Examiners' Report: Final Honour School of Mathematics Part B Trinity Term 2019

November 8, 2019

Part I

A. STATISTICS

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

  See Table 1.

	Numbers					Percentages %				
	2019	(2018)	(2017)	(2016)	(2015)	2019	(2018)	(2017)	(2016)	(2015)
I	59	(58)	(51)	(56)	(48)	39.07	(38.16)	(38.63)	(39.72)	(32.88)
II.1	67	(67)	(64)	(58)	(69)	44.37	(44.08)	(48.48)	(41.13)	(47.26)
II.2	20	(25)	(11)	(24)	(25)	13.25	(16.45)	(8.33)	(17.02)	(17.12)
III	4	(2)	(3)	(3)	(3)	2.65	(1.32)	(2.27)	(2.13)	(2.05)
P	0	(0)	(2)	(0)	(1)	0	(0)	(1.52)	(0)	(0.68)
F	1	(0)	(0)	(0)	(0)	0.66	(0)	(0)	(0)	(0)
Total	151	(152)	(132)	(141)	(146)	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.**

  BE Extended Essays, BSP projects, and coursework submitted for the History of Mathematics course, the Mathematics Education course and the Undergraduate Ambassadors Scheme, were double marked.

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

- **Numbers taking each paper.**

  See Table 5 on page 13.

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

None.

C. Notice of examination conventions for candidates

The first Notice to Candidates was issued on 18 February 2019 and the second notice on 1 May 2019.

All notices and the examination conventions for 2019 are on-line 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 convey their grateful thanks for their help and cooperation to all those who assisted with this year's examination, either as assessors or in an administrative capacity. The chairman would particularly like to thank Gemma Proctor for administering the whole process with efficiency, and also to thank Nia Roderick, Charlotte Turner-Smith and Waldemar Schlackow.

In addition the internal examiners would like to express their gratitude to Professor Schlichting and Professor Branicki for carrying out their duties as external examiners in a constructive and supportive way during the year, and for their valuable input at the final examiners' meetings.

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 2018 Part B examination, and in particular recommendations made by last year's examiners, and the Examiners' Report on the 2018 Part A examination, in which the 2019 Part B cohort were awarded their USMs for Part A;
- a document issued by the Mathematics Teaching Committee giving broad guidelines on the proportion of candidates that might be expected in each class, based on the class percentages over the last five years in Mathematics Part B, Mathematics & Statistics Part B, and across the MPLS Division.

Having said this, as in Table 1 the proportion of first class degrees in Mathematics alone awarded (39.07%) was high, and the proportion of II.2 and below degrees in Mathematics awarded (13.25%) was low, compared to the guidelines. One reason for this is that the examiners consider candidates in Mathematics and in Mathematics and Statistics together when determining USMs, and this year the Mathematics and Statistics candidates performed poorly compared to the Mathematics candidates, so that the averages for the two schools combined (27.87% firsts, and 12.57% II.2 and below) are consistent with the Teaching Committee guidelines.

Setting and checking of papers and marks processing

Requests to course lecturers to act as assessors, and to act as checkers 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 questions were initially set by the course lecturer, in almost all cases with the lecturer of another course involved as checkers before the first drafts of the questions were presented to the examiners. Most assessors acted properly, but a few failed to meet the stipulated deadlines (mainly for Michaelmas Term courses) and/or to follow carefully the instructions provided.

The internal examiners met at the beginning of Hilary Term to consider those draft papers on Michaelmas Term courses which had been submitted in time; consideration of the remaining papers had to be deferred. 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.

Camera ready copy of each paper was signed off by the assessor, and then submitted to the Examination Schools.

Except by special arrangement, examination scripts were delivered to the Mathematical Institute by the Examination Schools, and markers collected their scripts from the Mathematical Institute. Marking, marks processing and checking were carried out according to well-established procedures. Assessors had a short time period to return the marks on standardised mark sheets. A check-sum is also carried out to ensure that marks entered into the database are correctly read and transposed from the mark sheets.

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 Helen Lowe sorted all the scripts for each paper for which the Mathematics Part B examiners have sole responsibility, carefully cross checking against the mark scheme to spot any unmarked questions or parts of questions, addition errors or wrongly recorded marks. Also sub-totals for each part were checked against the mark scheme, noting correct addition. In this way, errors were corrected with each change independently verified and signed off by one of the examiners, who were present throughout the process. A small number of errors were found, but they were mostly very minor and hardly any queries had to be referred to the marker for resolution.

Throughout the examination process, candidates are treated anonymously, identified only by a randomly-assigned candidate number, until after all decisions on USMs, degree classes, mitigating circumstances notices to examiners, prizes, and so on, have been finalized.

There were very few errors in the examination papers, and those that did crop up were minor and were spotted and corrected early in the exams. The only such issue of real concern was a large font paper which acquired an additional character in a confusing place. This (quite correctly) led to a Mitigating Circumstances application from the affected candidate. In future, assessors should be extremely vigilant in checking large font versions of their papers, and further thought should be given to how these are prepared so as to minimise the possibility of such an error recurring.

Standard and style of papers

At the beginning of the year all setters were asked to aim that a I/II.1 borderline candidate should get about 36 marks out of 50, and that a II.1/II.2 borderline script should get about 25 marks, and emphasising the problems caused by very high marks.

This year one paper (B1.1, Logic) turned out to be too easy and marks were heavily bunched at the top end. This may be clearly seen, for example, in Table 5 and the data following it. This causes problems with rescaling and the assessor for this course next year should aim to avoid a repeat.

Timetable

Examinations began on Monday 3 June and finished on Saturday 22 June.

Determination of University Standardised Marks

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 $[0, 59.5)$, respectively.

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 $\to$ 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.

Following customary practice, a preliminary, non-plenary, meeting of examiners was held ahead of the first plenary examiners' meeting to assess the results produced by the algorithm, to identify problematic papers and to try some experimental changes to the scaling of individual papers. This provided a starting point for the first plenary meeting to obtain a set of

USM maps yielding a tentative class list with class percentages roughly in line with historic data.

The first plenary examiners' meeting, jointly with Mathematics & Statistics examiners, began with a brief overview of the methodology and of this year's data. Then we considered the scaling of each paper, making provisional adjustments in some cases. The full session was then adjourned to allow the examiners to look at scripts. This was both to help the external examiners to form a view of overall standards, and to answer questions that had arisen on how best to scale individual papers; for instance, to decide whether a given raw mark should correspond to the I/II.1 or II.1/II.2 borderline, an examiner would read all scripts scoring close to this raw mark, and make a judgement on their standard.

The examiners reconvened and we then carried out a further scrutiny of the scaling of each paper, making small adjustments in some cases before confirming the scaling map (those Mathematics & Statistics examiners who were not Mathematics examiners left the meeting once all papers with significant numbers of Mathematics & Statistics candidates had been considered).

Table 2 on page 9 gives the final positions of the corners of the piecewise linear maps used to determine USMs.

The Mathematics examiners reviewed the positions of all borderlines for their cohort. For candidates very close to the proposed borderlines, marks profiles and particular scripts were reviewed before the class list was finalised.

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.

Mitigating Circumstance Notice to Examiners

A subset of the board (the 'Mitigating Circumstances Panel') had a preliminary meeting to discuss the individual notices to examiners at Part B. There were 14 notices, which the panel classified in bands 1, 2, 3 as appropriate. A further 3 notices were received after the panel had met. The full board of examiners considered the 17 cases in the final meeting, and the certificates passed on by the examiners in Part A 2018 were also considered. All candidates with certain conditions (such as dyslexia, dyspraxia, etc.) were given special consideration in the conditions and/or time allowed for their papers, as agreed by the Proctors. Each such paper was clearly labelled to assist the assessors and examiners in awarding fair marks.

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	(27, 50)	(40.8, 57)	(46.8, 72)		13	22	14
B1.2	(12, 37)	(28.3, 57)	(42, 72)		22	26	14
B2.1	(10.34, 37)	(18, 57)	(35, 72)		18	10	3
B2.2	(9.36, 37)	(16.3, 57)	(33, 72)		18	10	2
B3.1	(9.42, 37)	(16.4, 57)	(36.5, 72)		28	19	6
B3.2	(15.68, 37)	(33, 57)	(40, 72)		9	5	4
B3.3	(14, 50)	(23.6, 57)	(35.6, 72)		12	4	2
B3.4	(16, 50)	(22.4, 57)	(41, 72)		26	17	6
B3.5	(0, 0)	(18.5, 57)	(38.8, 72)		15	13	5
B4.1	(12.81, 37)	(22.3, 57)	(36.5, 72)		24	19	6
B4.2	(10.85, 37)	(18.9, 57)	(32, 72)		20	17	5
B4.3	(16.65, 37)	(29, 57)	(41, 72)		4	11	3
B5.1	(0, 0)	(16, 57)	(33, 72)		4	23	8
B5.2	(15.05, 37)	(26.02, 57)	(35.2, 72)		14	27	7
B5.3	(12.86, 37)	(22.4, 57)	(37, 72)		9	13	6
B5.4	(12.29, 37)	(21.4, 57)	(39.4, 72)		10	14	5
B5.5	(12.35, 37)	(21.5, 57)	(39, 70)		6	27	9
B5.6	(13.95, 37)	(24.3, 57)	(37.8, 72)		8	21	6
B6.1	(17, 37)	(29.6, 57)	(41.6, 72)		8	14	4
B6.2	(14, 37)	(31, 57)	(40, 70)		3	4	2
B6.3	(12, 37)	(0, 0)	(30, 70)		1	4	5
B7.1	(13.55, 37)	(23.6, 57)	(35.6, 72)		11	7	3
B7.2	(8.78, 37)	(19, 57)	(28.8, 72)		10	4	0
B7.3	(10.68, 37)	(18.6, 57)	(36, 72)		10	9	2
B8.1	(12.69, 37)	(22.1, 57)	(42.5, 72)		30	31	7
B8.2	(12.69, 37)	(22.1, 57)	(42.6, 72)		18	13	3
B8.3	(15.33, 37)	(26.7, 57)	(40, 70)		18	45	19
B8.4	(13.95, 37)	(24.3, 57)	(37, 70)		9	21	6
B8.5	(11.48, 37)	(20, 57)	(36, 72)		11	10	9
SB1.1/SB1.2	(19.64, 37)	(34.2,57)	(53, 70)		6	27	9
SB2.1	(6, 20)	(15, 60)	(30.6, 72)		9	25	7
SB2.2	(15.16, 37)	(26.4, 57)	(40, 70)		15	34	12
SB3.1	(10.39, 37)	(18.1, 57)	(37.6, 72)		30	62	20
SB3.2	(13.27, 37)	(23.1, 57)	(40, 70)		2	11	3
SB4	(11.71, 37)	(20.4, 57)	(38.4, 72)		7	30	14

Table 3 gives the rank of candidates and the number and percentage of candidates attaining this or a greater (weighted) average USM.

Table 3: Rank and percentage of candidates with this or greater overall USMs

Av USM	Rank	Candidates with this USM and above	%
98	1	1	0.66
89	2	2	1.32
88	3	3	1.99
87	4	4	2.65
85	5	6	3.97
83	7	8	5.3
82	9	9	5.96
81	10	11	7.28
80	12	13	8.61
79	14	16	10.6
78	17	20	13.25
76	21	29	19.21
75	30	33	21.85
74	34	37	24.5
73	38	42	27.81
72	43	45	29.8
71	46	52	34.44
70	53	58	38.41
69	59	65	43.05
68	66	69	45.7
67	70	79	52.32
66	80	87	57.62
65	88	93	61.59
64	94	100	66.23
63	101	105	69.54
62	106	112	74.17
61	113	118	78.15
60	119	124	82.12
59	125	126	83.44
58	127	127	84.11
57	128	128	84.77
56	129	130	86.09
55	131	134	88.74
54	135	136	90.07
53	137	139	92.05
52	140	141	93.38
51	142	143	94.7
50	144	146	96.69
47	147	147	97.35
46	148	148	98.01
43	149	149	98.68
42	150	150	99.34
20	151	151	100

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

Table 4: Breakdown of results by gender

Class	Number								
	2019			2018			2017		
	Female	Male	Total	Female	Male	Total	Female	Male	Total
I	13	46	59	9	49	58	6	45	51
II.1	18	49	67	15	52	67	21	43	64
II.2	5	15	20	9	16	25	5	6	11
III	1	3	4	0	2	2	0	3	3
P	0	0	0	0	2	2	0	2	2
F	0	1	1	0	0	0	0	0	0
Total	37	114	151	33	119	152	32	99	131
Class	Percentage								
	2019			2018			2017		
	Female	Male	Total	Female	Male	Total	Female	Male	Total
I	35.14	40.35	39.07	27.27	41.18	38.16	18.75	45.45	38.93
II.1	48.65	42.98	44.37	45.45	43.7	44.08	65.62	43.43	48.85
II.2	13.51	13.16	13.25	27.27	13.45	16.45	15.62	6.06	8.39
III	2.7	2.63	2.65	0	1.68	1.32	0	3.03	2.29
P	0	0	0	0	0	0	0	2.02	1.52
F	0	0.88	0.66	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100

Table 4 shows the performances of candidates broken down by gender. The examiners were pleased to note that there is far better equality this year than in recent years, and were particularly encouraged to see the high percentage of female candidates getting firsts (35 percent, up from 27 and 18 in the previous two years) as well as the low percentage of female candidates getting II.2s (13.5 percent, down from 27 percent last year).

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	48	41.69	6.51	64.58	11.25
B1.2	63	34.65	9.94	65.87	15.04
B2.1	33	30.48	9.22	68.7	12.37
B2.2	31	29.03	8.18	69.1	10.55
B3.1	54	31.7	12	69.59	18.67
B3.2	18	37.89	7.58	70.44	16.13
B3.3	18	36.06	9.09	77	11.86
B3.4	51	34.98	11.54	69.71	18.93
B3.5	34	33.06	7.01	68.76	7.93
B4.1	47	34.77	8.18	72.91	12.42
B4.2	41	30.24	8.22	70.98	11.38
B4.3	18	36.72	6.11	67.17	8.82
B5.1	31	19.84	9.36	56.06	15.71
B5.2	50	31.84	6.37	66.54	11.28
B5.3	29	33.14	7.57	69.21	10.81
B5.4	30	32.3	8.18	66.97	10.78
B5.5	37	31.65	8.35	65.57	10.57
B5.6	37	30.32	5.24	63.43	6.59
B6.1	24	34.75	7.43	63.25	11.66
B6.2	11	35.36	10.58	66.82	17.28
B6.3	9	23.22	10.73	56.78	18.75
B7.1	22	32.27	8.15	68.73	12.77
B7.2	14	31.07	7.66	74.5	10.7
B7.3	24	27.62	10.45	63.79	17.1
B8.1	56	37.41	8.73	72.7	13.4
B8.2	27	38.44	5.73	70.7	7.73
B8.3	64	34.47	8.15	66.52	11.17
B8.4	29	29.41	8.49	61.62	15.07
B8.5	28	28.25	8.58	64.96	11.51
SB1	-	-	-	-	-
SB2.1	12	22.75	9.02	64.58	13.33
SB2.2	27	35.41	8.13	67.56	13.36
SB3.1	79	28.86	8.78	66.23	10.15
SB3.2	7	30	7.37	61.43	7.41
SB4	31	25.65	6.78	60.65	8.81
CS3a	-	-	-	-	-
CS4b	-	-	-	-	-
BO1.1	6	-	-	65	12.97
BO1.1X	6	-	-	65.83	13.96
BN1.1	11	-	-	67.90	4.61
BN1.2	10	-	-	65.6	2.79
BEE	7	-	-	73.85	7.10
BSP	8	-	-	70.62	11.19
102	-	-	-	-	-
127	-	-	-	-	-
129	-	-	-	-	-

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	22.81	22.81	2.61	48	0
Q2	18.10	18.38	5.06	36	1
Q3	20.33	20.33	3.02	12	0

Paper B1.2: Set Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.48	16.90	6.80	21	6
Q2	16.48	17.28	6.77	53	3
Q3	17.43	17.53	4.94	52	1

Paper B2.1: Introduction to Representation Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.31	16.07	5.32	27	2
Q2	14.16	14.16	4.9	30	0
Q3	16.33	16.33	6.02	9	0

Paper B2.2: Commutative Algebra

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.09	15.09	4.98	31	0
Q2	13.46	13.89	5.39	29	1
Q3	6.85	14.5	5.72	2	5

Paper B3.1: Galois Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.27	17.27	6.15	54	0
Q2	4	4.75	3.57	8	3
Q3	15.80	16.10	6.68	46	1

Paper B3.2: Geometry of Surfaces

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	20.2	20.2	3.84	18	0
Q2	17.4	17.4	4.80	15	0
Q3	12.4	18.66	9.01	3	2

Paper B3.3: Algebraic Curves

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	19.5	19.5	5.00	18	0
Q2	14.46	17.81	7.38	11	4
Q3	14.57	14.57	3.86	7	0

Paper B3.4: Algebraic Number Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.79	16.79	6.64	34	0
Q2	16.20	16.20	5.92	34	0
Q3	17.58	19.47	7.31	34	5

Paper B3.5: Topology and Groups

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.33	15.18	5.46	22	2
Q2	17.15	17.15	4.03	33	0
Q3	17.23	17.23	4.16	13	0

Paper B4.1: Functional Analysis I

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18.34	18.34	4.10	44	0
Q2	14.72	15.60	5.84	23	2
Q3	16.78	17.33	5.78	27	1

Paper B4.2: Functional Analysis II

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.68	15.75	5.93	20	2
Q2	14	14.53	5.71	30	2
Q3	15.28	15.28	3.65	32	0

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

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.94	17.94	3.52	17	0
Q2	18.55	18.55	3.56	18	0
Q3	22	22	-	1	0

Paper B5.1: Stochastic Modelling and Biological Processes

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.58	12.58	5.39	31	0
Q2	6.84	7.43	5.59	23	3
Q3	7.44	9	6.42	6	3

Paper B5.2: Applied PDEs

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.45	16.74	4.34	43	1
Q2	14.52	14.83	4.90	24	1
Q3	15.20	15.63	4.27	33	1

Paper B5.3: Viscous Flow

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.78	17.78	3.64	28	0
Q2	16.21	16.21	4.19	19	0
Q3	11.5	14.09	7.35	11	3

Paper B5.4: Waves and Compressible Flow

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.43	16.43	3.70	23	0
Q2	17.24	17.24	5.44	25	0
Q3	13.33	13.33	3.96	12	0

Paper B5.5: Further Mathematical Biology

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.78	16.78	5.19	33	0
Q2	15.97	16.25	4.57	35	1
Q3	6.75	8	2.26	6	6

Paper B5.6: Nonlinear Systems

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.67	15.67	3.60	34	0
Q2	12.95	15.66	6.07	18	5
Q3	13.95	13.95	3.78	22	0

Paper B6.1: Numerical Solution of Differential Equations I

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.81	16.14	5.14	21	1
Q2	12.33	19	8.26	3	3
Q3	18.25	18.25	3.19	24	0

Paper B6.2: Numerical Solution of Differential Equations II

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	7	7	-	1	0
Q2	17	17	7.05	10	0
Q3	19.27	19.27	3.92	11	2

Paper B6.3: Integer Programming

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	9.42	9.42	3.59	7	0
Q2	13.42	14.8	6.99	5	2
Q3	11.5	11.5	6.47	6	0

Paper B7.1: Classical Mechanics

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.38	14.38	3.93	21	0
Q2	16.35	16.35	4.55	14	0
Q3	18.09	19.88	6.51	9	2

Paper B7.2: Electromagnetism

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.85	13.69	6.91	13	1
Q2	8.25	14.5	7.32	2	2
Q3	17.53	17.53	3.50	13	0

Paper B7.3: Further Quantum Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.14	13	6.88	13	1
Q2	13.94	13.94	4.84	18	0
Q3	13.83	14.29	6.38	17	1

Paper B8.1: Martingales through Measure Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18.74	19.57	5.47	33	2
Q2	17.69	18.02	4.97	35	1
Q3	17.95	18.59	6.50	44	2

Paper B8.2: Continuous Martingales and Stochastic Calculus

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	19.09	19.65	4.20	20	1
Q2	19.26	19.26	3.14	19	0
Q3	17.76	18.6	4.58	15	2

Paper B8.3: Mathematical Models of Financial Derivatives

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.68	17.68	3.93	63	0
Q2	17.09	17.39	5.51	53	1
Q3	14.16	14.16	4.26	12	0

Paper B8.4: Communication Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.80	16.62	5.81	24	2
Q2	13.65	14.22	4.49	18	2
Q3	11.7	12.37	4.31	16	4

Paper B8.5: Graph Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.78	14.78	3.66	23	0
Q2	14.41	15	5.33	11	1
Q3	13	13	5.38	22	0

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

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15	15	-	1	0
Q2	21	21	-	1	0
Q3	19	19	-	1	0
PR	30	30	-	1	0

Paper SB2.1: Foundations of Statistical Inference

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	10.62	13	7.53	6	2
Q2	7.14	7.14	4.05	7	0
Q3	13.18	13.18	3.89	11	0

Paper SB2.2: Statistical Machine Learning

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18	18.4	5.11	20	1
Q2	16.39	16.39	5.68	23	0
Q3	17.75	19.18	6.06	11	1

Paper SB3.1: Applied Probability

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	13.29	13.29	5.00	77	0
Q2	12.37	12.60	4.19	23	1
Q3	16.65	16.65	4.82	58	0

Paper SB3.2: Statistical Lifetime-Models

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14	14	4.97	6	0
Q2	15.71	15.71	4.82	7	0
Q3	16	16	-	1	0

Paper SB4: Actuarial Science

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.96	13.4	4.78	25	2
Q2	11.8	11.8	3.56	20	0
Q3	12.1	13.17	4.25	17	3

D. 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

Everyone did Question 1, mostly scoring high. The last part of (c) was new and challenging, the main difficulty encountered was how to rigorously show that certain formulas were not instances of the given axioms.

Question 2 was also very popular, though few candidates managed to answer part (b)(i) correctly, because the statement to be proved via standard induction was not given and it was not easy to guess either. Hardly anyone made use of the simplicity of tautological atomic formulas in the underlying language.

The main conceptual challenge in Question 3 was the non-standard model of Peano arithmetic invoked in part (b)(iii). While those candidates who just used its existence (via the Compactness Theorem) took no risk, the ones who explored it further lost feathers in the fight.

B1.2: Set Theory

Problem 1. This was the least-attempted question perhaps due to (a) (iii) being perceived as tricky. (a)(i) and (a) (ii) were generally well done, (a) (iii) was indeed harder, with some getting only inequalities. Part (b) was generally well done though a number of students affirmed the assertion in (i), missing the possible failure if Y, V are empty. Part (c) (i) was generally well done, (ii) mostly also while fewer gave a correct answer to (iii).

Problem 2. In part (a), subparts (i), (ii), (iii) were generally well done. (iv) saw a lot of convoluted arguments but many got through. Part (b) was generally well done, and nearly everyone who attempted this problem answered (iii) correctly. In Part (c), many answered (i) well but many also did not correctly employ AC to make their choices, which was the point of the problem. (ii) was also generally well done, though quite a few lost their way.

Problem 3. In (a), parts (i) and (ii) were generally done with no problems. Many were careless in (iii). It is not sufficient to take well ordered sets A, B order isomorphic to α, β and then form $B-A$, nor even to stipulate $A \subseteq B$, as one needs A to be an initial segment for the sum order of $A, B-A$ to coincide with the order on B. (b) (i) was generally done without problems. In (iii) very many did not fully check that $\in$ is a well-order on A. The existence of minimal elements is not sufficient: it needs to be a strict total order. Part 3 was generally quite well done, though quite a few were careless about checking non-emptiness and fully checking the chain condition.

B2.1: Introduction to Representation Theory

Question 1 was mostly OK, the parts that proved more challenging were (b)(iii) (the implication: if f has an irreducible factor with multiplicity greater than 1, then A is not semisimple) and part (c)(ii). There was no need to use Artin-Wedderburn or the notion of the radical of an algebra to prove/disprove semisimplicity. In (b)(iii), it was fine to use the Chinese Remainder Theorem for rings (without proof).

Question 2: in (a)(iii), a common mistake was to give a map that wasn't well-defined, e.g., eae maps to right multiplication by a (rather than eae). For (a)(iv), it was acceptable to give an example in a concrete group algebra (e.g., $\mathbb{C}C_2$) rather than in an arbitrary finite group. Parts (b)(iii) and (c) proved to be quite difficult. Part (b)(iii) is a particular, easy case of the general construction of idempotents attached to irreducible characters (as in one of the problem sheets/lecture notes), but can be done directly as well. In part (c), many candidates correctly explained how to identify the conjugacy classes of the centre of G, but very few attempted to explain how one might obtain the characters of the centre.

Question 3 was attempted by fewer candidates than questions 1 or 2. Several solutions assumed that the group in (b) is the dihedral group D_{12}. The most difficult parts proved to be (c)(i) and (c)(iii).

B2.2: Commutative Algebra

Question 1 was universally popular with the students, with everyone attempting it without exception. The bookwork parts were mostly done well, although a large number of people seemed to be confused by the statement of Zorn's Lemma presented in the course. There were several ingenious solutions to the unseen parts (d) and (e), including a single perfect score of 25. However far too many people decided that part (d) was bookwork — the existence of minimal prime ideals was indeed proved for *Noetherian* rings during the lectures, but no Noetherian hypothesis was present in this exam question. Candidates who tried to replicate this proof received zero marks for part (d).

Question 2 was the next most popular question with over 85% of the cohort having a go at it. Some people confused the statement of the Cayley Hamilton Theorem with the statement of the Nakayama Lemma in part (a), which led them to lose most of the seven marks available. Part (b) was mostly done well except nearly everyone forgot to remember that it is necessary to show that 0 lies in a subset of the ring (or at least show the candidate subset is nonempty) for it to be an ideal. Parts (c) and (d) were quite hard but nevertheless one or two people got (d) out, and one got (c) out with several people coming quite close. In part (d), too many students declared that $IJ = J$ as being obvious; this cannot be the case as the wording of the question implied that you need to use the result of part (c) to establish this.

Question 3 was attempted by very few people. The bookwork parts (a) and (b) were done reasonably well, but (c) proved to be difficult and (d) even more so. The number of people taking on the question was small so it is hard to make any kinds of conclusions, although arguably the unseen material in Question 3 is easier than that in Question 2.

B3.1: Galois Theory

Q1 and Q3 were by far the most popular.

In Q1 (d) most students forgot to consider the issue of the irreducibility of the polynomial (or an equivalent statement).

Q2 (d) and (e) were not solved satisfactorily by any candidate.

In Q3 (c) the fact that the field extension is inseparable was overlooked by many.

B3.2: Geometry of Surfaces

Almost all candidates chose exercises 1 and 2.

Exercise 1: (c) after noticing the Euler characteristic is (strictly) positive, some candidates did not rule out the non-orientable surface case; (d) many candidates just assumed there was only one additional point at infinity in the compactification without checking the solutions after the suggested change of coordinates in the hint, candidates sometimes did not say which map they were applying Riemann-Hurwitz to, or did not explain why it was holomorphic (1 mark), computational mistakes occurred in correctly finding the branch points.

Exercise 2: (a) a lot of imprecision in defining a smooth surface in R^3 (as opposed to an abstract smooth surface); (b) candidates often forgot to explain why F was a parametrisation, using the non-zero condition in the assumptions; (c) imprecision in stating the theorem: it is crucial to say that one uses the same open set in R^2 as domain for both parametrisation maps.

Exercise 3: (c) candidates showed the maps were equal on an open neighbourhood of p, but didn't properly explain how to use connectedness and the openness of the condition to get equality everywhere; (d) very similar to the notes, but deals with the case of the upper half-plane as opposed to the disc model.

B3.3 Algebraic Curves

Question 1: An elementary question attempted by everyone. The most common faults were in (b), in not justifying P1, P2, Q3, Q2 in general position, and then in not computing coordinates of R1, R2, R3 correctly.

Question 2: Attempted by most candidates, but found more difficult than 1. In (b) many candidates did not get to the end of the computation of p1, p2, p3. In (c), candidates should have split into two cases (i) C singular (done using (a)), and (ii) C non-singular (done using (b)), but most candidates did not notice case (i).

Question 3: The least popular question. The few candidates who understood this part of the course well and applied Riemann-Roch correctly were able to get nearly full marks on (a),(b). No one did a good job of (c), typically candidates did not see that they can use the action of σ on w and $f(w) = w–2 + O(w–1)$ to deduce the eigenvalue of σ on f, and similarly for g.

B3.4: Algebraic Number Theory

1.(a) This was standard bookwork and many students did well. In defining the discriminant of a lattice, I expected students to be at least aware of the need to show independence of basis, but very few students did this. One mark was taken off for failure to notice this.

(b) Most students did well with this problem.

(c) This problem was done easily by many students, but a substantial number also experienced difficulty. Understanding the precise application of Eisenstein's criterion seems to have been a stumbling block. Also, many students had a bit of difficulty computing the discriminant, which could have been done with a standard formula.

(d) The first part on the norm criterion for being a unit was easily handled. However, many students struggled with finding units. Facility with computing norms was the main skill needed.

2.

(a) Most students stated things correctly, although the degree of precision varied. The marking was done mostly generously, provided the students gave evidence of understanding what the key points were.

(b) The first part was found easy by most students. However, the second was done correctly by very few students. It occurred to me that to produce two *principal* ideals that are coprime may have been a bit hard for students. On the other hand, since the examples of quadratic fields whose rings of integers are PIDs are quite standard, they should have been able to do this.

(c) This problem was done fairly well by many students. It was especially good to see many students factoring $(3-\alpha)$ with little difficulty.

(d) This problem was quite challenging, but I think it did perform the function of distinguishing those students who understood the basic notions relevant to working in rings of integers.

3. (a) This was mostly straightforward, and problems arose mostly from calculation errors.

(b) This was also a standard problem, but not a few students experienced difficulty writing out the logic clearly. The argument that goes into proving that the ideals $(y-\sqrt{5})$ and $(y+\sqrt{5})$ are coprime is a bit delicate.

(c) This was probably the most difficulty problem in the examination and many students struggled. However, a substantial number did seem to understand what needed to be done, and this was good to see.

B3.5 Topology and Groups

Question 1

28 attempts. Part (a) was mostly bookwork. It required the students to remember the definition of push-outs and their universal property, and to apply this knowledge. It was well done. Part (b) was harder. Most people could correctly explain what happens to the fundamental group of a space when a 2-cell attached. Question (b)(ii) was less well done. Many students claimed that the fundamental group of the wedge of two spaces is equal to their free product, which is not true in general because the basepoints need not be contained in a contractible open set. However, I gave significant partial credit for solutions along these lines. The final part (b)(iii) was difficult. Spaces such as the Hawaiian earings provide the required examples.

Question 2

41 attempts. Part (a) was about homomorphisms from finitely presented groups, and was well done. Part (b)(i) was straightforward, but (b)(ii) was found to be quite difficult. It could be answered by defining the map f one cell at a time. Alternatively, an explicit map, defined using polar co-ordinates on the disc, also gives the correct answer. Part (c) was a challenging question about Tietze transformations. There were several very good answers. When students were clearly going in the right direction but were unable to provide a complete sequence of Tietze transformations relating the two presentations, I gave partial credit.

Question 3

18 attempts. Despite its apparent length, this question was the most accessible of the three. The last part of the course, on covering spaces, is widely viewed as quite difficult. But this question mostly required students to understand just the basic properties of covering spaces. The one moderately difficult part was (b)(v), which required both the homotopy lifting property and the uniqueness of lifts.

B4.1: Functional Analysis I

No comments.

B4.2: Functional Analysis II

Q1: This question was tried by half of the candidates. Part (a) was handled mostly well with some minor exceptions. Part (b)(i) was handled reasonably well, though a number of candidates did not realise that injectivity is an immediate consequence of the fact that the trigonometric system is an orthonormal basis of L^2. Part (b)(iii) is somewhat tricky but most of those who attempted did very well using term-wise differentiation rule and (b)(i). Part (b)(ii) appears hardest. Many candidates who attempted this part arrived correctly at the idea of using the open mapping theorem or inverse function theorem but only some could pull it through.

Q2: This question was tried by three quarters of the candidates. The bookwork parts were handled mostly well with some minor exceptions. Most candidates had a feeling what an example for (a)(ii) would look like though some had difficulties in justifying their answers. Part (b)(iii) appears trickiest. It involves an application of the principle of uniform boundedness after establishing two-sided bounds for linear functionals from an easily derivable lower bound and those who realised the issue did well.

Q3. This question was tried by about three quarters of the candidates. Part (a) was handled reasonably well by most candidates, though some candidates missed a small difference for r and U in (ii) and (iii). Part (b)(i) and (ii) were handled somewhat less well – some candidates did not apply the Cauchy-Schwarz inequality correctly. A majority of the candidates who attempted (b)(iii) applied correctly known results to limit the possible sets for the spectrum though had difficulties in pinning down the correct set, which could be done by either explicitly pointing out the eigenfunctions or by showing that some operators are non-trivial.

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

Question 1 examined the notion of distributional derivative and its connections with the usual derivative. Most candidates attempted this question and all performed well on the routine bookwork part (a). Many lost some marks for not being careful enough with the integration by parts calculation required in part(b). Despite this most spotted that it was important for the given function to be continuous for the result to be true. The integration by parts argument in part (c) went generally well, while the final part (d) was missed by many.

Question 2 examined tempered distributions and the Fourier transform. All candidates attempted this question and there were many very good answers. All did well on the routine bookwork part (a), though some lost marks for giving careless proofs of the integrability of Schwartz test functions. The calculation required for (b) went generally well, even though a few struggled to convincingly show that the natural logarithm $\log|x|$ can be considered to be a tempered distribution. To show that E is a fundamental solution in part (c) caused some difficulty for about half of the candidates, whereas almost all easily found its Fourier transform. The final part (d) nobody got completely correct, though about half earned a few marks for doing a formal calculation.

Question 3 examined convergence of tempered distributions and built up an independent proof of the Poisson Summation Formula (meaning different from the one given in lectures and not using any prior knowledge about Fourier series). Only one candidate attempted the question, but did very well. The question looks long (slightly over one page) and this might be the reason for its unpopularity. Another one could be its explicit connection to the Part A Complex Analysis course in parts (b) and (c).

B5.1: Stochastic Modelling and Biological Processes

The first question was attempted by all candidates, the second question by 84% of candidates, while the third question was the least popular, but still attempted by 40% of candidates. Most of the candidates (95%) attempted at least two questions and can be divided into three groups:

(a) candidates who submitted Questions 1 and 2 for assessment (55%);

(b) candidates who submitted Questions 1 and 3 for assessment (11%);

(c) candidates who submitted Questions 1, 2 and 3 for assessment (29%).

The popularity of Question 1 does not necessarily mean that it was the easiest one. The submitted solutions included some perfect and elegant answers, but there was also a significant number of incomplete and incorrect solutions, which worryingly showed gaps in some candidates' understanding of background Prelims and Part A courses, which course B5.1 builds on. The majority of correct answers were based on the analysis of the chemical master equation. In part (b), many candidates noticed that there can be 1, 3, or 5 molecules of A_1 at any time in the system. They then approached the problem by deriving a system of three ordinary differential equation for three variables

$$f(t) = \sum_{n_2=0}^{\infty}\sum_{n_3=0}^{\infty} p(5, n_2, n_3, t), \quad g(t) = \sum_{n_2=0}^{\infty}\sum_{n_3=0}^{\infty} p(3, n_2, n_3, t), \quad \text{and} \quad h(t).$$

Solving this system, they obtained the correct answer to part (b). Other candidates chose an alternative approach, observing that the reactor contains exactly one molecule of A_1 after the first reaction (i.e. $A_1 + A_1 \to A_2 + A_2$) occurs exactly twice. Therefore the answer to part (b) can also be equivalently obtained by calculating the probability that the first reaction happens twice in the interval $[0, t]$.

Although Question 1 was attempted by all candidates, the candidates could also do very well if they only focused on Questions 2 and 3. Indeed, a couple of students in group (c) had their two best questions counted as Questions 2 and 3. In Question 2, many candidates correctly derived a system of three ordinary differential equations for $\langle V^2(t)\rangle$, $\langle U(t)V(t)\rangle$ and $\langle U^2(t)\rangle$. Some candidates did not know what to do with this system to get the answer to part (a) of Question 2, while others got the correct answer by looking for the steady state solutions of this system.

In Question 3, a common problem included using polar coordinates. Considering that a function, say ϕ, in the N-dimensional space only depends on the distance, r, from the origin, say $\phi \equiv \phi(r)$, the Laplace operator applied to ϕ can be given as

$$\triangle\phi = \frac{\partial^2\phi}{\partial r^2} + \frac{N-1}{r}\frac{\partial\phi}{\partial r}.$$

Some candidates used this formula for $N = 3$, but Question 3 considers a particle diffusing inside (or outside) circles, so we should have $N = 2$. Then the above formula simplifies to:

$$\triangle\phi = \frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r}.$$

This mistake does not much alter the approach to solving Question 3, but it does change some answers. For example, $1/r$ is a solution of $\triangle\phi = 0$ for $N = 3$, while $\log(r)$ solves $\triangle\phi = 0$ for $N = 2$.

B5.2: Applied PDEs

Q1. This problem was attempted by nearly all candidates. Part a was mostly well done; (a)iii did not require any computation, only the observation that characteristics within each family do not intersect, and therefore the domain of definition is the region intersected by both families of characteristics and the data curve.

The desired canonical form in part (b)i used characteristic coordinates $\eta = y - \log x$, $\xi = x$. Most candidates made this choice, either as a default or logically by noting the various x's present in the PDE. Alternative choices for ξ would lead to a a different canonical form. It was deemed that some guidance should have been given to steer candidates toward the choice $\xi = x$; therefore full marks were given on this part for those who correctly produced a different canonical form. Part (b)ii could be solved independently and required careful treatment of boundary conditions to produce the correct form. Part (b)iii simply involved tracing back through the changes of variables both through similarity construction and characteristic coordinates. For those candidates with a different but correct canonical form a generic answer that demonstrated the concept was accepted for full marks.

Q2. This question was attempted by about half of the candidates. Part (a) required the connection $P = au$, $Q = bu$ as conservation form in the case of semi-linear PDE $au_x + bu_y = c$; this bit of bookwork was missed by almost half of those who attempted this question. In (b)ii the key was to recognize that in the 'filling' region, $dx/dt = x/t$; combining this with the characteristic equation $dx/dt = u^3$ gave the desired solution.

Part (c) was largely hit or miss for candidates. The first two shocks begin at $(x, t) = (\pm 1, 1)$, and those two shocks then intersect at $(0, 3)$, creating a single shock following the t-axis and separating the constant solutions $u = \pm 1$.

Q3. This question was attempted by about two thirds of the candidates. The best answer to part (a) involved noting that the envelope marks the boundary of where the solution becomes multi-valued, and above this curve the solution surface would show a fold.

Part (b) was mostly straightforward, a small adaptation on the bookwork derivation and was handled well by most candidates. In part (c), constructing the parametric solution was also mostly straightforward, but obtaining the domain of definition was a significant challenge. This required consideration of (1) the characteristics at the endpoints of the boundary curve, (2) noting that the characteristics approach a finite curve as $\tau \to \infty$, and (3) computation of the envelope. The last step was a tricky calculation, but a fair bit easier to solve with the approach $G = \partial G/\partial s = 0$, where $G(x, y; s) = 0$ is the family of characteristics, than the Jacobian calculation. No candidates got all details correct, but several got very close.

B5.3: Viscous Flow

Question 1. All candidates attempted this question, and almost all received full marks for (a). A few candidates made sign errors in (iii) that were completely unrelated to the sign of **F** in (b).

Part (b) was mostly done well, despite the unfortunate sign error in **F** that was spotted and announced 15 minutes into the exam. A few candidates had difficulty identifying the correct pressure scale $[p] = 2\rho\Omega UL$.

In part (c) many candidates did not use the given structure of the solution: no pressure gradient, and a velocity that is horizontal and only a function of z. However, almost everyone eventually reached $u = Ev''$ and $-v = Eu''$. Many candidates could not proceed from there, either by eliminating v to obtain $-u = E^2u''''$, or (in one elegant solution) by considering $u + iv$. The solution that decays as $z \to -\infty$ is $u = e^{\eta}(U \cos\eta - V \sin\eta)$ with $\eta = z/\sqrt{2E}$. Several candidates obtained solutions involving z with incorrect powers of E so the integration in the last step came out incorrectly.

Question 2 was attempted by 2/3 of candidates. There was an unnoticed error in the definition of the Péclet number in the question, which was the reciprocal of the correct expression. All candidates who scaled the temperature correctly were given full marks for the affected section (b).

Many attempts at (a) omitted the pressure term from σ_{ij} and glossed over the justification for replacing $\partial_j u_i$ by $\frac{1}{2}(\partial_j u_i + \partial_i u_j)$.

Around half the attempts at part (b) found the correct $\delta = Pe^{-1/3} \ll 1$ scaling (with the correct definition $Pe = \gamma L^2/\kappa$). Several candidates tried a simple multiplicative scaling between T and θ, when one needs to write $T = T_\infty + (T_{\text{wall}} - T_\infty)\theta$ to convert the boundary conditions to $\theta = 1$ on the wall and $\theta \to 0$ far from the wall.

Most candidates found part (c) straightforward, however many of them lost a minus sign when integrating $f'(\eta) = -A\exp(-\eta^3/9)$ to get the given expression for f with η as the **lower** integration limit.

Very few candidates made much progress with part (d). The dimensionless heat flux leaving the wall is $-\partial_Y\theta = -X^{-1/3}f'(0)$, with a minus sign because $\mathbf{q} = -k\nabla T$. One then just needs to express the constant A in terms of a Γ function by substituting $w = s^3/9$ in the integral expression for A.

Question 3 was the least popular. About 1/3 candidates attempted it, of which half were largely successful.

In (a) several candidates took the velocity scale as Ω instead of Ωa. Several candidates simply asserted the dimensionless boundary condition, instead of calculating it from the dimensionless form of $\Omega\mathbf{k} \wedge \mathbf{x}$.

In (b) not everyone checked that $\mathbf{u}_0$ satisfied the boundary conditions as well as showing that $\nabla^2\mathbf{u}_0 = 0$.

The starting point for (c) is $\mathbf{u}_0 \cdot \nabla\mathbf{u}_0 = -\nabla p_1 + \nabla^2\mathbf{u}_1$. The left hand side was sometimes omitted, or $\mathbf{u}_0$ and $\mathbf{u}_1$ were swapped. The pressure p_1 was often omitted, though this mistake was harmless as the next step is to take the curl to eliminate ∇p_1. Taking $\psi(r,\theta) = F(r)\sin^2\theta\cos\theta$ gives $(d_{rr} - 6/r^2)^2F = -6/r^5$. Trying $F(r) = r^\alpha$ gives four homogeneous solutions with $\alpha \in \{-2, 0, 3, 5\}$, only two of which are bounded as $r \to \infty$, and $\alpha = -1$ gives the inhomogeneous right hand side.

In (d) a few candidates commented that the fluid flows radially outwards at the equator, as driven by inertia, and inwards again at the poles to satisfy mass conservation.

B5.4: Waves and Compressible Flow

Q1 The bookwork on the derivation of the wave equation in part (a) was very well done. The derivation of the normal models and natural frequencies in part (b) was also well done, though the majority of candidates contradicted themselves by not dealing correctly with the case of zero separation constant. While good progress was made by many on the analysis of the waveguide in part (c), only a significantly minority applied correctly the radiation condition in case (ii) to identify the waves that can propagate when Ω is larger than the cut-off frequency $\omega_{m,n}$. In part (d) only a handful of candidates superimposed correctly their solutions from part (c) to obtain a series solution for the upgraded wave-maker. Overall this question was found to be a touch on the harder side.

Q2 The derivation of the linearized problem in part (a) was very well done. The derivation of the solution in part (b) was also very well done by the majority of candidates — only a small minority failed to solve correctly the transformed problem. Good progress was made by about half of the candidates on the application of the method of stationary phase in part (c), with the remainder struggling to differentiate correctly $\omega(k)$ or becoming lost in the book keeping required to handle efficiently the two dominant contributions. Overall this question was found to be on the easier side.

Q3 The bookwork in part (a) was well done on the whole, though a a significant minority got lost in the algebra required to show that the flow is homentropic. The piston withdrawal problem in part (b) was based on a similar problem covered in both lectures and on a problem sheet. This was reflected by there being many excellent solutions to part (b)(i) and the derivation of the parametric solution for u and c underpinning part (b)(ii), but then progress stalled for nearly all candidates. In part (b)(ii) only a handful of candidates made progress on the manipulation of the solution into the given form and and on the ensuing analysis on the loss of positivity of the wavespeed c. There were, however, several excellent and complete solutions to part (b)(iii). Overall this question was found to be on the harder side.

B5.5: Further Mathematical Biology

- Question 1 was a variant on standard theory for modelling chemotaxis-driven pattern formation. Most candidates attempted this question and answered parts (a) to (d) well, although not all were able correctly to linearise the governing equations. Few candidates Attempted part (e) and/or were able to sketch the region of parameter space in which spatial patterning is predicted.

- Question 2 involved a combination of the Law of Mass Action and travelling wave analysis. Like question 1, it was popular with the candidates, most of whom scored well on parts (a), (b) and (c). In part (d), many candidates struggled to reduce the system to a single partial differential equation for u because they failed to recall the conservation law derived in part (b). Attempts at part (e) were generally good, with students recognising that the PDE was a variant on Fisher's equation.

- Very few students attempted question 3 and those that did found it challenging. Part (a) was done well and there were some reasonable attempts at part (c). Despite exercises covering similar cases, the students were unable to solve the diffusion equation in part (b), and this hindered their ability to complete part (d).

B5.6: Nonlinear Systems

- Most students choose Q1 as it involved more direct calculations. Most students answered easily Parts a and b (bookwork). Most students managed to do well and showed good understanding of the underlying material. Similarly in Part c many students identified correctly the period doubling bifurcation points and collected their results in the bifurcation diagram. Part d required a broad understanding of the material given in the lecturers. I was glad to see that some students approached this part, though no one managed to provide the complete analysis of the roots of the solution polynomial.

- Approximately half of the students chose Q2. Most of them derived conditions determining the local stability and type of the two fixed points in Part a, though only a few students could plot correctly the corresponding parameter curves in Part b. In part c, most students transformed the system into the Hopf normal form provided in the hint, but only a few of them could subsequently calculate correctly the corresponding Lyapunov and d coefficients as calculations of these are more technical. Few students forgot to shift the equilibrium to the origin before applying the transformation into the normal form. Nevertheless, I was glad to see that a few students provided the full answer to Part c.

- Approximately half of the students chose Q3. Most students answered easily Parts a and b (bookwork). Some students had problems with the calculation work in Parts c and d. Only a few students calculated correctly ν_{cr}, despite the provided hint. Part d required a deeper understanding of the material and I was glad to see that a few students gave the right answer here.

B6.1: Numerical Solution of Differential Equations I

In general, the exam reflected the material taught in class. It comes as no surprise that well prepared students manage to answer most of the exam questions. Some students had difficulties in computing Taylor expansions of vector valued functions in question 1. Fewer students attempted question 2. Again, some of these had difficulties with multi-variable calculus. Finally, most students' solutions to question 3(d) lacked rigor.

B6.2: Numerical Solution of Differential Equations II

Question 1 The question had similarities with problems worked during the exercise sessions but it was conceptually more demanding than the other two questions.

Question 2 corresponded to a main theorem from the lecture notes whose proof was only sketched in the lecture. Because of the structure of the different parts, it was not difficult to grab some marks in each sub-part.

Question 3 was addressed by all candidates. Questions of this type have been around in previous papers for several years and this was reflected in the very good performance of the candidates, except on the bits that were actually different from previous papers.

B6.3: Integer Programming

The uptake of all three questions was fairly evenly distributed, though Q3 saw a slightly smaller uptake (Q1 was solved 15 times, Q2 16 times, and Q3 10 times). The spread of marks within each question was also similar, though Q2 seemed to have been marginally easier than the other two. The overall raw marks saw a wide distribution, ranging from 11 to 48 (out of 50). Two minor typos were picked up during the exam and communicated to all candidates. I don't expect anyone to have been disadvantaged by these typos, as they were obvious from the context.

Q1: Weaker candidates struggled with the book work parts a) & b) (alternative disjunctions, definition of LP dual and statement of the Strong LP Duality Theorem, both drawn from the early parts of the course). Part c) concerned the inversion of an argument we had seen in the course, which required proving an "if and only if" statement. Some candidates got confused and proved the "only if" part twice in two different ways. Part d) drew on material from the later parts of the course (Lagrangian relaxation) and applied it to LPs, which are a special case of IPs but presented an unfamiliar feel.

Q2: This question contained quite a lot of book work of axiomatic flavour on submodular functions and matroids. Part c) required making a (novel) connection between this theory and a scheduling problem, which was well solved by several students. Overall, the candidates seemed to have liked this problem the best.

Q3: The bookwork section required explaining LP based branch-and-bound, one of the earlier topics of the course. This was generally well solved but many candidates left out important steps related to the propagation of bounds. Part b) was a novel but relatively easy test of understanding of the branch-and-bound framework. Part c) related to the branch-and-cut section of the course (one of the later parts of the course) and tested the students on their understanding of the simplex algorithm and the generation of Chvatal-Gomoroy cuts. This is material that entered the course under the changed syllabus. Some candidates ignored the instructions and solved the IP via ad hoc inspection. No points were awarded for such solutions, as the IP had been designed to be deliberately simple, so that the candidates' understanding of the cutting plane algorithm could be tested without onerous calculations.

B7.1: Classical Mechanics

1. Many candidates had difficulty identifying the number of degrees of freedom correctly (three). Cartesian coordinates were not used despite being the most efficient.
2. There were good solutions to the bookwork, but candidates found it hard to reproduce the formula that was asked for.
3. This had fewer attempts being on the later material but attracted some good strong solutions.

B7.2: Electromagnetism

Most students seemed to understand the main ideas and basic content of the lecture course however there where many computational errors, particular in the newer parts of the questions.

Q1: All students attempted this questions. There was some excellent work however students where confused in part (b) about applying correctly the boundary conditions and many marks where lost.

Q2: There were few attempts at this question and unfortunately a number of computational errors where made.

Q3: All students attempted this question and it was the one which drew the best answers.

B7.3 Further Quantum Theory

- Problem 1: Part (*a*) was bookwork and mostly well-answered, though there were some errors here already. In part (*b*) the first two parts were often answered well, though the nature of the ambiguities in the definition of the Clebsch-Gordan coefficients was often not well-explained (there is one phase ambiguity per irreducible representation appearing in the tensor product). Selection rules given in part (*iii*) were frequently incomplete. Part (*c*) was novel in principle, though most of it amounted to applying the rules for addition of angular momentum. Giving the states of the spin-3/2 Hydrogen atom was a problem in quite a few scripts, with the rules for decomposition of tensor products from the previous parts not enforced correctly. There were similarly many errors in part (*ii*). Very few attempts in part (*iii*), though when it was done it was done well.

- Problem 2: Part (*a*) was bookwork and was generally answered well, though the implication of probability conservation was often not well-justified. The second part was very similar to examples seen previously, and was also answered correctly by many candidates. Rather than derive the stationary wave function, a number of candidates had memorized a general formula from the lecture notes for piece-wise linear potentials, though this led to occasional trouble with reality conditions due to the relation $E < V_0$. The extension to include a WKB wave-function was either unanswered or caused problems on almost all scripts. Many candidates treated the problem as either a perturbation or as a bound-state problem, neither of which was relevant to the case in question. By using the WKB approximation for the wave function in the classically forbidden region, the result should have been nearly identical to part (*b*) with a simple replacement in the arguments of the hyperbolic trigonometric functions. In the case of a smooth function one would need to use the connection formulae at the end-points instead.

- Problem 3: Part (*a*) was bookwork and was almost uniformly answered well, with some small issues arising in the explanation of normalization assumptions. Part (*b*) required second-order perturbation theory, and was most straightforwardly done using the algebraic formalism (some candidates proceeded in terms of explicit wave functions, but this leads to integrals one would rather not do during an exam). Comparing to the exact result required completing the square in the perturbed Hamiltonian. Many candidates did not complete the second part, though the relevant computations had often already been done in part (*i*). Part (*c*) required first-order degenerate perturbation theory, and was made much simpler by expanding the perturbation in creation/annihilation operators and dropping terms that vanish in the relevant matrix. Very few candidates successfully carried out the calculation.

B8.1: Probability, Measure and Martingales

Question 1. This question outlined a different approach for constructing product measures where Dynkin's lemma for monotone classes plays a vital role. Almost all candidates attempted this question and answered well about the book work part about Dynkin's classes and the uniqueness for finite measures. While a few candidates are unable to apply Dynkin's lemma for producing proofs of the measurability required.

Question 2. Many candidates attempted this question which outlines a different version of the convergence theorem for martingales, and did well for the book-work part and answered well by following steps by steps. A few candidates used a wrong identity to show the domination in (b)(ii).

Question 3. About half of candidates attempted this question, and a few of them failed to answer part (a) in satisfactory way which requires the use of the Fubini's theorem twice. Most of candidates were able to construct a proof of Doob's maximal inequality for martingales, though not necessary used the approached suggested in the question. A few candidate failed to choose a proper increasing function to prove the inequality in part (c).

B8.2: Continuous Martingales and Stochastic Calculus

Question 1 was generally well answered. In part b, the importance of stating that the three statements of the convergence theorem are equivalent was sometimes missed. In part c, which is a proof from the lectures, students lost marks by forgetting to justify their convergences, which need a combination of monotone/dominated convergence (depending on the strategy taken), Fatou's inequality to show $\mathbb{E}[M_t^2] \leq \liminf_{n\to\infty} \mathbb{E}[M_{t\wedge R_n}^2]$ (where R_n is some localizing sequence), and Doob's L^2 inequality to move a supremum through an expectation. In part d, students struggled with the fact that A is only $\mathcal{F}_\infty$-measurable, in particular, $\{1_A M_t\}_{t\geq 0}$ is not a martingale, and you cannot simply work with $\omega \in A$ and assume that you have the bounds in expectation from part c. Some students failed to show that as $n \to \infty$ we have $M_{t\wedge S_n} \to M_t$ for $\omega \in A$, which follows from the definition of A. Some students also proved that $t \mapsto M_t^2$ converges on A, but then did not sufficiently justify that this implies M converges because M has continuous paths *and* $x \mapsto x^2$ has a *discrete* preimage.

Question 2 was also well answered. In part a, some students were not sufficiently clear where they had assumed properties of the normal distribution (in particular the mgf/characteristic function). In part bi, many students forgot to state that M must have right-continuous paths, which is needed in the theorem. In bii, some students gave examples where $\tau = \infty$, but did not show that the martingale they proposed converged, so X_τ was simply not defined. Part c was generally well done, but ciii caused some difficulties, as students often pulled the stopping time out of the expectation, rather than treating it as a random variable. Some students also applied the optional stopping theorem to B, rather than X, which does not yield the desired result.

Question 3 was also well answered. In part b, very few students noticed that the submartingale should be assumed to be at least right-continuous (otherwise Y_τ may not be well defined, and the optional stopping theorem does not hold). Part di was well answered, by applying Itô's lemma to the processes, but students often did not justify why the stochastic integral terms had expectation zero (as they are true martingales, as f is assumed to have bounded derivatives), and tried to argue for the independence of increments of $f(X)$, which does not hold. Part dii was less well answered. Some students tried to apply optional stopping with the stopping times $\tau_1 = \inf\{t : X_t \in A\}$, where $A = \{x : \nabla^2 f < 0\}$, and $\tau_2 = \inf\{t > \tau_1 : X_t \notin A\}$. (Instead setting τ_1 to be a stopping time when $\nabla^2 f < -\epsilon$ gives a successful proof.) This causes difficulty as it's then the case that $\tau_1 = \tau_2$, which leads to difficulty in proving the result. Some students argued that we could 'start our process inside A', which requires slightly different assumptions to those given.

B8.3: Mathematical Models of Financial Derivatives

Most students attempted the first question and students did reasonably well.

Most students got Parts (a) and (c) out. For students who made a reasonable attempt at this question, most marks were lost for:

- stochastic variables suddenly turning into real variables, without explanation;
- for not knowing the difference between the cost of hedging a portfolio as opposed to its current market value;
- not getting Part (d) out completely.

Some students put in quite a lot of information which was irrelevant to answering the question.

a question.

A great number of students attempted the second question. Almost all got Part (a) out (it was basically book work) and most managed to get Part (c) out (again this was book work). Many got most of Part (b) out, and some got Part (d) out. There was evidence that some students had run out of time by the end of this question and some solutions were somewhat rushed towards the end.

Fewer students attempted Question 3, and many of those were rushed attempts. I suspect this question was almost always done as the final attempt at a question. In general, students who did this question either did very well in the other question or quite badly at the other question.

B8.4: Information Theory

Question 1 was the most popular with nearly all candidates attempting it. Question 2 and Question 3 were approximately equally popular. For all three questions most candidates managed to get all points for part a) though a common reason for point detection was to ignore the case when the probability mass function puts mass zero on a point (e.g. in the definition of divergence or entropy). Most candidates made progress on Question 1b) though fewer managed to calculate capacities in 1c). Similarly, most got all points for 2b) though very few candidates made any progress on 2c), although some "guessed" the correct function without giving a rigorous derivation.

For 3b), few candidates realized that adding a "dummy" letter to the two-letter alphabet made the proof of 3bi and 3biii much easier; most candidates however, manage to write down an example that was asked for in 3bii. For 3c) few candidates made any progress, although some made successful first steps.

B8.5: Graph Theory

The first two parts of question 1 were mostly well done, though for (a) I was looking for some indication why deleting an edge can only create one extra component (e.g., adding an edge can only join the components it touches) since otherwise the solution is just to assert the statement in the question! In (b)(i) the intention was to use (a), but using standard properties of trees was allowed. In (b)(ii) surprisingly many candidates recalculated for the minimum, rather than using $c \geq n - m$ to deduce $m \geq n - c$. (c) was less well done. For maximum values, some candidates said that if $\kappa(G) = 2$ then there must be a vertex of degree 2, which is not true. Simply use that there is a separating set of size 2 (and for a short answer, apply (b) to the rest of the graph). The hard part is the lower bound in (ii), which requires showing the existence of a 3-connected graph which is (almost for n odd) 3-regular.

Question 2 was least popular. Most of (a) and (b) is bookwork and was reasonably well done, though there were quite a few incorrect proofs of the theorem. In the last part of (a) it's enough to show $t_2(n) - t_2(n-1)$ is increasing; this difference is just $\delta(T_2(n))$. For (c), there were a number of reasonable solutions to (i), but very few for (ii). The key idea is to (correctly) deduce how a triangle in G can be connected to the rest of the graph if there is no copy of H_2.

Question 3 was popular but proved difficult (generating a good spread of marks), and not always where I expected. A number of people had trouble with (b) (the idea is to note that there for $T \subset V_2$ there are no edges from $V_1 \setminus \Gamma(T)$ to T, and apply Hall's condition to the former set. In other words, the relevant property of the neighbourhood of a set is that there are no edges going outside it). (b)(i) was mostly OK (just apply Hall's condition each way to the two sets); very few managed (ii) (the key is that an odd component has more vertices on one side of the partition than the other). (d), which I expected to be hard, was often well done, especially the first part. For (i) one can construct an example thinking about Tutte's Theorem, or just spot that e.g., $K_{k,k+2}$ works.

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%.

Within Section A of the paper, no candidates attempted question 5 (Grassmann's 'extensive quantities' — a topic dealt with only briefly during the lecture course). At the other extreme, *every* candidate attempted question 4 (Euler's definition of integration), probably because this is a topic that was at the core of the lecture course. A common pitfall here, however, was a failure to comment on the fact that this was a definition of integration purely as anti-differentiation, in contrast to the area-based definitions that came before and after. Questions 1–3 were each attempted by two candidates, with only one candidate attempting question 6. Questions 2, 3 and 6 were fairly standard questions, whose associated topics were covered in some detail in the lecture course; question 1 was a little harder, having only been touched upon briefly in lectures.

Certain of the answers, particularly those to question 2, would have benefited from the inclusion of a diagram. Where candidates arranged their answers under the headings 'context', 'content' and 'significance', material was sometimes misplaced. This was particularly noticeable in some cases for 'content', where candidates included rather more information than was actually present in the extract — these details should have appeared under 'significance' or been omitted entirely. Another common problem was that under exam conditions some candidates forgot a point that was repeatedly stressed throughout the course: that we do not take 'significance' merely to mean 'importance', but in a broader sense of assessing where the extract in question sits within the wider development of mathematics.

This year's topic for the extended coursework essay was the late-eighteenth- and early-nineteenth-century (British) debate surrounding the validity of negative and complex numbers, with a focus on the writings of William Frend, George Peacock, and Augustus De Morgan. The submitted essays displayed great variety, both in choice of essay title, and in quality. The better essays were those that did not simply regurgitate the content of class discussions, and that displayed evidence of reading beyond those texts that had been set.

BEE, BSP and BOE essays and projects

Mark reconciliation was handled for essays and projects as part of the same exercise. Some assessors/supervisors did not make the deadline for submitting marks so the procedure was handled on a rolling basis once initial suggested marks were received, but overall the process went smoothly.

If the proposed marks were sufficiently close, as set out in the guidelines, then the supervisor and assessor were informed that the automatic reconciliation procedure would be applied unless they indicated that they wished to discuss the mark further. If the proposed marks differed sufficiently from each other, then the supervisor and assessor were asked to confer in order to agree a mark.

BN1.1: Mathematics Education

The assessment of the course is based on:

- Assignment 1 (Annotated account of a mathematical exploration) 35%
- Assignment 2 (Exploring issues in mathematics education) 35%
- Presentation (On an issue arising from the course) 30%

Each component was double-marked, with Dr Jenni Ingram plus myself, Dr Nick Andrews, as assessors. As recorded in the table below, each component was awarded a USM (agreed between assessors for double-marked components), and then an overall USM was allocated according to the weightings above. Where a significant difference between marks awarded by the two assessors arose or marks were across a grade boundary (these are underlined in the table), scripts was discussed in more detail before agreeing a mark.

As last year there were 12 students on the course this year and all but one went on to study for the BN1.2 (Undergraduate Ambassador Scheme) in Hilary Term.

BN1.2: Undergraduate Ambassadors Scheme

The assessment of the course is based on:

- A Journal of Activities (20%)
- The End of Course Report, Calculus Questionnaire and write-up (35%)
- A Presentation (and associated analysis) (30%)

- A Teacher Report (15%)

The Course Report and Journal were double-marked, with Dr Gabriel Stylianides and myself, Dr Nick Andrews, as assessors. I was sole assessor for the Presentations and the host school teacher provided grades for the Teacher Report.

There were 11 students on the course this year and all had previously studied for the BN1.1 course in Mathematics Education in Michaelmas Term. All students engaged well with the practical aspects of the course, demonstrating an ambassadorial role in schools, leading to good marks in these areas.

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

SB3.2: Statistical Lifetime Models

SB4: Actuarial Science

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

129: Early Modern Philosophy

E. Names of members of the Board of Examiners

- **Examiners:**
  Prof Ben Green (Chair)
  Prof Helen Byrne
  Prof Marco Schlichting (External)
  Prof Michal Branicki (External)
  Prof Jan Kristensen
  Prof Cornelia Drutu
  Dr. Neil Laws
  Prof Nick Trefethen

- **Assessors:**
  Dr Nick Andrews
  Prof Konstantin Ardakov
  Dr Philip Beeley
  Prof Chris Beem
  Prof Dmitry Belyaev
  Prof Helen Byrne
  Prof Ani Calinescu
  Prof Alvaro Cartea
  Prof Dan Ciubotaru
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  Prof Xenia de la Ossa
  Prof Paul Dellar
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  Prof Radek Erban
  Prof Andrew Fowler
  Prof David Gavaghan
  Prof Ben Green
  Prof Ben Hambly
  Prof Raphael Hauser
  Dr Chris Hollings
  Dr Jenni Ingram
  Prof Matthew Jenssen
  Prof Dominic Joyce
  Prof Peter Keevash
  Prof Minhyong Kim
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Prof Thomas Lukasiewicz
Prof Lionel Mason
Prof Kevin McGerty
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Prof Martin Robinson
Prof Damian Rossler
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Dr Catherine Wilkins