Examiners' Report: Final Honour School of Mathematics Part B Trinity Term 2015

October 27, 2015

Part I

A. STATISTICS

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

  See Table 1.

	Numbers					Percentages %				
	2015	(2014)	(2013)	(2012)	(2011)	2015	(2014)	(2013)	(2012)	(2011)
I	48	(49)	(54)	(57)	(54)	32.88	(31.01)	(34.34)	(34.34)	(36.24)
II.1	69	(78)	(78)	(79)	(67)	47.26	(49.37)	(49.68)	(47.59)	(44.97)
II.2	25	(21)	(21)	(21)	(19)	17.12	(13.29)	(13.38)	(12.65)	(12.75)
III	3	(9)	(2)	(5)	(7)	2.05	(5.7)	(1.27)	(3.01)	(4.70)
P	1	(1)	(2)	(3)	(2)	0.68	(0.63)	(1.27)	(1.81)	(1.34)
F	0	(0)	(0)	(0)	(0)	0	(0)	(0)	(0)	(0)
Honours (unclassified)	0	(0)	(0)	(1)	(0)	0	(0)	(0)	(0.6)	(0)
Total	146	(158)	(157)	(166)	(149)	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.**

  The following were double marked: whole unit BE Extended Essays, BSP projects, and coursework submitted for the History of Mathematics course, and the Undergraduate Ambassadors Scheme.

  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 20.

B. New examining methods and procedures

We followed the new procedures for considering factors affecting performance of individual candidates. There was a small procedural change relating to BSP projects.

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

We understand that the Teaching Committee of the Mathematical Institute has been discussing whether the exams should be extended from 90 minutes to 2 hours.

D. Notice of examination conventions for candidates

The first Notice to Candidates was issued on 26 February 2015 and the second notice on 29 April 2015.

All notices and the examination conventions for 2015 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. However we, and the Chairman in particular, do wish to single out for special mention Helen Lowe for providing excellent administrative support throughout and Charlotte Turner-Smith for her help and support whenever this was needed. We are extremely grateful to Waldemar Schlackow for the excellent work he has done in maintaining and running the database, assisting the examiners in the operation of the scaling algorithm, and in generating output data as requested by the examiners. We are also grateful to Nia Roderick and the rest of the Academic Administration Team for assistance during the logging in and checking of scripts.

In addition the internal examiners would like to express their gratitude to Professor Higham and Professor Thomas 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' meeting.

Standard of performance

The standard of performance was broadly in line with recent years. Hardly any candidates performed very poorly, so the Third Class was very small.

In setting the USMs, we took note of

- the Examiners' Report on the 2014 Part B examination, and in particular recommendations made by last year's examiners, and the Examiners' Report on the 2014 Part A examination, in which the 2015 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.

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.

Standard and style of papers

At the beginning of the year we took several steps to try to avoid having papers which were much too easy or much too hard: meeting the setters of several papers which had been troublesome in recent years, asking all setters to aim that a 1/2.1 borderline candidate should get about 36 marks out of 50, and a 2.1/2.2 borderline script should get about 25 marks, and emphasising the problems caused by very high marks. It was apparent from the reports received from setters that some of them had not fully complied with our requests, but there was enough response that we had no extremely severe cases of papers being too easy or too difficult. In general, we felt that questions were testing understanding rather more than in recent years.

Nevertheless there were some papers which were so easy that we had difficulty setting USMs fairly at the top, and there were some papers which were sufficiently hard that we felt unable to scale up the raw marks to the extent indicated by the algorithm. We shall pass to next year's Examiners lists of these papers, but we mention here two papers where there may be a persistent difficulty:

B5.3: The marks on this paper have been very high, or extremely high, for at least the last three years, and Examiners in those years were concerned about the course, but the syllabus has not been changed. The setter believes that this year's paper was particularly hard, yet two-thirds of the candidates obtained 40 or more marks out of 50. We **RECOMMEND** that the Teaching Committee reviews this course with a view to making the syllabus more challenging.

B8.2: Last year's Examiners report suggested that this course might be more suitable as a Part C course. This year's paper was considerably less hard than last year's but it was still a strong candidate for being the hardest of the papers for which we were responsible, with many low marks. If the course is to continue at Part B, future examination papers should be easier than this year's, but the lecturer's comments suggest that may be difficult to achieve.

Long questions. Two questions (both on the same paper) were so long that they did not fit on a single page. We were concerned about this, to some extent because of the amount of reading required, but even more because of the possibility of candidates failing to notice that the question continued on the next page. We did not press the setter to change these questions, but we feel that it is undesirable for questions to extend to a second page. We **RECOMMEND** that next year's Examiners should include in their letter to setters, and in the checklist for checkers, a requirement that the question should fit on a single page when adequate spacing is used.

Papers shared with Part C

This year there were four papers shared with Part C, one in Commutative Algebra and three in mathematical physics. As in 2013, the Part B candidates greatly outnumbered the Part C candidates on each of the papers in mathematical physics. The paper in Commutative Algebra was evidently extremely difficult for Part B and Part C candidates, and one of the mathematical physics papers was particularly easy. The USMs were set by the Part C examiners, having regard to the marks of the Part B candidates as well as the Part C candidates. They alerted us that it had been difficult for them to set the marks. We felt that the scaling of the marks was as fair for Part B candidates as it could be in the circumstances.

We understand that there will be only one shared course in 2015/16, and Commutative Algebra and two of the mathematical physics courses will be available only in Part B.

Papers outside the schedules

Two candidates were unable to complete online entries in the middle of Hilary Term because they wished to take a combination of papers that was not permitted. One candidate wished to take Algebraic Number Theory without taking Galois Theory. This is explicitly ruled out in Section 1.1.1 of the Part B synopses, and again in the preamble to the synopsis for Algebraic Number Theory. However the candidate gained no advantage by taking this combination, and we readily agreed to the Education Committee allowing a dispensation.

The other candidate wished to take a Part C course which has never been available in Part B. The candidate had been encouraged by his college to follow the course and had been badly advised by the college that he would be allowed to be examined on it in Part B. The college took no action to seek dispensation until the candidate was unable to complete his online entry. We would have strongly opposed dispensation for any candidate to take any Part C course (other than those specifically permitted in the Part B synopses) if we had known in time for the candidate to take an alternative course. In view of the timing and the circumstances, we agreed to dispensation but with great reluctance. Other candidates who may have wished to take some course outside the schedules but who observed the schedules or were properly guided by their colleges, may have felt aggrieved.

There is no explicit statement in the Part B synopses that there is no provision for candidates to be examined in any course other than those identified in the synopses. We **RECOMMEND** that

(a) A statement to this effect is included in Section 1.1.1 of the synopses. For example:

    There is no provision to be examined in Part B on any course other than those listed in Sections 2, 3 and 4 of these synopses. Any applications for dispensation to take any other course will almost certainly be rejected.

(b) The statement is circulated to students and tutors at the start of the academic year.

Changes of syllabus (old regs)

The need for papers on obsolete syllabuses appears to be increasing quite rapidly, due to students withdrawing during Trinity Term and returning after one or more years. At the beginning of 2014/15, the Examiners were informed of two candidates who had withdrawn from 2014 Part B shortly before the exams, and who would take the exams in 2015 based on the 2013/14 syllabus. This required setting two special papers on which all the questions were for a single candidate, and setting one question on another paper for a single candidate. There were 6 withdrawals in Mathematics Part B shortly before or during the exam period. Consequently any popular paper which will be discontinued or substantially changed in 2015/16 is likely to require an old-regs version to be set in 2016 (or 2017).

We believe that the amount of work involved in setting these special papers and questions is disproportionate to their benefit. Questions have to be set in draft, checked, modified, and confirmed. Setting a mathematics paper is usually the equivalent of several days' work for one person. One of the assessors involved remarked that it would have been much less work to conduct an oral examination, and that is undoubtedly true. The benefit is small because Examiners cannot be confident about assigning final marks fairly on a paper with only one or two candidates. We think it is common practice in other universities that candidates who defer are required to take the new-syllabus paper.

We **PROPOSE** that further consideration is given to the possibility of requiring candidates who defer to take the new-syllabus paper; and of allowing oral examinations in limited circumstances (for example, the discontinuation of a paper).

Such changes would require changes to University policy or regulations, so we offer here some suggestions for improving the present system.

1. At the beginning of Trinity Term a college asked the Mathematical Institute and Department of Statistics whether the college should apply to the University's Education Committee for the setting of alternative versions of any papers for a candidate who had withdrawn from the 2013 exams. The Mathematics Examiners were previously unaware of this candidate's circumstances, although the candidate had entered for the examination at the usual time. Ideally the Examiners should be informed of such candidates in Michaelmas Term before any papers are set. As a minimum, the information should be apparent to the Examiners' supporting staff as soon as examination entries are completed. That could be achieved if the online exam entry were to require candidates to confirm, or not, that they wish to be examined on the current syllabus.

2. When a request is made for old-syllabus versions of any papers, the current practice is that the college and the candidate are told, for each paper, whether or not a special version will be set for that candidate. In cases where the change of syllabus has been small (up to about 30% of the paper), this potentially creates an inequity amongst candidates taking the current-syllabus version of the paper, as described in the next paragraph.

Consider a candidate Z who has deferred Part B and requests old-syllabus versions of papers A and B arising from syllabus changes. Suppose that Z is told that a special version of paper A will be set, and that Z will take the standard version of paper B. Then Z or the college passes this information to candidate X but not to candidate Y, both of whom will be examined on the current syllabus of both papers. Now candidate X can infer that paper A will examine a topic which is in the current syllabus but was not in the earlier syllabus, and also that paper B will examine only topics which were in the syllabus in both years. Candidate Y is unaware of this, so there is inequity in X's favour on both papers. If the change of syllabus is substantial (more than about 30%) then X's advantage on paper A would be nil, as X and Y would both expect that some part of the new material would be examined.

In order to remove this inequity (and also to streamline the process of determining whether a special paper should be set), we recommend that the Mathematical Institute adopts one of the following procedures.

Option 1. The reply is always that an old-syllabus paper will be set. If this is the universal response, no inferences could be drawn from it. A variant paper is then set up, but the questions might be identical to those on the new-syllabus paper.

Option 2. Each change of syllabus approved by the Teaching Committee is placed in one of three categories:

(a) Insignificant: Then Candidate Z would take the standard paper and be treated in the same way as X and Y.

(b) Small: Then Candidate Z would take the standard paper, but the Examiners would be required to consider whether Z was disadvantaged and to adjust Z's mark accordingly.

(c) Substantial: Then an old-syllabus paper would be set for Candidate Z. It would probably share some questions with the new-syllabus paper, and the two papers might even have identical questions.

It would be desirable for this classification of change of syllabus to be made without knowledge of the draft questions. It would be carried out (preferably) by the Institute's Teaching Committee (advised by subject panels) when they approve the change of syllabus, or by the Examiners at the beginning of the academic year. Any enquiry would automatically get the response corresponding to the already agreed classification of the change.

Timetable

Examinations began on Monday 1 June and finished on Friday 19 June.

Reconciliation of marks for projects

Arising from last year's Examiners report, the procedures for reconciliation of proposed marks for BE extended essays and BSP projects were simplified without breaking any of the required principles. There was a small saving of administrative effort, without any loss of rigour in the process. Due to illness of one assessor, the reconciliation of marks of two BSP projects had to be achieved by an adapted procedure.

For the BSP peer reviews a mark-sheet was used for the first time. The proposed marks were slightly lower than the extremely high levels of previous years.

Consultation with assessors on written papers

As in 2013/14, we had more interaction with assessors about scaling of marks than in the past. As usual we asked asked the assessors to suggests ranges for which raw marks should map to 60 and 70. A large majority of assessors offered their own proposals. Within a few days of receiving the mark-sheets we calculated the marks that the standard algorithm would propose to map to 70 and 60, and compared them with the assessor's suggestions (if offered), and then we reported to the assessor. There were many papers where we felt that the algorithm's suggestions were appropriate but they did not agree with the assessor's suggestions, so we asked the assessors whether they would be content with the algorithm (most replied that they would be). There were several papers where neither the Examiners nor the assessor thought that the algorithm worked appropriately, and in these cases the consultations with the assessors were very useful indeed. There were two papers where we set a scaling function which was significantly more generous than the assessor wished but less generous than the algorithm suggested. On all other papers, we felt that the final scaling function had the approval of the assessor.

Determination of University Standardised Marks

As in 2013/14, the examiners had more consultation with assessors than has been the general practice in the Department. In other respects, 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 $[70, 100]$, $[60, 69]$ and $[0, 59]$, 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 P2P3 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 in general and 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. At this stage the number of candidates provisionally in the First Class, and the number of candidates provisionally in the Lower Second Class or below, were both smaller than the numbers of candidates in the same field who had Part A marks in the same ranges. This effect had been observed in Part B in 2013 and 2014 in the case of Lower Seconds and below, but not in the case of the Firsts. We were advised that the same effect has been observed quite often in other examinations, and it is thought to be an instance of regression to the mean. Despite the reduction from Part A, the number of provisional Lower Seconds and below was still higher than normal. We then made a provisional change to parameters which had the effect of raising most of the USMs by one mark on all papers where we apply scaling functions. Then we considered individually the scaling of those papers which had been identified as problematic, making provisional adjustments in some cases. The full session was then adjourned to allow the external examiners to look at scripts.

The examiners reconvened and agreed to confirm the provisional change to parameters. 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 17 gives the final positions of the corners of the piecewise linear maps used to determine USMs.

At their final meeting on the following morning, 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.

Factors affecting performance

Under the new procedures, a subset of the examiners had a preliminary meeting to consider the submissions for factors affecting performance in Part B. There were no Part 12 submissions, and four Part 13 submissions which the preliminary meeting classified in bands 1, 2, 3 as appropriate. The full board of examiners considered the four cases in the final meeting, and certificates passed on by the examiners in Part A 2014 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. Details of cases in which special consideration was required are given in Section E.2.

Prizes

This was the first year that some Part B candidates had received a prize in Part A of the preceding year. The Teaching Committee had expressed a wish that the two Gibbs prizes available between Mathematics and Mathematics & Statistics should be awarded for the best performances in Part B only, and we acted accordingly. In awarding the other prizes, we took into account whether or not each candidate had got a prize in Part A, and for those candidates who had not been awarded a prize in Part A, we took account of both Part A and Part B marks.

Rules, guidance and reality

General rules and guidance about University examinations are now published in various places other than the grey book, including

(PG) *Policy and Guidance for Examiners and others involved in University Examinations*, aimed at Examiners and other members of staff (but including rules affecting students), available on the Education Committee Webpages

(UE) *University Examinations*, aimed at students and available in the Proctors Office Webpages

(SH) *Student Handbook*, also available in the Proctors Office Webpages

(EA) (a) *Examinations and Assessments*, in the section Oxford Students of the University Website, and (b) general information sent to candidates by the Exam Schools (thought to be similar to the section *Sitting your Examinations* in (a)

(NC) Notices to Candidates sent by the Examiners

(OA) An oral announcement made by the chief invigilator at the beginning of each examination.

In reality, many students, and also some tutors and assessors, are unaware of much of the guidance in (PG) and (UE) as these documents are not very prominent. Other useful things do not appear in any of these places. We give some examples here; none of the comments are specific to Part B and most of them are not specific to mathematics.

Queries in Examinations. Candidates are told in (EA), (NC) and (OA) that they may raise queries about the examination. They are also told in (EA):

> *Don't ask if you do not understand a word or phrase on the exam paper, neither examiner nor invigilator is permitted to answer*

There had been some anecdotal evidence that the number of such queries had been increasing in recent years. We drew attention to the guidance in our Notice to Candidates for Part B, and in a notice to assessors attending the examination, and we think that there were fewer such queries this year.

Candidates are told in (NC) and (OA) that an assessor will be present for the first 30 minutes (to respond to queries about errors or ambiguities). However we do not think that they are told that

(a) They may raise questions of this type after more than 30 minutes, as an assessor may still be in contact (by telephone)

(b) If they have a query which cannot be answered (for example, because the assessor is not permitted to answer or cannot be contacted), they should write in their script what the query is and how they are interpreting the question.

We **RECOMMEND** that candidates are given this guidance, in the invigilator's announcement and/or in the Notice to Candidates.

Candidates contacting assessors. Section 15.1 of (PG) states (in part)

Any complaint or query about the content, conduct, or outcome of an examination, by a candidate or their tutor should be made by the Senior Tutor, who is invited but not required to comment on the issues, and should be addressed to the Proctors. This prevents chairs and individual examiners from being lobbied or pestered in any way, and in particular ensures that no unfair advantage is given to particular candidates or groups of candidates by reason of a Senior Tutor's or tutor's acquaintance with an examiner. Examiners must on no account discuss any matter relating to individual candidates with tutors, Senior Tutors, or candidates. Any attempt at direct communication with examiners by individual candidates should be reported to the Junior Proctor, who will advise the examiners. Such communications compromise the anonymity of the examination process, and are not in candidates' interests.

There appears to be widespread ignorance of this rule amongst students and assessors. We know of 4 cases where a candidate contacted an assessor after an examination to raise some concern about the paper. We doubt that this problem is confined to Part B (although it is more likely in Parts B and C where candidates are aware that their lecturers set the exams) or even to Mathematics.

Ignorance of these rules can be excused to some extent as (PG) is not the most prominent of documents and it is not addressed to students. We suggest that the Proctors Office and Education Committee should give more publicity to the rules above (if they wish to retain them), and we **RECOMMEND** that the Mathematical Institute should consider giving publicity to it in handbooks as well as in Notices to Candidates in all four years.

Complaints after release of results. Many candidates ask their tutors if there can be a re-mark or check of scripts as they think their marks are surprisingly low. In (SH), (UE) and (EA) there is very firm guidance that the Proctors will not ask examiners to re-mark. The question of whether an administrative check of scripts will be allowed is addressed in (PG), (SH), (UE) and (EA), but the wording varies and different versions give different impressions.

In July 2014 the Junior Proctor wrote to colleges informing them that requests based on any of four typical grounds would not be allowed. One of these grounds was that one mark was lower than the others. To the best of our knowledge no amendment of the 2014 letter was announced in 2014/15, so we had assumed that the 2014 guidance still applied. However when we asked the Proctors Office why a request for a check was forwarded to us in July 2015, we were told that the current proctorial policy is that a request will be passed on if the mark on one paper is more than 10 marks below the candidate's average mark, as this is deemed to be a "very significant" difference.

This principle clearly affects Mathematics very particularly because we have a much wider range of marks than most subjects. Of 146 Part B candidates 83 (57%) had one or more Parks B marks which were more than 10 below their Part B average. In total there were 116 such marks (10% of all the marks in Part B). For comparison, only 9 of 267 candidates in FHS English had such a mark, corresponding to 3% of candidates and 0.5% of marks. Thus such a mark in Mathematics is much less significant than in English. By mid-August only two requests for a re-check of the marks had been passed on to us by the Proctors Office, so the work involved in re-checking has been very small. We could imagine that the number will become much larger in future if the current policy becomes more widely known.

Nevertheless we are concerned that the Proctors' position could be seen as implying that there are suspicions about the reliability of a very large proportion of our marks, despite all our scripts having been independently checked. We doubt that the Proctors really believe that they have very significant evidence of errors in large numbers of our marks, but that interpretation could be made, and that would be very unfair to all the people involved in the process. The Chairman has written to the Junior Proctor making these points, but no reply has been received by mid-August.

We **RECOMMEND** that the Mathematical Institute and/or the MPLS Division should discuss this matter with the Proctors before the 2016 examinations, with a view to replacing the 10-mark-below-average principle by an interpretation which takes account of the differences in mark patterns in different subjects.

We suspect that many Mathematics students are not aware that all scripts and marks are independently checked. This information is routinely included in Examiners reports, but few students read them. We **RECOMMEND** that the Examiners Second Notice to Candidates should include information about the checking of scripts and marks and the extremely low probability of a request for checks or re-marks being fruitful.

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	(13.78,37)	(24,57)	(39,72)		9	20	15
B1.2	(13.56,37)	(23.6,57)	(40.1,72)		22	24	14
B2.1	(4.14,37)	(17,57)	(32.7,72)		11	10	1
B3.1	(10.8,37)	(18.8,57)	(38.3,72)		15	22	6
B3.2	(15.74,37)	(27.4,57)	(40.9,72)		10	7	3
B3.3	(9.65,37)	(16.8,57)	(36.3,72)		12	8	2
B3.4	(12.75,37)	(22.2,57)	(40.2,72)		10	19	4
B3.5	(15.74,37)	(27.4,57)	(40.9,72)		13	14	8
B4.1	(10.69,37)	(18.6,57)	(35.1,72)		21	14	6
B4.2	(8.27,37)	(17,57)	(32,72)		19	12	5
B5.1	(12.52,37)	(21.8,57)	(41.3,72)		15	25	13
B5.2	(15.51,37)	(27,57)	(34.5,72)		14	22	9
B5.3	(20.11,37)	(35,57)	(42.5,72)		11	17	5
B5.4	(12.18,37)	(21.2,57)	(39.2,72)		10	16	4
B5.5	(12.06,37)	(21,57)	(36,72)		10	19	12
B5.6	(12.18,37)	(23.5,57)	(31.7,72)		9	15	7
B6.1	(17.58,37)	(30.6,57)	(39.6,72)		4	10	5
B6.2	(16.2,37)	(28.2,57)	(43,70)	(48,85)	4	8	5
B6.3	(9.08,37)	(15.8,57)	(35.3,72)		7	16	6
B7.1	(17.81,37)	(31,57)	(38.5,72)		10	10	5
B8.1	(10.34,37)	(18,57)	(32,72)	(2,8)	22	17	11
B8.2	(5.86,37)	(17,57)	(33,72)		9	7	2
B8.3	(18.84,37)	(32.8,57)	(43.2,70)		12	23	16
B8.4	(14.25,37)	(24.8,57)	(36.8,72)		12	17	13
B8.5	(13.21,37)	(23,57)	(38,72)		21	29	19
C2.6	(6,37)	(18,57)	(26.72)		8	8	1
C7.2	(8,37)	(21,57)	(32,72)		8	5	3
C7.3	(9,37)	(24,57)	(36,72)		2	9	2
C7.4	(21.00,37)	(33,57)	(41,72)		4	6	3
SB1	(19.19,37)	(33.4,57)	(48,70)		6	11	6
SB2a	(13.10,37)	(22.8,57)	(42.3,72)		11	16	5
SB3a	(12.06,37)	(21,57)	(36,72)		25	32	17
SB3b	(11.49,37)	(20,57)	(35,72)		10	15	6
SB4a	(18.84,37)	(32.8,57)	(43.2,70)		6	12	13
SB4b	(17.69,37)	(30.8,57)	(41.2,70)		5	9	12

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	%
90	1	1	0.68
86	2	4	2.74
85	5	6	4.11
82	7	9	6.16
81	10	10	6.85
79	11	14	9.59
78	15	16	10.96
77	17	20	13.7
76	21	22	15.07
75	23	23	15.75
74	24	33	22.6
73	34	34	23.29
72	35	38	26.03
71	39	44	30.14
70	45	49	33.56
69	50	54	36.99
68	55	61	41.78
67	62	69	47.26
66	70	78	53.42
65	79	87	59.59
64	88	95	65.07
63	96	106	72.6
62	107	111	76.03
61	112	113	77.4
60	114	117	80.14
59	118	123	84.25
58	124	128	87.67
57	129	131	89.73
56	132	135	92.47
55	136	138	94.52
54	139	139	95.21
53	140	140	95.89
52	141	141	96.58
49	142	142	97.26
48	143	143	97.95
41	144	144	98.63
40	145	145	99.32
36	146	146	100

B. Equal opportunities issues and breakdown of the results by gender

Table 4 shows the performances of candidates broken down by gender.

Table 4: Breakdown of results by gender

Class	Total		Female		Male	
	Number	%	Number	%	Number	%
I	48	32.88	7	17.07	41	39.05
II.1	69	47.22	25	60.98	44	41.9
II.2	25	17.12	8	19.51	17	16.19
III	3	2.05	1	2.44	2	1.9
P	1	0.68	0	0	1	0.95
Total	146	100	41	100	107	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	49	30.78	7.97	64.08	11.19
B1.2	63	34.11	9.12	68.25	12.89
B2.1	22	30.36	9.59	71.45	11.96
B3.1	44	32.84	9.17	69.23	12.67
B3.2	20	37.9	6.24	71.35	10.83
B3.3	22	34.41	10.72	74	15.44
B3.4	35	31.83	9.59	63.4	14.2
B3.5	37	35.14	8.63	66.76	14
B4.1	41	32.8	8.45	71.88	11.31
B4.2	36	29.19	10.42	70.16	13.76
B4.3	1	–	–	–	–
B5.1	52	32.79	8.69	66.38	10.46
B5.2	45	32.4	4.85	67.69	9.25
B5.3	34	39.65	6.21	68.47	12.5
B5.4	31	32.42	7.99	68.1	7.91
B5.5	41	28.59	6.69	64.41	8.31
B5.6	32	28.03	6.44	65	10.91
B6.1	19	35.16	4.6	65.05	8.11
B6.2	17	36.06	9.14	64.94	11.76
B6.3	29	25.28	9.88	62.52	13.98
B7.1	25	37.08	5.58	69.96	12.2
B7.1a	1	–	–	–	–
B7.2b	1	–	–	–	–
B8.1	47	24.31	7.01	62.77	11.43
B8.2	17	23.06	10.2	60.18	16.22
B8.3	44	37.14	7.29	64.48	13.41
B8.4	40	31.38	6.96	65.6	10.7
B8.5	66	31.11	7.76	65.7	10.57
BSP	12	–	–	69.42	6.26
C1.2	1	–	–	–	–
C2.6	18	20.22	11.83	58.39	21.12
C7.1b	1	–	–	–	–
C7.2	16	25.25	7.61	62.69	10.93
C7.3	12	33.33	4.52	69.33	6.44
C7.4	13	41.23	6.07	75.69	15.26
BS1	6	32.67	10.86	66	4.73
BS2a	14	37.07	5.09	69.36	7.62
BS3a	55	31.95	6.6	68.84	8.77
BS3b	15	31.93	7.69	70.4	9.88
BS4a	20	34.35	8.88	59.8	14.47
BS4b	16	32.38	8.43	58.88	13.67
BO1.1 Exam	7	–	–	64.14	9.91
BO1.1 Essay	7	–	–	70.71	10.12
BN1.2 7 8	–	–	66.38	14.02	
BEE	5	–	–	–	–
OCS1	4	–	–	–	–
OCS2	4	–	–	–	–
N102	1	–	–	–	–
N122	1	–	–	–	–
N127	1	–	–	–	–

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	16.2	16.2	4.05	46	0
Q2	12.6	13.6	6.20	27	3
Q3	14.6	15.9	6.12	25	3

Paper B1.2: Set Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	16.5	16.6	4.51	34	1
Q2	17.7	18.0	5.90	51	1
Q3	16.0	16.2	4.74	41	1

Paper B2.1: Introduction to Representation Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	13.5	13.5	5.09	17	0
Q2	14.8	15.1	6.14	19	1
Q3	17.6	19.1	5.64	8	2

Paper B3.1: Galois Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.3	17.3	5.12	43	0
Q2	11.9	15.3	7.36	12	5
Q3	15.1	15.7	5.49	33	3

Paper B3.2: Geometry of Surfaces

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.7	15.7	4.53	13	1
Q2	20.6	20.6	3.07	16	0
Q3	18.7	20.4	4.63	11	2

Paper B3.3: Algebraic Curves

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18.6	19.3	6.75	15	1
Q2	16.3	16.3	5.89	19	0
Q3	14.8	15.7	4.75	10	1

Paper B3.4: Algebraic Number Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.3	15.3	5.44	20	0
Q2	15.4	15.7	5.27	22	1
Q3	16.9	17.2	4.59	27	1

Paper B3.5: Topology and Groups

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.7	14.7	6.12	26	0
Q2	19.9	19.9	4.69	35	0
Q3	16.2	17.2	3.67	13	2

Paper B4.1: Banach Spaces

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.5	15.5	4.18	33	0
Q2	17.4	17.4	4.92	36	0
Q3	14.4	15.7	5.97	13	3

Paper B4.2: Hilbert Spaces

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.9	15.9	4.15	35	0
Q2	12.5	13.0	7.73	21	1
Q3	10.9	13.8	8.86	16	5

Paper B5.1: Techniques of Applied Mathematics

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.6	14.8	5.00	45	1
Q2	17.5	17.4	4.64	45	1
Q3	16.6	18.2	6.83	14	2

Paper B5.2: Applied PDEs

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	19.1	19.1	3.05	44	0
Q2	13.7	14.3	3.48	22	1
Q3	12.2	12.6	4.07	24	2

Paper B5.3: Viscous Flow

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.9	18.3	3.03	22	1
Q2	21.1	21.1	4.79	30	0
Q3	19.6	19.6	2.28	16	0

Paper B5.4: Waves and Compressible Flow

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.7	18.5	5.56	21	1
Q2	14.3	14.3	5.40	25	0
Q3	15.22	16.19	4.77	16	2

Paper B5.5: Mathematical Ecology and Biology

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	11.6	12.2	4.75	27	3
Q2	16.2	16.2	3.13	40	0
Q3	10.6	13.1	6.53	15	5

Paper B5.6: Nonlinear Systems

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	13.7	14.4	5.56	25	2
Q2	15.7	16.9	5.47	11	1
Q3	12.3	12.5	3.96	28	1

Paper B6.1: Numerical Solution of Differential Equations I

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.6	17.9	2.57	18	1
Q2	16.6	17.9	5.04	16	2
Q3	12.2	15.0	6.76	4	1

Paper B6.2: Numerical Solution of Differential Equations II

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	19.2	19.2	3.53	13	0
Q2	14.7	14.7	5.31	10	0
Q3	18.2	19.7	8.32	11	1

Paper B6.3: Integer Programming

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	11.7	11.7	6.92	24	0
Q2	10 6	15.5	7.53	8	5
Q3	12.6	12.6	5.33	26	1

Paper B7.1: Classical Mechanics

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.5	17.9	4.08	21	1
Q2	15.9	18.3	6.67	12	2
Q3	19.6	19.6	3.66	17	0

Paper B8.1: Martingales through Measure Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.5	12.7	4.12	37	1
Q2	11.0	11.0	4.05	43	1
Q3	12.3	13.6	5.27	14	2

Paper B8.2: Continuous Martingales and Stochastic Calculus

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	11.9	12.5	6.20	15	1
Q2	11.3	11.3	6.15	6	0
Q3	10.0	10.5	5.35	13	1

Paper B8.3: Mathematical Models of Financial Derivatives

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	20.9	21.3	4.11	40	1
Q2	13.7	14.7	5.65	29	4
Q3	18.8	18.8	5.78	19	0

Paper B8.4: Communication Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	17.3	17.3	3.80	40	0
Q2	6.5	8.3	2.93	3	5
Q3	14.5	14.5	4.54	37	0

Paper B8.5: Graph Theory

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	14.8	14.8	3.59	54	0
Q2	15.5	15.5	5.14	56	0
Q3	16.0	17.7	6.05	22	3

Paper SB1: Applied Statistics

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.3	15.3	1.15	3	0
Q2	11.5	11.5	2.12	2	0
Q3	10	10		1	0
Q4	15.7	15.7	4.62	3	0

Paper SB2a: Foundations of Statistical Inference

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	20.2	20.2	2.81	14	0
Q2	16.9	16.9	4.02	14	0

Paper SB3a: Applied Probability

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.0	15.4	4.21	45	2
Q2	17.2	17.4	3.66	53	1
Q3	10.7	11.9	4.22	12	3

Paper SB3b: Statistical Lifetime-Models

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	15.6	15.6	4.72	13	0
Q2	17.5	17.5	3.03	14	0
Q3	9.5	10.3	3.00	3	1

Paper SB4a: Actuarial Science I

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	18.1	18.1	4.62	19	0
Q2	16.1	16.7	5.80	18	1
Q3	8.6	14.3	10.23	3	2

Paper SB4b: Actuarial Science II

Question	Mean Mark		Std Dev	Number of attempts	
	All	Used		Used	Unused
Q1	12.3	12.8	5.69	10	1
Q2	18.0	18.0	3.95	15	0
Q3	15.1	17.1	5.21	7	2

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 have also been removed.

B1.1: Logic

Question 1: Almost all candidates took this question which, though only about propositional calculus, proved rather challenging to them. The weaker candidate struggled to find the somewhat unexpected negative answer to part (a)(iii). In part (b)(ii), even stronger candidates lost themselves in an induction on formula complexity where simply listing the 16 formulas in at most 2 propositional variables (up to equivalence) would have worked more easily. Only 2 candidates gained full marks.

Question 2: A third of the candidates had difficulties with the derivations in (b). Most candidates had the correct intuition for the positive answer to part (c), but only very few gave a vigorous proof. Again only 2 candidates scored 100%

Question 3: had a quarter very poor solutions and a quarter very good ones (again with just 2 got 25 out of 25 marks). Most candidates got a wrong answer for part (c), showing considerable creativity in producing a formula which separates among finite models those of even cardinality from those of odd cardinality where, with some good thought, it is clear that no such formula can exits.

B1.2: Set Theory

Question 1. Part (a) was very well done, and nearly everyone could correctly state CSB in (b)(i). Part (ii) was very poorly done, and part (iii) troubled many. Surprising how many simply could not correctly manipulate iterated cardinal exponentiation. Part (c) was generally well done, by replacement over well-orders of ω. Quite a few gave a nicer solution starting with the existence (by Hartogs Theorem) of an uncountable ordinal.

Students seemed to make unnecessarily hard work of (iii).

Question 2. (a) (i) and (ii) were well done, as were the pure bookwork (b) (i) and (c) (i). Many made hard work of (b) (ii), and definitions and recursions were often poorly articulated. Part (b) (iii) was also made too hard work by many. Many saw how to do (c) (ii), though quite a few offered fallacious proofs.

Question 3. Part (a) was generally well done. Many saw how to reduce (i) to the standard ordered pair, others repeated the argument that the usual ordered pair works, which is laborious but fine. Most saw that (ii) fails. Many also worked through (iii) correctly, a few saw that this too can be reduced to the standard ordered pair, as from $\{P(\{x\}), P(\{x, y\})\}$ one recovers $\{\{x\}, \{x, y\}\}$. Part (b)(i) was very well done. As for (ii), proving that $WO(X)$ is a set was generally well done. Few managed the second part, even though variants of this problem are on the problem sets and past papers. Part (c) (i) was generally well done. For (ii), many offered a solid solution by recursion, while quite a few saw there was an easy solution (take $x = 0$). Quite a few got into confusion, perhaps due to running out of time.

B2.1: Introduction to Representation Theory

Question 1: A popular question. Part (c) was solved completely only by 1 candidate. Surprisingly few correct answers to (d) which is based on a question from a problem sheet.

Question 2: Parts (a) and (b) were answered well by many candidates. In (c) a common mistake was to assume the a complement to B must be the subspace of diagonal matrices.

Question 3: The least popular question, which seems also the one with shortest solutions. A common error in (d) was to claim that $g \to p(g^{-1})$ is a representation of G.

B3.1: Galois Theory

Question 1: This was the most popular question and there were several excellent solutions. The majority of the problems where in parts (c)(iii) and (c)(iv) where some students seemed to be confused about how to use the fundamental theorem of Galois theory in this particular example.

Question 2: This was the least popular question. Maybe this question was unpopular because is not similar to other past exam questions, however the setter thinks it was not particularly hard. Most of the marks lost were in parts (c), there where also excellent attempts. There was a minor error in part (c)(i) of the question: where it says "for some *positive* integer n", it should have said "for some *non-negative* integer n".

Question 3: There was a good number of good attempts to this question with a few excellent ones, on a question that was not particularly easy. Most of the marks in this question were lost by mistakes when computing the Galois groups in part (c) and (d). Some students were able to quote the correct general facts about cyclotomic or Kummer extension but then were confused when applying them to the example in the question.

B3.2: Geometry of Surfaces

Question 1(a) and 2(a), (b) went very well. Almost nobody did Question 1(b) even though it was bookwork. Question 2(c) required some care, many candidates did not explain how the six copies were to be glued or glued them incorrectly. Four out of 20 candidates got near perfect scores (90%+) Ten out of 20 candidates got very high scores (80%+)

B3.3 Algebraic Curves

Question 1. A surprising number of people failed to plot the hyperbola correctly, even though this is essentially an A-level question.

Question 2. A relatively common mistake was not to include the "without common component" clause in the statement of Bezout's theorem. Another source of problems was to fail to spot correctly the "easy" flexes of the curve in (c) which makes (d) very hard (partial credit was given for explaining the procedure without carrying it through correctly).

Question 3. Common mistakes included a coherent explanation of how the group structure arises, and what its properties are, given the map ϕ; identifying the correct geometric procedure to get $2p$ from p; and calculational mistakes in (b)(iii).

B3.4: Algebraic Number Theory

All 3 questions were answered to a similar standard on average, and similar numbers of candidates answered each question.

In Question 1, most candidates did well on (a),(b),(c)(i)(ii), but some had trouble with the congruence manipulations in (c)(iii)(iv).

In Question 2, many had the right broad ideas for (c)(ii)(iii), but didn't all provide complete justifications.

Question 3 included a harder than average class group computation; most candidates made a strong attempt (with some getting it out completely); several candidates took the wrong generator, and ended up with C_4 or C_2, rather than the correct answer of C_8.

B3.5 Topology and Groups

Question 1. This question, on homotopy, fundamental groups and fixed points, proved quite popular. The bookwork at the beginning was generally done well. Candidates performance on the question about retractions and the Brouwer fixed point property was rather mixed, although this example had been seen in a problem sheet. The part about the Fixed Point Property being a homeomorphism invariant and the open disc not having this property was well done on the whole. Quite a few candidates managed the first part of part (c), about maps of the sphere. The last part, about selfmaps of odd-dimensional spheres, proved more challenging but a few candidates got the right idea by using the embedding in $\mathbb{C}^n$.

Question 2. This question, on group presentations and the non-Hopfian Baumslag- Solitar group, was very popular. Almost all candidates attempted it and most did well, with some essentially perfect solutions. Overall, most candidates showed they had a very good understanding of group presentations and how to work with them in concrete situations. Candidates mostly showed a very good understanding of the bookwork. Most were also able to apply this successfully to show that the given map induced a homomorphism from the group to itself, and to show that it was surjective. The last part, showing that the homomorphism was not injective, proved more difficult but quite a few candidates managed it. Several people made the mistake of giving a word that was product of conjugates of powers of the relator.

Question 3. This question, on covering spaces, was the least popular but still received 20 attempts (out of 52). The bookwork (part (a)) was generally very well done. In part (b) most candidates gave a good explanation for how to derive the fundamental group of real projective space. The 1-dimensional case created slightly more problems. Part (c) proved more challenging. Quite a few people were able to use the criterion of part (a) and prove a lift existed, and many realised that a map from S^n to S^1 with the given property induced a map of projective spaces. No-one was quite able to put all the ingredients together and use a uniqueness of lifts argument to prove the final result, though a couple of candidates made good progress towards this.

B4.1: Banach Spaces

Question 1. The bookwork part was done generally well. In part (c) many candidates forgot the special case of $p = \infty$. Several candidates noticed that (d)(iii) implies (d)(ii). The standard mistake in (d)(iii) was to show that the truncated series converges to the full series in a larger space and since the full series is not in l^2, the sequences does not converge in l^2. One also has to show that there are no other possible limits.

Question 2. This was the most popular question with the highest average mark. In part (c) surprisingly many candidates gave an example which is not linear or not a functional at all. In part (d)(iv) many candidates tried to use $K = X\backslash N \cup \{0\}$ which is not a vector space.

Question 3. This was the least popular problem. It was possible to get quite a few marks by knowing the definitions and some very basic properties. Two main mistakes were: showing that the main candidate for an inverse operator does not work and claiming that there is no inverse and forgetting to check that the linear operator should be bounded.

B4.2: Hilbert Spaces

Question 1

This was attempted by almost all candidates, who were enticed, no doubt, by the invitation to prove the Closest Point Theorem from early in the course. Part (b) was new, but simple for those who realised they should use the reverse triangle inequality for the norm; those who did not spot this got in a mess. As anticipated (and intended), part (c)(i) contained components which were challenging. Few candidates appreciated that they needed to show that the limit defining $f(x)$ existed; some were alert to well-definedness but confused this with f being bounded. Many attempts to get a lower bound for $\|f\|$ proceeded by plugging in x_n (or x_m) for x and then fudging. In (c)(ii) virtually all saw how to put the ingredients together to get the conclusion. However not all appreciated that they had to prove that $\|x_n - y_0\| \to 0$ and not all who did realise this were able to supply a proof.

Question 2

Part (a) caused few problems: almost all candidates recognised that they needed to prove and apply the Uniform Boundedness Theorem or alternatively to specialise its proof. It was disappointing that more than one statement of the Baire Category Theorem omitted to indicate the class of spaces for which its conclusion holds.

Part (b) was new. Those who in (i) sought to apply (a) by first using the definition of the adjoint had no problems. Curiously, a number converted $\|T^*y\| = 1$ to $\langle T^*y, T^*y\rangle = 1$ before bringing in T—not a good move. The condition in (b)(i) should have sent a clear signal that the right strategy in (ii) was to use (i) to prove T^* invertible (invertibility of operators was thoroughly covered in lectures, including the relevance, albeit in a rescaled form, of the condition from (i)). Rather few candidates picked this up.

Part (c) (covered in a problem sheet) caused good candidates no problems.

Question 3

This question attracted both strong and weak answers, and very few mid-range marks were awarded.

The handling of infinite series and of limits by the weaker candidates was conspicuously poor. In (a), all too often infinite sums were written down which were not yet known to converge. Some found it difficult to prove Parseval's formula correctly without being given the stepping stones which lectures provided.

In (b)(i), the more capable candidates realised that they should set up an isometric isomorphism with ℓ^2, whence it is immediate that the Hardy space is a Hilbert space. Those who got a map into ℓ^2 but didn't then try to prove that it was surjective got into difficulties.

Part (b)(ii) was done relatively badly, despite appearing on a problem sheet. Many candidates showed a poor grasp of results from complex analysis, failed to handle limiting processes correctly, or mangled inequalities.

Part (b)(iii) (reproducing kernel) was new. Conversion to a problem in ℓ^2 was perhaps the slickest method. This rider was solved confidently by some. Others did not know how to start.

B4.3: Dynamics and Energy Minimization

Question 1: This question test basic materials of the course and their application to ODE.

Question 2: This question tests basic knowledge about weak derivatives in 1-dimension and some simple applications to 1-d variational problems.

Question 3: This question tests basic understanding of the heat flow in 1-d.

B5.1: Techniques of Applied Mathematics

Question 1: Attempted by most candidates. Part (a) caused the most trouble - people generally had the right idea, but got bogged down in inefficient computation. Parts (b) and (c) were largely hit or miss.

Question 2: Parts (a) and (b) were well handled on average. Part (c) (ii) gave the most trouble, few candidates seeing how to formulate the 1st order ODE from the degenerate kernel and then solve to obtain an ansatz for eigenfunctions.

Question 3: Attempted by few candidates, but done well by those who did. Some people were not clear on boundary conditions and the "natural domain" in (a). Part (c) was approached in a variety of ways but with good success.

B5.2: Applied PDEs

Question 1 was done well by most candidates: they were able to reproduce the bookwork and apply Charpit's Equations to an unseen example.

Question 2 & 3 were more demanding. While most candidates were able to complete the first part of each question, few were able to apply the relevant theory.

Question 2 was particularly challenging, with no candidates completing part (c) and many not realising how to apply the theory from the earlier part of the question.

Question 3, while challenging, was tackled better, although few students completed part (c) and there were many algebraic errors in identifying the correct similarity transformation.

B5.3: Viscous Flow

1. Question 1. The book work aspects of this question were very well done.

    - Some candidates gave the boundary conditions for v at a and b to be Ω_1 and Ω_2 respectively (rather than $\Omega_1 a$ and $\Omega_2 b$).
    - The majority of candidates were unable to compute the torque per unit length (in the axial direction) exerted on the inner wall at $r = a$.
    - Most candidates did not make the connection that if the flow is steady, the left hand side of equation (2) (see paper) is zero, and thus the torque per unit length exerted on the outer wall must be equal and opposite to the torque per unit length exerted on the inner wall.

2. Question 2. This question was attempted by the majority of candidates, and was very well done.

    - In 2(a) some candidates did not give the correct reasoning for $p_x = 0$ in the boundary layer equations.
    - A few candidates were unable to sketch the boundary layer thickness as a function of α.

3. Question 3. This was the least popular question, but was in general well done. Some students were unable to state what the physical significance of Q was, and very few candidates were able to complete part (d).

B5.4: Waves and Compressible Flow

The take-up of the 3 questions was fairly even, as was the spread of marks on each one.

Q1: Part (a) was generally very well done, although many candidates had algebraic confusions between square roots and fourth roots, and some simply assumed that the solution was trigonometric without using all the boundary conditions. Part (b) was well done and most candidates achieved full marks. Part (c) was a straightforward application of the method of stationary phase, and the main difficulty was found to be evaluating the phase at the stationary value, for which algebraic mistakes were frequent.

Q2: The most popular question. Many candidates failed to notice the request in part (a) to find an expression for the pressure in terms of the velocity potential, which would have helped them in part (c). The derivation of the linearised equation and boundary conditions for the velocity potential was generally well done (though often not presented at all well). The distinction between the appropriate boundary conditions for the elliptic and hyperbolic equations was rather poor (a surprising number of candidates classified them the wrong way around). Part (b) was quite well done. While a number of candidates managed to calculate the expression for the drag, no one achieved full marks on part (c).

Q3: Everyone who attempted this question got the marks for part (a). Part (b) was identical to a question on the problem sheets, but the majority of candidates got lost in the algebra trying to arrive at the expression for the shock velocity. Many such candidates then gave up on sketching the density, which was rather disappointing. Part (c) was generally well done, with solid reasoning for the structure of the characteristic diagram with an expansion fan. The resulting sketches of the sound speed were quite well done, but no-one appreciated the fact that $x = L$ would remain inside the expansion fan forever in the last part (a common misconception was that a vacuum would form in this case, which does not happen until U is somewhat larger still).

B5.5: Mathematical Ecology and Biology

Question 1: There was a typographical error in (c)(ii) where the "t" should have read "τ". In all the answers, candidates did indeed read it as τ. There was also a mistake in (c)(i), where $\cos^{-1}(\frac{-A}{B})$ should have been $\cos^{-1}(\frac{A}{B})$.

Part (a): Many candidates said that the 2nd term on the RHS modelled a delay but failed to say from where this delay came.

Part (b) (iii) To fully answer this question candidates needed to show that the steady state was linearly stable for $\tau = 0$ but a number of candidates did not do this.

Part (c)(ii) This part was done badly by everyone and the reason why no one scored highly on this question. What it boiled down to was that most candidates did not know how to compute $\frac{dexp(f(\tau))}{d\tau}$ where $f(\tau)$ is the product $\lambda(\tau)\tau$.

Question 2: Very good answers up to (c)(ii) but for (c)(iii) most candidates did not realise the significance of the condition $b > a$, which made the nullclines intersect in a certain way. Virtually all candidates got this wrong. As a result, most did not get very far with (d) and (e).

Question 3: Many candidates struggled with explaining that there was a density-dependent chemotaxis term and this also caused problems with linearisation and also with correctly stating the boundary conditions. As this was not the standard diffusion-driven instability problem, most candidates struggled on (b) and (c).

B5.6: Nonlinear Systems

Question 1: Popular question. Part (a) Well done. Part (b) Many students didn't explain the method of averaging. Others got the integrals wrong. Part (c)(i) Some students had trouble with showing $\dot{x} = y - fF(x)$. Part(c)(ii) About half the students attempting this got it out, fewer got the correct period.

Question 2: Least popular. Part (a) Straightforward but some student also included Hopf bifurcation, when the question said 1-D eqn. Part (b) Some students didn't prove 'abstracting' part. Part (c)(i) Fine. Part (c)(ii) Some nice procedures. Part (c)(iii) More labelling on squares and their extensions would have been good.

Question 3: Part (a)(i) Most popular question. Most students found all 3 equilibria, but had trouble with the 3rd $(x_e, y_e), y_e \neq 0$ equilibrium's linear stability analysis. Part (a)(ii) Most answered correctly. Part (b) Nearly everyone knew the statement for the Poincaré-Bendixson theorem. Part (i) Fine (ii) Many had problems converting from cartesian to polar coordinates. Part (iii) Fine, on the whole. Part (iv) Fine.

B6.1: Numerical Solution of Differential Equations I

Question 1: Parts (a)-(c) uniformly well done. Only a couple approached the problem part of (d) although many understood A stability and gained partial marks.

Question 2: Surprisingly only a few gave correct answers for part (a), parts (b) and (c) well done by most, and many good attempts for part (d).

Question 3: Only a few attempts, bookwork parts (a)-(c) had some good work, the difficult unseen part (c) had two excellent attempts.

B6.2: Numerical Solution of Differential Equations II

Question 1: generally solved well with part (c) resulting in most points lost.

Question 2: forming the finite difference matrix precisely caused some difficulty as did the Tylor series in parts (b) and (c). Maximum principle well solved.

Question 3: part (a) e-values often only bounded rather than determined precisely. SOR and shooting in parts (b) and (c) respectively well solved.

B6.3: Integer Programming

The exam produced a good distribution of marks across all three questions, as well as in overall terms. Question 1 and Question 3 saw the largest uptake.

Even though Question 1 contained more book work than the other two questions, the unseen part was somewhat more challenging, leading to 21 as the highest mark achieved (there were several candidates who earned full marks on the unseen part but lost points on other parts). The lowest mark achieved was 1.

Question 2 was avoided by many students, even though those who attempted it achieved slightly higher marks than average. The highest mark achieved was 23, and the lowest was 3.

Question 3 was again similar to Question 1 in distribution and uptake, but with somewhat less book work. The highest mark achieved was 22, and the lowest was 1.

There were a few candidates who scored very low marks and showed no substantive understanding of the course even in straightforward book work questions. The highest overall mark achieved was 43, and the lowest was 6.

B7.1: Classical Mechanics

Question 1: Lagrangian mechanics. Part (a) required the candidates to explain how to determine the normal frequencies and normal modes for a point of stable equilibrium for a general Lagrangian system (which is bookwork). A surprisingly large number of candidates forgot that the kinetic term T_{ab} depends on the generalised coordinates. Otherwise answers to part (a) were generally of a high standard. Part (b) required the application of part (a) to a simple spring pendulum. Many candidates were able to derive the correct Lagrangian (with occasional computational errors, especially signs in the potential energy). Part (ii) was generally less well answered. Many candidates didn't correctly expand to quadratic order around the stable equilibrium point, and some forgot to describe the normal mode motion.

Question 2: rigid body dynamics. Parts (a) and (b) required candidates to derive the kinetic energy of an axisymmetric rigid body, in terms of Euler angles. This is bookwork. Most answers were generally of a high standard. Part (c) required candidates to derive the principal inertia for a thin uniform disk, which was a worked example in the lecture notes (but was not covered in the lectures themselves). Again, answers were largely complete. Many candidates did much less well in part (d). There were some very muddled answers to part (i), and (with a couple of exceptions) very few candidates got near to the end of part (ii). (This result was famously worked out by Feynman.)

Question 3: Hamilton mechanics, specifically focussing on Poisson brackets. Parts (a) and (b) are bookwork, and were well answered. Part (c) required candidates to compute a number of Poisson bracket relations for an $n-$dimensional harmonic oscillator. The computations increase in difficulty, and only a few correctly derived the last Poisson bracket relation between angular momentum and the Fradkin tensor F_{ab}. A few candidates noticed that the Hamiltonian is 1/2 the trace of F_{ab} (which wasn't necessary to answer the question). Having noticed that, they might also have noticed then that $\{L_{ab}, H\} = 0$ is a simple corollary of the last relation.

B8.1: Martingales Through Measure Theory

This paper was with hindsight on the difficult side. Not that the questions seem unfair, but they are a little difficult and quite long.

Question 1: part (a) was fine for most people. (b) is a standard proof from the notes, but not that many candidates managed it. The first part of (c) relates to material covered on the problem sheets; again the attempts here were disappointing. The rest was a bit tricky.

Question 2: part (a) is very standard bookwork. Most solutions were good. Part (b) is a variant of an argument covered in lectures and on the problem sheets. The extension is slightly tricky, but a candidate who gave the argument in lectures could obtain a fair number of marks. All presentations of the martingales were informal to at least some extent. For (c) there were no complete answers, but some partial ones.

Question 3: not many candidates attempted this, perhaps because it is on material from near the end of the lectures. Those that did generally managed well. Part (b) was harder than intended (depending exactly what you allow yourself to assume), since it does not say that X and Y are non-negative. This didn't cause a problem in practice: full marks were given for solutions that did assume this, or if the candidate noticed the problem and made any reasonable attempt at a solution.

B8.2: Continuous Martingales and Stochastic Calculus

Question 1. Almost all candidates attempted this question and the standard of answers was good overall. Very few candidates managed to answer correctly the last part (c). Often candidates forgot to check the integrability condition for a martingale or made computational errors when computing $\mathbb{E}[(M^\lambda, M^\lambda)_+]$.

Question 2. About 40% of candidates attempted this question and the standard of answers was good overall except for a few scripts where only small comments were made. Candidates typically wrote long, instead of brief, answers to "how is Z_t defined in (b). Last part of part (c) was rarely answered correctly.

Question 3. Over 2/3 of candidates attempted this question and the standard of answers was lower than for questions 1 and 2 but decent. Some students tried to prove τ_a and ρ_a were stopping times instead of quoting standard results. Many missed the correct reasoning in (b) even though this was bookwork (see problem sheets). Some used Itô's formula incorrectly or without justifying why certain terms are 0, or made silly computational errors. Many did not give proper arguments when computing $\mathbb{E}[\tau_a^2]$ despite similar arguments being bookwork. Part (d) required more insight and very few thought if Y and Z were right- or left- continuous.

B8.3: Mathematical Models of Financial Derivatives

Question 1. This was the most popular question. Nearly all candidates attempted it. It was invariably done very well. The marks were extremely high. The question did not stretch candidates. Part (c), for instance, was very straightforward (in essence only a numerical substitution into a given formula). Part (d) was a standard binomial American option problem with no path-dependence. Part (e) had a minor path dependence structure, but again this troubled few if any candidates.

An error that did appear on some occasions was that some candidates, though they did check for early exercise in part (d), then used the hold value of the option for the next backwards iteration step, even when this was less than the exercise value. A few candidates did not properly justify the no-arbitrage (NA) condition in part (a), just stating that the risk-neutral probability lying in (0, 1) was sufficient, but of course while this is equivalent to NA, one was asked to show that violation of this condition did indeed lead to arbitrage, using a simple one-step strategy. One candidate forgot that the NA inequalities had to be strict.

Question 2. This was the next most popular question, but was the least well answered. Nearly all candidates failed to produce a clean and correct treatment of the computation in part (d). Some candidates failed to follow instructions and use the PDE approach along with part (a) in order to obtain the result in part (c). This was a non-conventional proof, so it tricked candidates who did not invoke the idea that $V(S, t) := S$ clearly solves the BS PDE. All candidates' use of Itô's formula did not distinguish carefully between a process X_t and an associated function $V(S, t)$, where $X_t = e^{r(T-t)}V(S_t, t)$, and also did not point out that functions are evaluated at random values of their arguments when applying the Itô rule. This was not penalised, as it was apparent that candidates had been given the approach used in the scripts in lectures.

Question 3. A slightly less popular question, but one that was done very well. It required, in large part, identical or very similar arguments to those seen in lectures and problem sheets.

B8.4: Communication Theory

Question 1: This question was attempted by all candidates. Part (a) was designed to be easy but many students struggled with using concavity to prove inequality. Parts (b) and (c) were relatively straightforward for the majority of students. Part (d) which is worth 10 marks was a real test for the students. While it was related to known material it required original thinking. Only the very strongest students got all 10 marks.

Question 2: This question was very unpopular, attempted by less than 20% of the students. Even though its subject, Shannan's channel coding theorem, is central to the course, students did not anticipate that it would occur on the exam. More specifically, the question required a proof of the converse to the channel coding theorem. The proof is not very hard. It is clear the students decided to revise other aspects of the course.

Question 3: Almost all students attempted this question. The difficulty of the parts increases gradually. Most students did at least moderately well on parts (a) and (b). Part (c) was answered well by a large number (around half) of the students. Part (d), which has a short neat answer if you can spot it, was only successfully answered by two or three students.

B8.5: Graph Theory

Questions 1 and 2 were the most popular. Question 1 was mostly reasonably well done, though almost all answers had minor mistakes (in various different places). Only one candidate gave the intended solution to the last part (contract all negative cost edges, which must be included, then the apply usual algorithm); others gave algorithms that also work but mostly without justification.

Question 2 with hindsight this question was a bit on the easy side, apart from (b) which could have been awarded more marks. Some failures of exam technique (going into much too much detail on subparts of (b), and not enough on the main part of (a)). Many candidates spotted that (as intended) (b) and (c) combine to give quick answers to most of (d).

Question 3 was the least popular, but those that did attempt it mostly scored well. The start is quite tricky bookwork; perhaps not so many candidates knew it. The very last part was quite hard, with only a few candidates finding a counterexample.

BSP: Structured Projects

Assessment for this course is in three parts: a project completed at the end of HT (75%), a peer review completed over the Easter vacation (10%) and a presentation given at the start of TT (15%).

This year students were offered a choice of five topics: mathematical finance (chosen by 5), thermohaline circulation (1), CSF infusion test (2), diffusion limited aggregation (3) and reaction-diffusion equations (2).

Written projects and peer reviews were double-marked by two assessors, a different pair for each topic. Oral assessments were also double-marked, by a different pair of assessors. The standard of the oral presentations was high and often excellent.

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 paper consisted of two halves, which carry equal weights. In section A ('extracts'), the candidates were invited to comment upon the context, content and significance of two samples of historical mathematics (from a choice of six). Out of nine candidates, three people answered each of questions 1, 4 and 5; two people answered question 3, whilst no one answered question 2. Question 6 was the most popular question by far, with seven people having answered this one.

The popularity of question 1, on Torricelli's trumpet, was a little surprising, given that Torricelli's work appeared only briefly in one lecture. An explanation might be found in the fact that variations on this particular question, involving 'indivisibles', have appeared on several past papers, and so the candidates had probably had much practice at questions similar to this one. The even greater popularity of question 6 probably stems from a similar source. Similar factors again probably explain the unpopularity of question 2, on Mersenne and perfect numbers: like Torricelli, Mersenne appeared only briefly in one lecture, but there has not been a question like this on any past paper. Moreover, although we did cover the necessary mathematics in the lecture, number theory is of course only a Part A short option that not all (or any) of the candidates will have taken they were therefore probably less comfortable with this material.

There was great variation in the quality of the answers to the questions from the first section of the paper; some were a bit muddled. In many cases, it was necessary to mark an answer down not because of the poor quality of what was there, but because of the omission of certain important points that ought to have been there. The organisation of answers into 'context', 'content' and 'significance' was generally good, although in a couple of instances, candidates took too broad a view and failed adequately to link their writings on 'significance' to the specific extract under study.

In section B of the paper, candidates were invited to write an essay, taken from a choice of three. In this case, question 8 attracted six responses, and question 9 three; no candidate attempted question 7. The latter was a type of question that has appeared in many past papers: describe and assess the contributions of mathematician X to the development of mathematics. In previous years, this has been a figure such as Newton, Euler or Lagrange, whose work was the sole (or near-sole) focus of at least one lecture. This year, however, the subjects were Jacob and Johann Bernoulli, whose work, whilst certainly featuring in the course, was not concentrated in a single lecture, but scattered throughout several. This was therefore a challenging question, which required candidates to pull knowledge from a cross-section of the lecture course. It is therefore not so surprising that no one attempted it. Similar reasoning may also explain the relative unpopularity of question 9: the material necessary to answer this question was also scattered throughout the course, but was perhaps a little more clearly sign-posted than that on the Bernoullis. In connection with this question, it should also be noted that some candidates displayed an imperfect understanding or a lack of historical sensitivity.

The popularity of question 8 probably stemmed from the fact that much of the necessary material was concentrated in a single lecture, and so was probably quite easily linked together by the candidates to form an answer. Responses to this question were generally done well, although some of them suffered from problems similar to those of some answers from section A: what was there was good, but important points were missing. There were opportunities in answering this question for candidates to pull in knowledge gained during the HT reading course, but this was sometimes done at the expense of other, more relevant, points.

To turn to the extended coursework essays, the standard of these varied considerably. All the essays displayed some level of understanding of the material, though some were of course better than others. What varied perhaps more dramatically from essay to essay was the presentation: some were very well structured, whilst others were quite muddled, which tended to obscure the points that their authors were trying to make. The range of sources used whilst researching the essays was quite broad, with several candidates using materials that they had evidently found for themselves. These sources were used well in most cases, although a couple of candidates were too reliant on secondary sources: resulting in an essay that was rather more descriptive than analytic, and so did not contain enough of the candidate's own ideas. The accuracy and style of citation of sources was poor in some cases disappointingly so, given the haranguing over proper referencing that the students were subject to during the course.

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 Teachers Report (15%)

The Journal and Report were double-marked. There was a sole assessor for the Presentation. Each part was awarded a USM, and then an overall USM has been allocated according to the weightings above. There were 8 students on the course this year, which is slightly lower than in recent years. It is hoped that the re-introduction of the BN1.1 course next year will see an increase in numbers opting for both courses. All students engaged well with the practical aspects of the course leading to quite a few first class marks being awarded in these areas. Most candidates were able to evaluate these experiences critically in writing, leading to the vast majority gaining high 2.1 marks overall. It is anticipated that with all candidates for the BN1.2 course next year having previously followed the BN1.1 course there will be greater opportunity to develop all candidates reflective writing.

Statistics Options

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

SB1 Applied Statistics

SB2a: Foundations of Statistical Inference

SB3a: Applied Probability

SB3b: Statistical Lifetime Models

SB4a: Actuarial Science I

SB4b: Actuarial Science II

Computer Science Options

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

OCS1: Lambda Calculus & Types

OCS2: Computational Complexity

Philosophy Options

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

102: Knowledge and Reality

122: Philosophy of Mathematics

127: Philosophical Logic

E. Comments on performance of identifiable individuals

Removed from pubic version of report

F. Names of members of the Board of Examiners

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  Prof. Raphael Hauser
  Prof. Des Higham (External)
  Prof. Nigel Hitchin
  Prof Dominic Joyce
  Dr. Neil Laws
  Prof. Mason Porter
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- **Assessors:**
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