2: Electromagnetism

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	9.24	9.95	4.04	19	2
Q2	9.14	9.29	3.52	21	1
Q3	9	10.7	5.23	10	3

Paper B7.3: Further Quantum Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14	14	4.67	20	0
Q2	11.13	11.13	4.84	16	0
Q3	7.14	10.25	4.3	4	3

Paper B8.1: Martingales through Measure Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.52	12.77	5.03	47	1
Q2	11.53	11.53	5.82	17	0
Q3	13.2	13.93	5.26	46	3

Paper B8.2: Continuous Martingales and Stochastic Calculus

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	4.33	4.5	3.14	4	2
Q2	15	15.43	5.71	30	1
Q3	16.18	16.69	5.11	32	1

Paper B8.3: Mathematical Models of Financial Derivatives

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.29	17.29	6.87	42	0
Q2	16.65	18	8.17	23	3
Q3	16	19.26	7.61	19	6

Paper B8.4: Communication Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	13.51	13.95	5.36	39	2
Q2	17.24	17.58	6.43	40	1
Q3	12	13.82	4.64	11	4

Paper B8.5: Graph Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.15	16.72	6.93	25	1
Q2	18	19.26	6.6	19	2
Q3	14.53	15.38	5.33	16	1

Paper SB1.1/1.2: Applied Statistics/Computational Statistics

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.33	15.33	2.16	6	0
Q2	15.67	15.67	2.25	6	0
Q3	16.2	16.2	5.07	5	0
Q4	8	8	0	1	0
PR	25.33	25.33	2.58	6	0

Paper SB2.1: Foundations of Statistical Inference

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.65	16.65	4.91	17	0
Q2	18.4	18.4	4.95	15	0
Q3	11.8	12.75	5.36	4	1

Paper SB2.2: Statistical Machine Learning

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.88	19.07	5.68	15	1
Q2	15.96	15.96	3.39	24	0
Q3	14.09	16.22	7.98	9	2

Paper SB3.1: Applied Probability

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.82	17.08	5	48	1
Q2	17.35	17.35	4.87	48	0
Q3	16.17	16.17	5.57	18	0

Assessors' comments on sections and on individual questions

The comments which follow were submitted by the assessors, and have been reproduced with only minimal editing. The examiners have not included assessors' statements suggesting where possible borderlines might lie; they did take note of this guidance when determining the USM maps. Some statistical data which can be found in Section C above has also been removed.

B1.1: Logic

Question 1 This was the most popular question where one could gain very easy 10 marks in part (a). Several candidates failed to take care of the fact that in sequent calculus (SQ) the set of assumptions may change from line to line. Others used a double negation rule without proving it (though it is easy to do so in SQ). And didn't set up the proof of the Completeness Theorem for SQ the right way, even though it is the exact same setup as in the course.

Question 2 Many candidates had difficulties presenting a concrete example in part (a)(ii). In part (b)(i), axiom A7 was often applied in order to replace different closed terms in a formula rather than only replacing different variables for each other. Very few candidates got part (b)(ii) right, especially regarding the interpretation of predicate symbols. And in part (c)(iii) the models presented were in general no term models, indeed, but they often failed to be models of the given theory at all.

Question 3 In part (b)(i) only few candidates managed to produce a complete list of vector space axioms in the given language. In part (c)(ii) candidates often failed to point out that the cardinality of a vector space over a finite field is countably infinite if and only if its dimension is so. Otherwise this part was very well done.

B1.2: Set Theory

Question 1 (a) These assertions (both true) were generally clearly shown.

(b) These were generally well done, with (i) and (ii) generally proved by transfinite induction. Attempting (iii) by induction caused difficulties. Part (iv) was accomplished in various ways: suitable distributive laws, explicit orders, or via (iii).

(c) This question was generally well done, showing carefully that in (i) the chain condition holds, while offering clear examples of its failure in (ii).

(d) This problem was found difficult, with many offering arguments that depended on the Axiom of Choice via Cardinal Comparability.

Question 2 (a) These bookwork questions were generally done without difficulty.

(b) This problem is of a standard type. It was generally carefully done though some were careless in the formal set up. Constructing the required sequence of sets requires class recursion under suitable hypotheses.

(c) These cardinality problems were found challenging with many offering only incomplete attempts. Upper bounds were rather easy in (i) and (iii) but lower bounds required some ingenuity. Various solutions were given. In (ii) both upper and lower bounds require some work, not always fully articulated.

Question 3 (a) These were generally well done, most finding the counterexample in (iii).

(b) Part (i) was generally well done. Many gave the standard approach in (ii), but quite a few tried to write down an explicit fixed point. While the first uncountable ordinal worked well, smaller choices led to long arguments that did not always conclude.

(c) This was generally well done, though some treatments of (i) were overly complicated.

B2.1 Introduction to Representation Theory

Question 1 Q1 was the least popular question, perhaps understandably so as it involved the most amount of unseen material. Several candidates had a good go at parts (a,b,c) nevertheless. However the more difficult part (d) proved to be a challenge too far, and no-one managed to get to the end of it correctly.

Question 2 Q2 was done well by those candidates who attempted it. Several people got full marks and it was pleasing to see students were comfortable with both proving and applying the formula for the character of the induced representation.

Question 3 Q3 was the most popular question. Part (a) was bookwork and part (b) was seen in problem classes. The calculation of the character table in part (c) was mostly done well up to the point of having to calculate the values of the degree three irreducible characters on the elements a and a^3. Some students came up with the pretty idea of inducing a linear character of the index 3 subgroup of G generated by a up to G, as an alternative to relying on the Row and Column Orthogonality Theorems; this solution is more elementary but arguably more tricky.

B2.2: Commutative Algebra

Question 1 Q1 and Q2 were the most popular questions. In (a) of Q1, an inductive argument is needed and this was not seen by all the candidates.

Question 2 In Q2 (c), some students attempted to give proof using localisation, but without exploiting the noetherian property.

Question 3 Q3 was also attempted by quite a few candidates. Only a few students used the standard basis of open subsets of Spec(R) when tackling Q3 (d).

B3.1: Galois Theory

Question 1 Part (a) was standard, but some people forgot to check the homomorphism property. Part (b) was mostly done well, but not everyone saw the shortcuts (i): $Q(\eta)$ is real hence can't be equal to $Q(\zeta)$, and (ii): ζ is a root of t^2 - η t + 1. In part (c), it was a little disappointing to see a large number of students unable to calculate the subgroup lattice of C2 $\times$ C4 correctly. For the last part, only very few students spotted the trick of using the subfields generated by ζ_3 and ζ_5, together with part (a).

Question 2 Possibly the easiest question, containing a large part of bookwork, but surprisingly not as popular as it should have been. Parts (a,b,c) were done well. For part (d), an intimate knowledge of the group structure of the symmetric group S_4 would have been helpful: all you have to do is show the image of the Galois group contains no 3-cycles and that the discriminant of cubic the polynomial whose roots are three given quantities is a square.

Question 3 Parts (a) and (b) were uniformly done well. Part (c) was probablematic, especially the forward implication. Almost no-one got part (d) correctly as it was intended. Several students gave correct alternative proofs for part (d) ignoring the "deduce" instruction, nevertheless earning significant partial credit.

B3.2: Geometry of Surfaces

Question 1 For (a), I preferred candidates to include orientability/non-orientability in the statement of the classification, which some did not. For (b), I preferred candidates to give some evidence that they could calculate vertex identifications in the planar model, rather than just saying $V = 2$.

Parts (c),(d) were found most difficult. For (c), the correct necessary and sufficient condition is that pairs of identified sides should have the same length, and internal angles should sum to 2π at each vertex. For the majority of candidates who did not see this, they could still have computed the area to be 4π using Gauss–Bonnet and got the marks for that, but most did not.

For (d), the intended 'famous result' was the Gauss Uniformization Theorem, preferably in the form stated in the course, that a compact connected Riemann surface admits a compatible Riemannian metric of Gaussian curvature $\kappa = 1, 0$ or -1. Only a minority got this; more realized that the Uniformization Theorem was wanted, but could not state it correctly.

Question 2 Nearly all the candidates knew the bookwork and did very well on (a). Most did well on (b)–(d) too. Part (e) was difficult, and only one candidate got it completely correct, so I gave part marks. Say for $n = 3$, β acts by rotation by $2\pi/3$ about the (vertical) z-axis, and α acts by rotation by π about the (horizontal) x-axis (many candidates incorrectly said α was a reflection), and $\alpha\beta$, $\alpha\beta^2$ also act by rotation about (horizontal) axes in the x, y plane. The surface must have symmetries α, β, and for the action to be free, must not intersect the axes of rotation of $\beta, \alpha, \alpha\beta, \alpha\beta^2$.

The picture I was hoping for was of a horizontal torus with rotational symmetry about the z-axis, with holes drilled through around the axes of rotation of $\alpha, \alpha\beta, \alpha\beta^2$ (horizontal at angles $2\pi/3$), each axis adding two holes, so genus 7. The most common picture had the extra holes drilled vertically rather than horizontally, giving a surface with the correct symmetry, but intersecting the axes of rotation of $\alpha, \alpha\beta, \alpha\beta^2$, giving a non-free action.

Question 3 This question really rewarded candidates who could calculate without making mistakes. Disappointingly, this excluded the majority, so the marks on this question were lower than questions 1,2.

The point of (b) was that X is preserved by the ambient isometry of $\mathbb{R}^3$ which rotates the (x, y) plane by angle t, and translates the z axis by t, for $t \in \mathbb{R}$; this acts on the coordinates (u, v) of X by $(u, v) \mapsto (u, v + t)$. Only a few saw this. Most candidates verified laboriously that $\boldsymbol{r}(u, v+t)$ satisfies the equation for X, which is trivially true as $\boldsymbol{r}(u,v)$ does. With hindsight, the question would have been clearer if it had said 'map $\boldsymbol{r}(u,v) \mapsto \boldsymbol{r}(u, v+t)$' rather than 'map $(u,v) \mapsto (u, v+t)$'.

Some candidates defined Gaussian curvature κ as the product of principal curvatures $\kappa_1\kappa_2$, rather than giving the formula $(LN - M^2)/(EG - F^2)$. Those attempting to compute using $\kappa_1\kappa_2$ invariably came to a sticky end.

B3.3 Algebraic Curves

With hindsight the tricky parts of the questions were probably not quite tricky enough, so that candidates who knew and understood the course well and could calculate without making mistakes could get close to full marks. Many candidates did make plenty of mistakes in calculations, especially in Question 2. Questions 1 and 2 were by far the most popular. Only one candidate managed 3(d),(e).

B3.4: Algebraic Number Theory

Question 1 Parts (a) and (b) were well answered; part (c) was found difficult by many of the candidates, with only a few getting out (c)(ii) and (iii) completely.

Question 2 Question 2 was very well answered in general by most of those who attempted it.

Question 3 For part (b), many candidates had trouble explaining why no principal ideal could have norm 2; for part (c), some candidates had trouble with the initial Minkowski bound computation; part (d) was not attempted by all candidates but was general well answered by most of those who attempted it.

B3.5 Topology and Groups

Question 1 This question tested the understanding of homotopy theory. The general level of solutions was good. In part (a)(ii), some solutions missed the check that the constructed spaces were not homotopy equivalent, and in some cases, the retraction was not continuous. Part (b)(ii) was generally fine, but some candidates did not use that A was a retract, or they assumed it was a homotopy retract. The description of the homotopy was sometimes missing in part (b)(ii). There were a number of incorrect proofs for (b)(iii), but several candidates got the right maps.

Question 2 This question was very popular and there were lots of good solutions. It tested knowledge of the Seifert–van Kampen theorem. The solutions were generally longer than for the other two questions. Many of the definitions in part (a)(i) were imprecise. In part (a)(ii), one has to take canonical presentations for the definition of pushouts. Part (b)(i) was generally fine, though some solutions failed to identify $\langle a, b \,|\, aba^{-1}b^{-1}\rangle$ as $\mathbb{Z}^2$ and $\langle a \rangle$ as $\mathbb{Z}$.

Question 3 This questions turned out to be more difficult than the other two. It tested knowledge of covering spaces. In part (a)(i), the definition of a covering space was often missing details, such as X and $\widetilde{X}$ have to be path-connected. Part (a)(ii) was usually fine, but the proof that the number of preimages of a point is locally constant was sometimes imprecise. There were relatively few correct proofs for part (a)(iii). Most noticed that the map induced on π_1 has to be trivial, but they thought this automatically meant the map was null-homotopic. The key is to lift the map to the universal cover of S^1, which is contractible. In part (b)(ii), some had issues with induction. The simplest argument involves removing a leaf. In part (b)(iii), there were often missing details from the proof that $\widetilde{X}$ admits a graph structure. Part (c) was harder, but there were several correct solutions.

B4.1: Functional Analysis I

Question 1 Almost all candidates attempted this question. Parts (a), (b)(ii) and (d) were handled generally well. Surprisingly, the bookwork part (b)(i) caused some problem. A typical answer for part (c) involves showing, for any Cauchy sequence (x_n), the convergence of (Tx_n) and $(x_n - STx_n)$. While most candidates handled the former correctly, only about a quarter could handle the latter. About a third of the candidates attempted part (e), and about half of them answered it correctly.

Question 2 Parts (a) and (b) were handled generally well. In part (c), most candidates tried a 3ε-argument, but quite a few messed up the order in which the parameters should be chosen. In part (d)(i), while most could identify a suitable dense subspace, a large number of candidates incorrectly deduced the existence of T by invoking an extension theorem. Few candidates attempted (d)(ii), almost all of them thought of an oscillatory function, but only a handful constructed the right function.

Question 3 About half of the candidates attempted this question, and most of them did well on the other problem(s) they tried. Parts (a), (b)(i), c(ii) were handled generally well. The other parts were tried with variable degrees of success.

B4.2: Functional Analysis II

Question 1 (a) Most of the candidates know the meaning of weak convergences and uniform boundedness of Principle. (b) Some of the candidates did not use the fact that sequentially weakly closed set is closed. They did not mention the convexity of K. Moreover, for the question (ii), some candidates did not used the Bessels' inequality and constructed correctly the space. (c) Some candidates did not use the convexity of K. Overall, this is a successful paper with lots of concepts covered and can distinguish whether the candidates understand the concepts or not.

Very few students attempted to tackle Qn1 related to definitions and properties of weak convergence in Hilbert spaces. Although from the technical point of view it was the easiest question.

Question 2 Qn 2 contains a certain bookwork. One could expect that students would go through it easily but it was not so.

Question 3 Qn 3 was the most popular one among students. The first part of it has been done well by many of them. In part (b), the difficult point was to prove completeness of the corresponding operator space. No good solutions were in part (c) where students try to calculate operator norms directly. Here, one needs to use Parseval's identity and computation of the norm with the help of inner product

B4.3: Distribution Theory

Question 1 1 was attempted by many candidates despite probably being the hardest question on the paper. There were a few good solutions, but nobody got the full 25 marks. Parts (a)(i)–(ii) consist of bookwork and easy variants and only few marks were lost here. The calculation of the distributional derivative in (a)(iii) also didn't cause any difficulties, but many lost marks in (a)(iv) on the nondifferentiability of the Takagi function and its distributional derivative. Part (b) concerns a distribution defined via a principal value integral and (b)(i), where candidates must show that it is well-defined, attracted some good answers. Only very few candidates managed to give a correct counter example in (b)(ii).

Question 2 was the least popular question. Part (a) is book work and was done well by those who attempted it. Part (b) elaborates on the RiemannLebesgue lemma and rates of convergence. Despite not being difficult only very few got this part right.

Question 3 was the most popular question. It explores localisation of distributions, fundamental solutions and the Cauchy-Riemann equations. Part (a) is book work and an easy example that was also covered in lectures. It was done well by all candidates. The calculations required for full marks in (b)(i) was only presented by very few candidates, whereas the remaining parts (b)(ii)–(iv) went quite well.

B4.4: Fourier Analysis and PDE's

Question 1 was attempted by most candidates. Part (a) consists of book work and closely related material and it was done by all with very few marks being lost. However, all candidates lost some marks on part (b). The question concerns the Bessel kernel on the real line and has some resemblance to a question on one of the problem sheets where a subordination principle was used to calculate a Fourier transform in n dimensions.

Question 2 was the least popular question, but went well for those who attempted it. Part (a) consists of book work and variants thereof and as expected went well with very few losing any marks. The second part concerns L^2 based Sobolev spaces and versions of the convolution rule.

Question 3 was attempted by most candidates. It concerns periodic distributions and Fourier series, and starts in (a) with some book work and variants that mainly consist in rewriting formulas that are given in the question. Part (b) is an example involving the Poisson summation formula, where the latter is not immediately applicable. But using some of the reasoning from part (a) it is not difficult to show that it still applies. The marks being lost in this question were mainly because this argument was not done carefully enough.

B5.1: Stochastic Modelling and Biological Processes

Question 1 In all questions, candidates demonstrated good understanding of the bookwork material. In fact, there was a relatively large proportion of candidates who attempted to solve all three questions and many of them presented good attempts to solve the parts of each question covering bookwork.

Question 1 covered the material from the first third of the course. Most of the candidates were able to write down the chemical master equation and they applied a range of techniques to further analyse it. Common difficulties included errors in solving both time-dependent and stationary chemical master equations.

Question 2 Most of the candidates showed that they have to solve suitable PDEs in 2D or 3D. Common difficulties included errors in using polar (in 2D) and spherical (in 3D) coordinate systems to solve the corresponding PDEs.

Question 3 Question 3 covered the material from the last third of the course. It was nice to see that the candidates showed good understanding of the more advanced course material. Some of them presented very good attempts at all parts of Question 3, with a few candidates even getting perfect raw marks of 25.

B5.2: Applied PDEs

Question 1 This question had two parts, the first (part (a)) was about find a 3D Green's function for Laplace's equation and writing down a general solution for the boundary value problem in question. This part was generally well done by most students who attempted this question. Typical errors involved getting signs wrong. In the second part (part (b)) the task was to find a self-similar solution for a fourth order PDE boundary value problem. The formulation of the ODE boundary value problem was generally done well, though some students complicated the task by expanding derivatives and introduced algebraic errors or got lost in the algebra as a result. Some did not realise that the similarity exponent β is not fixed by scaling arguments. Despite the hints, only very few students realised how to solve the linear ODE / boundary value problem. Even fewer understood the interplay between the boundary conditions and the permissible roots for n and also the restriction arising on β (namely, that $\beta > 0$ is required).

Question 2 Q2(a) was bookwork and usually done well. Q2(b) had two parts, the solution for $t < 1$ and for $t > 1$. The former was done well, thought students often went to too much trouble by rederiving the solution in the smooth parts using characteristics rather than "plugging into" the PDE/initial values. Marks were dropped for not showing the rarefaction wave is a solution, or showing the shock trajectory satisfies the RH condition. The part for $t > 1$ was more difficult and students did not explain well what happens at $t = 1$ and did not change u_- to the appropriate time dependent form, hence obtaining the wrong shock trajectory. Q2(c), subparts (i) and (ii) were done well, sometimes the sketches of the initial condition were very unclear or the idea of "periodic repetition" not made clear in words of formulae in (ii). The last part (iii) was difficult and only few students made progress here. The difficulty was to obtain the right rarefaction wave and recognising how this affected the shock trajectory. The limit $t \to \infty$ was almost never obtained correctly.

Question 3 Part (a) was essentially bookwork or a straightforward calculation for the characteristic speed. Most students got this right, except for some algebraic errors when calculating the characteristing speed. Similarly, most student got the Rankine-Hugoniot condition for the shock speed right and, except for algebraic errors, obtained the expression for u_1 and s in terms of h_1 in (b). The difficult part was part (c). A large number of students got the criterion for causality right but failed in the subsequent algebra or in arguing correctly through all cases. Some obtained a value for H but in a number of cases this value was not correct due to algebraic error.

B5.3: Viscous Flow

Question 1 This question was attempted by all bar one of the candidates. The bookwork contained in part (a) was generally done well although some candidates forgot to define the fluid velocity u when stating Reynolds' Transport Theorem (RTT), some forgot later that they couldn't directly apply RTT to a vector quantity, and some candidates were lax in their definitions of the stress vector and stress tensor (the most common mistake was to not define n as the normal to the surface element). In part (b), the lack of explicit mention that the flow was steady threw a few candidates off track, while others stated incorrect no-slip and no-penetration boundary conditions. Almost all candidates found the solution for w_1. Disappointingly few candidates made a credible attempt at solving the problem for w_2; some did not spot the boundary conditions for at $x = + - a$ were no-longer homogeneous, some did not spot that they needed to look for a symmetric solution, many did not remember the fundamental steps needed to apply boundary conditions in a fourier series setting. The solutions by those candidates that successfully navigated these issues were mainly plagued by algebraic manipulation errors.

Question 2 This was the least popular question. In part (a), several candidates thought about the normal component of the stress despite the question asking only for the tangential part (the phraseology "dimensionless shear stress at the interface" and "tangential component of the stress at the interface", both meaning the same thing, possibly confusing these candidates). Some did not give a credible account of why the given solution satisfied both Navier-Stokes and Euler equations. In part (b), some candidates failed to write out the scaling and consequent choice of delta in a logical way and many candidates forgot to state the matching conditions with the outer flow. In part (c)(i), some candidates copied the answer from the question sheet hoping to gain credit for it, while others forgot to expand the boundary conditions in a credible way. Only a small handful of candidates tried to find the second solution to the differential equation for g. No candidates got the answer correct, and hence none found how the velocity at the surface varied with gamma.

Question 3 This was the second most popular question, but contained a typo with v' appearing twice in the question instead of w'. All bar one candidate took this in their stride, and most got full or nearly full marks for part (a). The derivation of the lubrication equation was done in several ways, often well, but the explanations of why $p' - > 0$ as $x - > + -$ infinity were less convincing. Part (c) was badly done; some candidates merely checked that the solution given satisfied the differential equation, some candidates used the form of the solution to make (sometimes incorrect) choices for constants in their solutions; both factions did not receive many marks. Those that tried to solve the differential equations and boundary conditions had limited success, with algebraic manipulation causing issues and no candidate correctly arrived at the answer. The rider at the end of part (c) was only attempted by a few students; of these some did not spot that the flux was constant, others were slipped up by trivial calculations. Only one candidate got the dimensionless flux correct and only one got the dimensionless range of x required; neither redimensionalised these values correctly.

B5.4: Waves and Compressible Flow

Question 1 This was the most popular question, attempted by all but three candidates. There was a wide range of marks, from almost perfect to almost nothing. Parts (a) and (b)(i) should have been very familiar, but several candidates struggled even with deriving the standard linearised boundary conditions for Stokes waves and separating the variables in Laplace's equation. Part (b)(ii) was trickier (although similar to a question on the 2017 past paper which was covered in a consultation session). Many candidates did not appreciate the need to make the boundary conditions homogeneous before attempting to separate the variables. In (b)(iii), most candidates correctly stated that the amplitude is predicted to blow up as ω approaches one of the natural frequencies, and were also able to say something reasonable about what really happens.

Question 2 This question was also popular, attempted by 3/4 of candidates, and again there was a very wide range of marks. Many candidates struggled even to correctly state the incompressible Euler equations, let alone complete the required derivation, which is admittedly fiddly, but was covered both in the lecture notes and on Problem Sheet 2. The elementary substitution in part (a)(ii) caused surprising difficulty for some. Part (b)(i) was generally done quite well, although some candidates attempted to impose the wrong boundary conditions on w (or W). In part (b)(ii), everyone could at least state the definitions of phase and group velocity, but there were many errors in actually evaluating c_g. Of course it's easier to differentiate ω^2 rather than ω (as realised by the stronger candidates), and maybe a hint would have helped. Most candidates were able to make good progress in part (c)(i), although they often made extra work by not spotting straight away how to use part (b) (with $n = 1$). Very little progress was made in part (c)(ii), the main problem being simplifying the expressions for c_g from part (b) to a form that can easily be analysed. Partial credit was given for those who convincingly explained the concept of bounding c_g as a function of k, even if some details were missing.

Question 3 This was by some margin the least popular question, although several who attempted it were able to get very good marks. Parts (a)(i) and (ii) were entirely bookwork, which just didn't seem to have been learned properly by the weaker candidates, who were also let down by poor basic algebraic manipulation. The new calculation in part (a)(iii) caused a lot of difficulty, although most were at least able to interpret the result. In part (b), almost all were able to correctly state the required modified Rankine–Hugoniot conditions, but again many really struggled with the following basic algebraic manipulations. The underlying problem seemed to be a lack of clarity over which quantities they're trying to evaluate and which to eliminate. The graph sketching in part (b)(ii) was generally done well, although full marks required some justification (e.g. involving monotonicity) for uniqueness of the root for v.

B5.5: Further Mathematical Biology

Question 1 This question was only answered by a few candidates and only one candidate made significant progress. Many candidates found it challenging to derive expressions for $\wedge_1$ and $\wedge_2$, in part because they did not always see how to use the boundary conditions, and several lost marks for the biological interpretation.

Question 2 Most candidates answered this question. Most did not correctly identify the range of possible phase plane behaviours in part (a). In part (b) the majority of candidates could not properly justify why, under suitable conditions on I, the system can display travelling waves.

Question 3 Almost all candidates answered this question. Most parts were well done, though candidates tended to lose marks for algebraic errors in part (d).

B5.6: Nonlinear Systems

Question 1 This was a popular question. Many (most) candidates knew what they should do for both the centre manifold reduction and the Poincaré-Lindstedt method, but there were a lot of silly algebraic mistakes. Quite a few candidates got into trouble in part (c) by replacing

$$\cos^2 t \sin\tau = \left(\frac{1+\cos 2\tau}{2}\right)\sin\tau,$$

rather than setting

$$\cos^2 t \sin\tau = (1-\sin^2\tau)\sin\tau = \sin\tau - \sin^3\tau,$$

and using the formula given in the hint.

Question 2 This was another popular question. The question gave lots of opportunity to make mistakes, which many candidates seized. Again, lots of these were simple algebraic mistakes (the number of candidates who solved

$$y(y+\mu-\mu^2) = 0 \text{ by saying } y = 0 \text{ or } y = \mu - \mu^2$$

was disappointing). Most candidates knew to consider complex eigenvalues as well as real eigenvalues in part (b), but a few forgot that when b is negative

$$|a+\sqrt{b}| = a^2 - b \quad \text{not} \quad a^2 + b.$$

The most common mistake was in part (c) in which many candidates wrote the centre manifold as $y = h(x, \mu)$ rather than $x = h(y, \mu)$, and ploughed on regardless even though they could see their final answer did not make sense. This error was perhaps more common because the two eigenvalues of the linearised system at the bifurcation point were $\lambda = 0$ and $\lambda = 1$. Even some candidates who thought about the centre linear subspace got confused into thinking it was due to the zero eigenvalue rather than the unit eigenvalue (as it would have been for a continuous dynamical system rather than a discrete map). In sketching the bifurcation diagram in part (d) many candidates ignored their results from part (a) and (b).

Question 3 This was an extremely unpopular question, despite being probably the easiest question on the paper. It had the highest percentage of bookwork in part (a), and part (b) was very straightforward. The unseen part (c) looks scary, but was also actually straightforward, and those candidates who did attempt the question did well.

B6.1: Numerical Solution of Differential Equations I

Question 1 The question was concerned with the finite difference approximation of a boundary-value problem for a second-order nonlinear differential equation with a cubic (and therefore monotonically increasing) nonlinearity, subject to homogeneous Dirichlet boundary conditions. Almost all candidates who took the paper attempted the question, and it was pleasing to see that even though the lectures did not explicitly cover nonlinear boundary-value problems for second-order ODEs and elliptic PDEs, the majority recognised that the motonicity of the nonlinearity was the key to successfully answering the question. A small minority erroneously wrote e_j^3 instead of $u(x_j)^3 - U_j^3$ in the difference equation relating the global error $e_j := u(x_j) - U_j$ to the consistency error φ_j. Also, several candidates defined the discrete Sobolev norm $\| \cdot \|_{1,h}$, whose definition was required by the question, as $(\|\cdot]|_h^2 + \frac{1}{2}\| \cdot \|_h^2)^{\frac{1}{2}}$, including the unnecessary factor 1/2, but the presence of the superfluous factor 1/2 did not, ultimately, impact on the final answer.

Question 2 Only less than a third of the candidates who took the paper attempted this question, which was concerned with the finite difference approximation of an elliptic eigenvalue problem posed on the unit square:

$$-\Delta u + u = \lambda u \qquad \text{for } (x, y) \in \Omega := (0, 1)^2,$$

subject to the homogeneous Dirichlet boundary condition $u|_{\partial\Omega} = 0$. The answers offered by those who attempted the first two parts of the question were mostly close to being complete.

In several of the solutions to part c) of the question Taylor series expansion of the function $x \mapsto \sin(x)$ was used, but without truncating the Taylor series using a standard formula for the remainder term, as a result of which, instead of the desired bound

$$|\lambda_{1,1} - \Lambda_{1,1}| \leq Ch^2,$$

those candidates ended up with a bound of the form

$$|\lambda_{1,1} - \Lambda_{1,1}| \leq C(h^2 + \mathcal{O}(h^4)).$$

They then, mysteriously, and without any justification, discarded the $\mathcal{O}(h^2)$ term to deduce the required inequality.

Part (d) of the question proved to be more challenging, and only two of those who attempted the question managed to produce a complete answer.

Question 3 The question was concerned with the finite difference approximation of the PDE

$$\frac{\partial u}{\partial t} + \frac{\partial u}{\partial x} = a\frac{\partial^2 u}{\partial x^2},$$

subject to the initial condition $u(x, 0) = u_0$. Candidates were asked to construct implicit and explicit central-difference approximations to the problem. This was a popular question, and was attempted by all candidates taking the paper. Parts (a), (b), and (c) of the question were generally well done, although some candidates erroneously approximated the first derivative term with respect to x in the PDE by an explicit central difference scheme even in part (a) of the question where an implicit scheme was requested. The stability analysis of the explicit scheme in part (d) of the question was more challenging and several of the candidates ended up using only one of the two inequalities $\nu^2 \leq 2a\mu \leq 1$. In the final part of the question, where the proof of practical instability of the explicit central difference scheme for the first order hyperbolic PDE $u_t + u_x = 0$ was required to be shown, most of those who attempted the question didn't get beyond (correctly) stating that the complex modulus of the amplification factor was greater than 1.

B6.2: Optimisation for Data Science

Problems 1 and 2 proved to be more popular than Problem 3, presumably because candidates solved the questions in order of presentation.

Question 2 seems to have been easier than the other two problems. Though it contained new material, the solution could be derived by adapting seen material, and many students succeeded in doing this, proving a excellent understanding of the material. The solutions to all three problems I saw were generally of high quality, with serious attempts at very technical derivations extending over several pages. The students on this course were highly motivated, and many went over and beyond the course materials, engaging in additional independent study, as became apparent in discussions in lectures, classes and consultation sessions.

B6.3: Integer Programming

Problems 2 and 3 proved to be more popular than Problem 1. I suspect that the candidates felt less confident with the technique of Lagrangian duality, which was needed to solve this problem. this was also reflected in a lower average achieved on this problem, albeit with a higher standard deviation due to the lower uptake.

B7.1: Classical Mechanics

Question 1 This was the most popular question and was often well answered. Common issues were not successfully calculating the derivative of the spring potential to prove that we are at equilibrium - this was tricky - and expanding the potential for small angles. There were some good attempts at part (c), although several students recalculated the solution to the equations of motion rather than using part (b).

Question 2 Of those that attempted this question, there were generally good answers to the first part, although complete arguments were required for full marks. Part (b) had many good attempts, particularly in deriving the Euler equations with an external torque. Going to the complex ODE caused some issues, despite the same trick being used in the course. Solving the ODE also caused problems, but there were several complete solutions. In the last part care was needed to distinguish the angular velocity and angular momentum.

Question 3 This question on Hamiltonian mechanics was generally well answered by those that attempted it. There were excellent answers to part (a) in particular. Parts (b) and (c) were often well answered. Common issues in part (b) were in choosing the correct direction and method to prove that the transformation is canonical, and not calculating the dynamics of θ. Those that had the PDEs for the generating function and attempted a solution often got part (c) correct.

B7.2: Electromagnetism

Question 1 This question was attempted by all but 5 candidates. Part a) was purely book-work, but surprisingly many students struggled with algebra, integration, or differentiation. Furthermore, in a.i) it was often missed to note that $\phi = 0$ for $r < a$, and many students derived the values of $q^\star$ and $\mathbf{r}^\star$ from scratch, which was not required and may have cost precious time. A few answers tried to enforce $q^\star = -q$ from the image through a plane, and many failed to notice that a.iii) gave away the correct value of $q^\star$. Only two answers to a.iii) used the quicker method appealing to Gauß' theorem, whereas all other answers attempted the integral in spherical polar coordinates, which is correct but probably took more time. Part b.i) was almost always attempted and quite well done. Most answers correctly identified the need for infinitely many image charges and often computed their locations correctly, but frequently their magnitudes were computed wrongly. Only a few students attempted the geometric series in b.ii), probably due to incomplete results in b.i). Unexpectedly, only 6 students attempted c.i), and only one made substantial progress, while most apparently did not recall that the potential is given by the Green's function. Consequently, c.ii) was attempted by only one student. Finally, merely 4 students attempted d), which is a pity, as this question offered 3 points for a simple limit calculation.

Question 2 This question was the most popular and attempted by all but 3 candidates. Producing the Gauß and Ampère laws in part a.i) was no problem but many candidates lost points by not distinguishing the total from the free current and charge densities. In a.ii) roughly half the candidates used the static field equations and where therefore unable to derive the energy density, which requires the time-dependent equations. Unexpectedly, part b.i) caused severe problems and no answer was satisfactory. Some assumed wrongly that $\mathbf{E}$ and $\mathbf{B}$ are always orthogonal, or made unsupported assumptions about the potentials. A few observed that the equipotentials Σ_a and Σ_b imply that $\mathbf{E}$ is radial at $\rho \in \{a, b\}$, but failed to notice that this argument does not prove anything for other values of ρ. Part b.ii) was dealt with much better, however only a single answer received full marks. Several candidates forgot the regions $\rho < a$ and $\rho > b$ where the fields vanish. Surprisingly, instead of the simple Gauß law, many candidates tried to determine ϕ by solving the Laplace equation in cylinder coordinates. This longer calculation often led to errors in the algebra, and some struggled to correctly incorporate the boundary conditions and continuity of ϕ at $\rho = c$. In some cases, candidates guessed the formula for $\phi(\rho)$ based on the value $\rho(c)$ given in the hint, but those guesses had a dependence on ρ in the denominator of ϕ, an error that could have easily been catched by checking the guess against the general piecewise form $\phi(\rho) = A \log \rho + B$ that most candidates identified correctly. Only very few candidates attempted b.iii). Those who correctly recognized that one needs to integrate the Poynting vector, failed to do the integral due to lack of time or a wrong and too complicated result in b.ii). The last part c) was attempted by only one candidate.

Question 3 The was the least popular question, attempted by roughly half of the candidates. Part a) was done very well, although many candidates forgot to mention that the potentials also ensure $\nabla \cdot \mathbf{B} = 0$ and $\nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$. In b) some struggled to integrate the δ-distribution with argument $t - t' - R(t')/c$, which was done in the lectures. Part c) was dealt with quite well from those who attempted it; in i) some failed to explain why $\mathbf{r}_0(t_r^\pm)$ can be replaced by $\mathbf{r}_0(t_0)$; in ii) some did not realize that for the negative charge, the sign of $\mathbf{r}_0$ changes, and many did not attempt to compute $\mathbf{A}$ (presumably for time reasons). The last parts d.i) and d.ii) were attempted by only 3 candidates each. They computed the leading order of $\mathcal{P}$ in d.ii) correctly, but struggled to extract the factor $\sin^2 \theta$ from the vector products. Part d.i) was purely an exercise in differential vector calculus, but only one answer correctly calculated $\mathbf{B}$ and noone made significant progress on $\mathbf{E}$.

Summary. All three questions received a wide spread of marks and thus differentiated of candidates. The average scores were close together (between 8.5 and 9) and suggest that the three questions were of comparable difficulty for the candidates. Apart from Q1.c.ii), Q2.b.iii), Q2.c), and Q3.d.i), each subquestion had at least one perfect or near perfect answer. Very few students attempted the last part of each question, which especially in the case of Q1.d) and Q3.d.ii) meant that a lot of easy points were lost. It is apparent that many students could have gained more points given additional time, and that overall the exam was a little bit too long.

B7.3: Further Quantum Theory

Question 1 This question was attempted by all candidates. The bookwork section at the start about the basics of irreducible spin representations of angular momentum was well answered in almost all cases. The perturbation theory part was attempted by most with roughly the correct strategy but very few managed to achieve the full set of corrections without errors. The issue of degeneracy was irrelevant in both parts of the question, though this required some careful consideration of the structure of the problem and was not well-explained in most cases. The exact energy levels could be determined using partial results from part (c) by writing an explicit four-by-four matrix and identifying its eigenvalues, but this was not attempted by most. The last part could be solved independently and was attempted at least in part by many; it required a simple argument involving the expansion of coupled angular-momentum states using Clebsch–Gordan coefficients, which was recognised in most attempts but not well executed in many.

Question 2 This was a scattering problem and the basics of the bookwork was completed in many attempts, though the precise definition of the S-matrix and especially the argument for its unitarity based on preservation of norms in $\mathbb{C}^2$ was often lacking. The heart of the problem was a computation of reflection and transmission coefficients off of a pair of Dirac delta functions. This was an elaboration on the single delta-function case seen in the final homework assignment, but caused quite a bit of trouble. In a surprising number of cases, the effect of the delta function on the matching of derivatives of the wave function was not correctly identified despite setting up the relevant integral identity. The better attempts did set up the matching correctly, but the subsequent calculation was a little involved and generally was not completed without fatal error. (In most attempts, the calculation was not very well-organised; it could be done without great complication by mimicking the organisation of the piecewise constant potential case seen in class.) Many of the marks for part (d) could be achieved by a careful explanation of the method for identifying bound state energies by analytic continuation of scattering data, but only a few attempts gave a detailed account.

Question 3 This was a WKB approximation problem and when it was attempted it proved difficult. For the setup, it was important to recognise the basic point that the WKB wave function in the region $0 < x < x^1$ could be a combination of growing and decaying exponentials due to the additional classically allowed region at negative values of x. This caused a number of problems. The connection formulæwere summarised well in general terms in most but attempts though some candidates had elementary misunderstandings about the topic. Few candidates got far into the problem of constructing the full WKB solution, but it could be done using the connection formulæ(at the level of shifts by $\pi/4$ in the arguments of cosines) and imposing vanishing of the wavefunction or its first derivative at $x = 0$ (corresponding to even and odd solutions, which was sufficient for reasons of symmetry of the potential). Though the calculations required were not too involved, they did need to be set up carefully and perhaps candidates were running low on time when getting to this point.

B8.1: Probability, Measure and Martingales

Question 1 For part (a), students generally completed this bookwork section well. Most students correctly identified the λ-system that contains the π-system. Some minor slips with the definition of a λ system. In part (b), quite a few students tried to prove independence with weaker conditions, like pairwise independence instead of an arbitrary finite subset. Not a lot of students gave a complete reasoning for the independence with respect to $\mathcal{H}$ but this was not penalised harshly. In part (c), very few students recognised that τ_K is a stopping time before applying results on stopped martingales or optional stopping. Finally, quite a few students were able to complete the first and last part of (d) even if they were unsure as to how to fill in the details of (d)(ii). Some had the right idea for (ii) and showed that the martingale satisfies a bound required to apply the results of (c), very few candidates provided complete justification here.

Question 2 Part (a) was mostly well done. Students who lost a mark, or two, did so most often by not arguing, or only partially, the closedness under monotone limits (with bounded limit) in the monotone class theorem. Parts (b)(i)-(iii) were also mostly well done but often with some slips or omissions. In particular, the easy inclusion in (ii) which followed since each X_n was a measurable function of X was sometimes either forgotten or argued in long-winded way. In (iii) the most common mistake was to show that the family (Z_n) is bounded in L^1 and try to conclude UI only from that. Part (b)(iv) is where most students struggled. Very few were able to give the expression for the conditional expectation and argue convincingly. None actually used the defining properties of the conditional expectation to simply give an answer and check it works. This had some adverse consequences for (c)(i) as it was hard to establish the martingale property without a proper formula. Finally, it seemed that students run out of time for (c)(iii). While some concluded quickly from L1 martingale convergence theorem that the first displayed formula holds, they then did not know how to finish the argument.

Question 3 This question was divided into two, part (a) about martingales and stopping times, and part (b) about Jensen's inequality and conditional expectations. Starting with the first, most candidates scored full marks for (i), with a minority losing a mark for mistakes on basic operations of set theory. For (ii), most of the students understood the main calculation that makes M^τ a martingale, and most (but not all) of these adequately distinguished between the two cases $\tau > n$ and $\tau \leq n$. In (iii) most students recognised that the unstopped process is not a martingale but a submartingale, with some answers lacking rigour but this was only penalised harshly. In (iv) the vast majority of students obtained the correct formula for the expected value of the stopping time, but in many cases they did not justify the use of the optional stopping/sampling theorem carefully enough. For those who did, the most popular strategy was to use the version of the OST that requires the stopping time to have finite expectation and the process to have a bound on the conditional expectation of the absolute increments, not the more straightforward approach of using dominated convergence and monotone convergence on different parts of

$M_{\tau\wedge n}$. Onto (b), most students correctly solved (i) and one inequality in (ii), with a sizeable minority confusing convex with concave. Almost everyone, however, struggled to prove the equality in (ii). (iv) is where the fewest marks were gained out of the whole of Question 3: very few candidates even attempted it.

B8.2: Continuous Martingales and Stochastic Calculus

Question 1 Question 1 was attempted by just 8 candidates and most of them could not progress too far. Two other questions were answered by most of candidates. There was a good spread of results with averages 15 and 16 marks correspondingly.

Question 2 Most of the candidates had the right approach to Question 2, but some of them could not complete computations. One recurring mistake was an attempt to use the hint about cubic increments in (b)(i) instead of (b)(iii).

Question 3 There was a wide spread of different mistakes in Question 3. Some candidates stated one version of the OST but used a different one. Functions in (b) and (c) are not continuous at the origin, so one has to justify the application of the Ito formula. Many candidates failed to do this. Another subtly point was in (b)(i). In order to compute the exit probability one has to argue that the stopping time is a.s. finite, otherwise it is impossible to extract the information from the OST. A significant minority of candidates could not apply Levy's characterisation in (c).

B8.3: Mathematical Models of Financial Derivatives

Overall, students did very well. Students could answer questions on the key ideas of the Blac-Scholes model, hendging, and pricing of perpetual American options.

B8.4: Information Theory

Question 1 Part (a) is interesting. A strong student can do it in seconds, while weak student struggled a lot. Part (b) is standard and most student can get all points in the proof. Part (c) is a preparation for part (d) on a simple real function. Quite a lot students could not do part (c) completely, while many of them can still do (d) with the results from (c).

Question 2 Part (a) and (b) are similar. Some students missed minus signs in these two parts, and some also tumbled in part (b) even with perfect answer to (a)! Part (c) is the easiest in the whole paper, and only several students lost one or two marks in (c.ii), and typical mistakes include confusion on the probabilities and the cardinality of a set. For part (d), some students didn't tried to prove the condition for the comparison; some students could not prove the last inequality by construction and stuck in the Kraft-McMillan's inequality (which is correct but not useful in this question).

Question 3 Part (a) is from lecture notes and had been explained by similar exercises, while we cannot rule out failure cases. Part (b) need a good understanding on the Shannon's second theorem, while quite a lot of student got full marks in this part. Part (c) is a new question and (c.iii) is expected to be hard, while many students did surprisingly well.

B8.5: Graph Theory

All three questions were attempted by a similar number of students, and were generally done reasonably well.

Question 1 In question 1, several students gave various different constructions for part (e). In particular, some students noted that if we subdivide one edge of a K_{r+1} into two edges, the resulting graph cannot be edge-coloured with r colours as both parts of the subdivided edge must receive the same colour. It then just remains to include this graph as a subgraph of some r-regular graph. Generally (e) seemed to be the hardest part for most students, although many proofs for (b) and (c) were unnecessarily long-winded.

Question 2 In question 2, quite a few students just stated that the polynomial $p_G(x)$ was the number of x-colourings. This only makes sense when x is a non-negative integer and $p_G(x)$ should be defined as the unique polynomial that interpolates these values. In (b) many students proved that x^t divides $p_G(x)$ by induction, which is a reasonable alternative proof. Showing that the number of k-colourings is divisible by k^t is not quite enough without explaining why $k^t \mid p_G(k)$ for all positive integers k implies $x^t \mid p_G(x)$. A common mistake in (c) was assuming that G/e always has $m-1$ edges. This is only the case when $\ell \geq 4$. Some students also did not realise that G/e can have a cycle which is one edge shorter than in G. In (d) students often claimed that the graph was a cycle with trees attached, and then proceeded to count colourings by removing leaves. This is ok, but only provided that one proves the structure of the graph is of this form.

Question 3 Question 3 was again reasonably well done, although there were more mistakes made on this question. Several students tried to prove Menger using the edge capacity version of Max-Flow Min-Cut, but this only gives edge disjoint paths. One should also note that the max flow can result in some directed cycles, which should be ignored/deleted. In (d) some students found k internally vertex disjoint paths from some $u \in U$ to some $w \in W$. However the question asked for fully vertex disjoint paths so the paths must start at different u_i and end at different w_j. Several students proved (d) by going back to MFMC rather than just using Menger's theorem. In (e) full marks were given only if a counterexample was found for a general k, rather than just for $k = 2$.

BO1.1: History of Mathematics

Both the extended coursework essays and the exam scripts were blind double-marked. The marks for essays and exam were reconciled separately. The two carry equal weight when determining a candidate's final mark. The first half of the exam paper (Section A) consists of six extracts from historical mathematical texts, from which candidates must choose two on which to comment; the second half (Section B) gives candidates a choice of three essay topics, from which they must choose one. The Section B essay accounts for 50% of the overall exam mark; the answers to each of the Section A questions count for 25%.

Throughout the course, candidates were invited to analyse historical mathematical materials from the points of view of their 'context', 'content', and 'significance', and these were the three aspects that candidates were asked to consider when looking at the extracts provided in Section A of the exam paper. A number of candidates chose to use these as subheadings within their answers. The assessors were impressed by the particularly high standard of the answers offered this year, both in terms of factual recall and in understanding.

The Section A questions 1–6 were attempted by 2, 6, 0, 5, 7, and 6 candidates, respectively. The relative unpopularity of question 1 was perhaps due to the difficulties of the sixteenth-century English in which it was written. That question 3 attracted no answers is probably attributable to the fact that it drew upon material that appeared in just one lecture, and then only briefly. The remaining Section A questions all touched upon topics that had been dealt with in considerably more detail within the lecture course. In question 2, candidates were invited to discuss Fermat's tangent method and its place in the early development of calculus. A key observation that was omitted by several candidates was that Fermat's method was a *general* procedure, in contrast to prior techniques that had been applicable only to particular curves. Another problem with some answers to this question was a failure to give a full and accurate interpretation of Fermat's diagram — i.e., to explain the meaning of the various labels, and to indicate why certain lines were included. A common fault in answers to question 4 was the misinterpretation of Fourier's 'i' as standing for $\sqrt{-1}$, when in fact it simply labelled a general integer in his formula. Question 5 required candidates to discuss the gradual acceptance of complex numbers; Hamilton's representation of complex numbers as pairs of real numbers was commonly omitted, however. The definition in question 6 was in some cases misinterpreted: this *is* a sufficient definition for a group in the finite case.

Some candidates clearly had a lot of knowledge that they wanted to get down on the page, some of it going well beyond the course content. However, this did not necessarily serve these candidates well in connection with the Section A questions, where they often strayed a little too far from the extract at hand. Students taking this course certainly should be encouraged to read more widely, but they need to take care in how they deploy their knowledge in the exam. This wider knowledge became much more useful within the greater freedom afforded by the essay questions of Section B. All three of the questions in this section covered topics that had been explored in depth in the lecture course, so candidates had a wealth of examples to draw upon in each case. Questions 7–9 were generally well done, and attracted roughly equal numbers of answers: 4, 5, and 4, respectively.

The extended coursework essays were of a decent standard overall, though marks were lost in places for too great a reliance on secondary sources — the use of primary sources was a central part of the reading course upon which this work was based, and so this should have been reflected in the submitted essays. Similarly, a lack of decent referencing and proper bibliographies was penalised in a number of cases. The better essays were those that took a particular question or point of view as their central thread, rather than simply providing a narrative account of the writings of Newton, Maclaurin, and Saunderson.

Statistics Options

Reports of the following courses may be found in the Mathematics & Statistics Examiners' Report.

SB1.1/1.2: Applied and Computational Statistics

SB2.1: Foundations of Statistical Inference

SB2.2: Statistical Machine Learning

SB3.1: Applied Probability

Computer Science Options

Reports on the following courses may be found in the Mathematics & Computer Science Examiners' Reports.

CS3a: Lambda Calculus & Types

CS4b: Computational Complexity

Philosophy Options

The report on the following courses may be found in the Philosophy Examiners' Report.

102: Knowledge and Reality

127: Philosophical Logic

D. Comments and Recommendations from the Examination Board

There were no specific recommendations from the Examination Board.

E. Names of members of the Board of Examiners

- **Examiners:**

  Prof Damian Rössler (Chair)
  Prof Jochen Koenigsmann
  Dr. Neil Laws
  Prof. Kevin McGerty
  Prof. Irene Moroz
  Prof. Gui-Qiang Chen
  Prof John Hunton (External)
  Prof Anne Skeldon (External)

- **Assessors:**
  Dr Akshat Mudgal
  Prof. Alan Lauder
  Prof. Alex Scott
  Prof. Alvaro Cartea
  Prof. Andras Juhasz
  Prof. Andrea Mondino
  Prof. Andreas Muench
  Dr Andrei Constantin
  Prof. Andrew Dancer
  Prof. Andy Wathen
  Dr Carmen Constantin
  Dr Charles Parker
  Dr Christian Schroeder de Witt
  Prof. Christina Goldschmidt
  Prof. Christopher Beem
  Prof. Christopher Breward
  Prof. Christopher Douglas
  Prof. Christopher Hollings
  Prof. Damian Rössler
  Prof. David Steinsaltz
  Dr Difan Yuan
  Prof. Dmitry Belyaev
  Prof. Dominic Joyce
  Dr Emilio Rossi Ferrucci
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  Dr Erik Panzer
  Dr Fergus Cooper
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Prof. Paul Balister
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Prof. Peter Jeavons
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Dr Philip Beeley
Dr Pierre Roux
Prof. Radek Erban
Prof. Raphael Hauser
Prof. Renaud Lambiotte
Dr Rob Cornish
Dr Robert Hinch
Prof. Robin Evans
Prof. Ruth Baker
Prof. Standa Zivny
Dr Thomas Wasserman
Prof. Victor Flynn
Dr Yifan Jing
Prof. Yuji Nakatsukasa