Examiners' Report: Final Honour School of Mathematical and Theoretical Physics Part C and MSc in Mathematical and Theoretical Physics Trinity Term 2018

November 2, 2018

Part I

A. STATISTICS

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

  See Table 1.

	Numbers			Percentages %		
	2018	(2017)	(2016)	2018	(2017)	(2016)
Distinction	25	(31)	(18)	59.52	(76)	(85.71)
Pass	17	(10)	(3)	40.48	(24)	(14.29)
Fail	0	(0)	(0)	0	(0)	(0)
Total	42	(41)	(21)	100	(100)	(100)

Table 1: Numbers and percentages in each class

- **Numbers of vivas and effects of vivas on classes of result.**
  No vivas were held.

- **Marking of scripts.**
  All dissertations and mini-projects were double-marked, after which the two markers consulted in order to agree a mark between them.

All written examinations and take-home exams were single-marked according to carefully checked model solutions and a pre-defined marking scheme which was closely adhered to. A comprehensive independent checking procedure is also followed.

B. New examining methods and procedures

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

None.

D. Notice of examination conventions for candidates

Notices to candidates were sent on: 5 October 2017 (first notice), 7 November 2017 (second notice), 16 February 2018 (third notice) and the 2 May 2018 (final notice).

The examination conventions for 2018 are on-line at http://mmathphys.physics.ox.ac.uk/students.

Part II

A. General Comments on the Examination

Table 2 gives the rank of candidates and the number and percentage of candidates attaining this or a greater (weighted) average USM.

Table 2: Rank and percentage of candidates with this or greater overall USMs

Av USM	Rank	Candidates with this USM and above	%
92	1	1	2.38
91	2	3	7.14
88	4	4	9.52
86	5	6	14.29
85	7	9	21.43
83	10	12	28.53
81	13	13	30.95
80	14	14	33.33
79	16	16	38.09
78	17	17	40.47
76	18	19	45.23
74	20	23	54.76
73	24	24	57.14
72	25	25	59.52
69	26	26	61.90
68	27	29	69.05
67	30	31	73.80
65	32	32	76.19
64	33	35	83.33
63	36	36	85.71
62	37	38	90.47
60	39	39	92.86
58	40	40	95.23
57	41	41	97.62
54	42	42	100

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

This section has been removed the from public report, as the cohort contained fewer than 6 candidates

Oral Presentation All candidates passed the requirement to give an oral presentation on a specialist topic.

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

The number of candidates taking each paper is shown in Table 3. In accordance with University guidelines, statistics are not given for papers where the number of candidates was five or fewer.

Table 3: Numbers taking each paper

Paper	Number of Candidates	Avg USM	StDev USM
Advanced Fluid Dynamics	1	-	-
Advanced Philosophy of Physics Essay 1	1	-	-
Advanced Philosophy of Physics Essay 2	1	-	-
Advanced QFT	21	71	11.92
Advanced Quantum Theory	12	73.83	13.02
Algebraic Geometry	2	-	-
Algebraic Topology	3	-	-
Applied Complex Variables	4	-	-
Collisionless Plasma Physics	3	-	-
Differentiable Manifolds	10	65.50	7.72
Functional Analysis	1	-	-
Galactic and Planetary Dynamics	5	-	-
General Relativity I	17	66.18	10.09
General Relativity II	17	70.94	7.87
Geometric Group Theory	1	-	-
Geophysical Fluid Dynamics	3	-	-
Groups and Representations	30	78.40	16.43
Introduction to Quantum Information	17	69.65	20
Kinetic Theory	8	72.25	20
Lie Groups	1	-	-
Networks	4	-	-
Nonequilibrium Statistical Physics	5	-	-
Numerical Linear Algebra	2	-	-
Mathematical Geoscience	1	-	-
Perturbation Methods	11	67.64	12.03
Quantum Field Theory	39	73.14	14.07
Quantum Matter	7	73.14	14.50
Statistical Mechanics	1	-	-
String Theory I	22	68	7
Supersymmetry and Supergravity	15	70	11.61
Dissertation (single unit)	13	73.15	9.77
Dissertation (double unit)	8	84	5.27

The number of candidates taking each homework completion course is shown in Table 4. In accordance with University guidelines, statistics are not given for papers where the number of candidates was five or fewer.

Table 4: Numbers taking each homework completion course

Paper	Number of Candidates	Percentage completing course
Advanced Fluid Dynamics	4	-
Advanced Quantum Field Theory	4	-
Astrophysical Gas Dynamics	2	-
Aspects of Beyond the Standard Model and Astroparticle Physics	5	-
Collisional Plasma Physics	1	-
Conformal Field Theory	23	100
Cosmology	7	100
Group and Representations	30	100
Introduction to Gauge-String Duality	7	71.4
Kinetic Theory	1	-
Nonequilibrium Statistical Physics	5	-
Lattice Quantum Field Theory	3	-
Quantum Field Theory in Curved Space Time	8	100
Quantum Matter	2	-
Quantum Processes in Hot Plasma	1	-
Renormalisation Group	10	100
Soft Matter Physics	3	-
String Theory II	11	90.9
Symbolic, Numerical and Graphical Scientific Programming	11	100
The Standard Model	2	-
Topics in Quantum Condensed Matter Physics	3	-
Topological Quantum Theory	19	100

D. Assessors' comments on sections and on individual questions

Advanced Quantum Field Theory

1. a) Standard good. Often all diagrams in (ii) not identified. Majority of question done well by students.
   b)Most students could identify diagrams and write down amplitudes, but most could not manage the manipulation needed for final result.

2. a)Majority of students could answer well. Minus signs often missed out due to fermions. b)Answered well. Most could not manage (ii) but this was meant to be more challenging.

3. a)Many students failed to correctly calculate transformations for ψ, leading to issues with (ii). Otherwise answered well.
   b) Those who attempted generally good. The inversion needed for (i) often missed, possibly due to time.
   Generally some drop in marks in question 3, which I would put down to time running out for some students.

Advanced Quantum Theory

Question 1 was concerned with a 1D problem of spinless fermions with quadratic pairing terms. Part (a) was about the structure of the ground state in absence of the pairing term for a non-trivial dispersion. The majority of students realized that the Fermi sea consisted of two parts. Part (b) was concerned with deriving an appropriate form for a Bogoliubov transformation needed in part(c). This required the analysis of two sets of anticommutation relations. Part (c) was about diagonalizing the Hamiltonian by using a Bogoliubov transformation. Here a common problem was to keep track of the momentum summations and eventually restricting it to positive momenta. Finally, part (d) was about calculating expectations values of the fermion number operator in the ground state and excited states. This part caused some problems, in particular the explanation of the fractional value in the excited state.

Question 2 was concerned with the transfer matrix approach to one dimensional Ising models. The first part (discussion of the transfer matrix approach to the 1D Ising model with periodic boundary conditions) posed no problems. The modification of the approach for the case of open boundary conditions was worked out correctly by almost all students as well. The main part of the question dealt with an Ising model on a lattice with triangular-linear geometry, which required the construction of transfer matrices involving several sites. Even though this part was not easy most students handled it very well. The only part some students struggled with was the physical interpretation of the zero temperature limit of the entropy per site.

Collisionless Plasma Physics

Question 1. Students completed sections (a)-(c) without problems. In part (d), apart from issues with the integrals, the students found difficult to determine the density near the surface of the planet. The ion densityvanishes at the surface of the planet. However, if the approximate expression in part (c) is used, the density near the planet must be approximated to the same order in R/L to obtain that the density vanishes.

Question 2. In section (a), some students did not justify their approximations, and in particular they did not explain why it was necessary to assume $\omega \gg \sqrt{\Omega_i \Omega_e}$. All the students could obtain the equations needed to solve section (d), but not all described the wave propagation.

Question 3. Apart from a few sign errors, the students could solve the problem. They also noticed and corrected two typos in the question. .

Geophysical Fluid Dynamics

Candidates generally produced answers of high quality, showing a depth of understanding.

Summary of questions:

- Q1 A problem on Ekman layers, including time-dependent currents. Done well, with candidates only dropping marks by missing a cancellation between the acceleration/pressure gradient in the interior flow, failing to include the acceleration in the interpretation of the final force balance, or running out of time.
- Q2 A problem on shallow water waves in a channel. All candidates recovered full marks on parts (a) and (b), and made good progress with

(c) losing marks for algebraic errors or interpretting the meridional structure of the waves. A common place to lose marks was in (d), failing to spot one of the two modes that were possible in Patagonian fjords, or running out of time.

Q3 A problem on quasigeostrophic dynamics, and Eady's model of baroclinic instability. Done very well. Marks were lost in (d) for failing to interpret the sign of the eddy flux, and failing to rule out a barotropic instability.

Groups and Representations

Question 1: A standard question on finite Abelian groups which was attempted by all the students. Very few difficulties were encountered.

Question 2: This question on the quartermonic group, given in matrix form. Some marks were lost on problems with calculations, in particular ducking the conjugacy classes. Further problems were gaps in writing down the representations explicitly and a misunderstanding of part (d).

Question 3: A very unpopular question.

Question 4: A question on represenstions of the B_3 /A_3 Lie algebras. It was quite well done. Problems arose from simple numerical mistakes in calculating the weights, and, in some cases, from a poor misunderstanding of branding.

Kinetic Theory

Question 1: Most candidates did question 1 very well, and several wrote comments that showed a high level of understanding beyond what was explicitly required. There was an obvious typo in the question with $\nabla_v \Phi$ instead of $\nabla_x \Phi$ in equation (†). This was spotted and corrected within the first 30 minutes.

(a) Some mention of indistinguishable particles or permutations was needed for full marks in (a), rather than a vague statement about "normalisation" to justify the factors of N and $N(N-1)$ in the f_1 and f_2.

(b) Surprisingly many candidates reproduced the derivation of the full BBGKY hierarchy for the s-particle distribution, rather than specialising it for the 1-particle distribution. Several used p_i and q_i notation instead of the x_i and v_i notation in the question. Common mistakes where completely omitting one of the two terms that appear when taking ∂_{x_i} of the interaction Hamiltonian H' (the term that may be shown to be an exact divergence), not justifying the appearance of the $(N-s)$ factor, and not recalling that the particles had unit mass.

(c) Some candidates lost marks by omitting the x and $|x - x_2|$ arguments in calculating $\Phi(x)$ from $\phi(|x - x_2|)$ via an integral over x_2.

(d) This caused a surprising amount of trouble in remembering to multiply by $1 + \log f$, and use $(d/dt)(f \log f) = (1 + \log f)df/dt$ etc. Many candidates treated $\log f$ as a constant when taking it inside space and time derivatives (as when taking moments with respect to v) or made other calculational errors. Several candidates wrote about a collision integral and asserted the Boltzmann H-theorem, rather than showing that the given equation conserves entropy.

Question 2: Most students were able to make useful progress on this question. Parts (a) and (b) baffled (almost) no one. Part (c) was done adequately by most, although some students failed to explain what the integration contour was and some jumped to the answer (which had been given them) without really doing all the steps of the derivation honestly. In part (d), no one realised that $p = -\gamma$ was a pole but $p = \gamma$ was not, if you looked carefully at the limit of $p \to \gamma$ before throwing out any terms with t in the exponential. Most arrived at the right result (which was given). Their command of the Cauchy theorem was shaky at best but their determination to get at the required result unshakeable. In part (e), most did not realise that the solution would be a Maxwellian with temperature increasing linearly with time. Most understood (or guessed) that particles would be heated and some realised that that meant that the short-correlation-time approximation could not hold forever. Essentially no one was able to estimate for how long it would hold or to work out the condition for this to be compatible with $\gamma t \gg 1$ (slow evolution).

Question 3: Mean mark 20.37. SD 4.57 The second part was undermined by the students not being given a value for Newton's constant - the setter assumed standard Physics data sheets would be issued. In consequence every candidate scored the full 3 marks for this part. The candidates who scored less than 20 failed to prove the virial theorem. Few candidates could state Jeans' theorem clearly. Otherwise they had a solid grasp of the material.

Q3 was confined to material covered in the lectures or problem set and all candidates found it rather easy. The material is pretty advanced, however, and only published from 2012 onwards so I think the high scores are a tribute to the quality of the candidates. Several candidates lost marks through small algebraic errors or failure to answer a specific question probably through oversight rather than ignorance. The mark scheme proved satisfactory.

Nonequilibrium Statistical Physics

Question 1 was a generalisation of something they had seen, and they were relatively successful in answering the familiar part and less so in answering the new elements. Question 2 was the most familiar question and the students all performed well on it. No one attempted question 3, which was a new question and least familiar. Overall the performance was reasonably good.

Quantum Field Theory

Comments on the paper for inclusion in the Examiners' Report

Most of candidates proved a good understanding of the subject, with few of them delivering a very good or excellent work. All candidates attempted to solve three problems and in most cases successfully finished at least half of them.

- Q1: part a) and the beginning of part b) has been successfully finished by most candidates. Many students, however, struggled with finding eigenstates of Q. Many had difficulty with writing proper one-particle states and only few candidates found correctly both eigenstates of Q. In part c) the main difficulty has been with finding correct conditions for the existence of a stable vacuum.
- Q2: The main difficulty was in part c): many candidates have not found a general form of Feynman diagram required for this question and only few of them found proper symmetry factor. Also many struggled with a proper evaluation of the Feynman integral. Few candidates made mistakes in the derivation in part e).
- Q3: Only half of candidates decided to solve this problem. Most of them solved parts b) and c) correctly. Some candidates provided insufficient explanation in parts a) and/or d).

Q4: Many candidates provided incorrect or incomplete derivation in part a). In particular, only few of them correctly argued the relation to the Feynman propagator. The main difficulty in part b) was to properly argue that only connected diagrams contribute to the two-point correlation function. In part c) only few students provided all required Feynman diagrams and their Feynman integrals, with many struggling with correct symmetry factors.

Quantum Matter

Seven student took this exam and overall the performance was fairly good.Except for question 2g every question was answered correctly by at least one student. There were a fair number of dropped factors of 2, -1, L and N. Students were not penalized for these too much. Question 1 was done very well by most students. I was a bit surprised that questions 1b and 1c proved problematic, since these were meant to be easy marks. In question 1e all students assumed the chemical potential to be zero. This was accepted without penalty (the assumption was implicitly encouraged by the way the question was stated). Question 2 was more difficult. Question 2g gave everyone trouble with no correct answers. Unfortunately, it seems that some of the words used (in the spirit of Landau Fermi liquid theory) might have acted a bit like an anti-hint. This was not the intention. The point of this question was simply to use Galilean invariance. Essentially all students instead tried to do a Landau Fermi liquid theory calculation which led nowhere. Perhaps the question should have had a hint that the answer is no more than two lines. Question 2e also seemed to be problematic although a few students got it (or almost got it). Unfortunately, those who fell on 2e inevitably made no progress on 2f as a result.

Supersymmetry and Supergravity

Question 1: Candidates showed good command of the bookwork elements of the question. However, few were able to realise that exponentials were required to satisfy the symmetry in parts (d) and (e).
Question 2: There were a range of good attempts to this question.
For the last part either U(4) or SU(4) were accepted as correct answers.
Question 3: This was generally attempted well although there were a few fragmentary answers from candidates who may have run out of time.

C3.1: Algebraic Topology

Question 1. All candidates attempted this question; the standard of answers was generally reasonable and included two perfect answers. (b) Most candidates here correctly applied the resolution procedure for Tor and Ext, but there were errors concerning more elementary matters of tensor products and homomorphisms of abelian groups. (c.i/ii) Most candidates correctly applied the universal coefficient theorems, but there were a number of elementary errors in computing kernels of maps of abelian groups. (c.iii) There were a few excellent answers here, though also many candidates failed to prove (or understand they needed to prove) that the manifold would have to be of dimension 2, before arguing from Poincare Duality, and also many candidates failed to apply Poincare Duality with $\mathbb{Q}/\mathbb{Z}$ coefficients, despite the structure of the question indicating that was the appropriate path.

Question 2. Fewer candidates attempted this question, and half of those who did struggled with it. There was one strong answer. (b.iv) A couple candidates clearly identified a simple example, for instance the projective plane cross a circle, but some erroneously suggested the three-dimensional projective space. (c) Almost no one successfully identified that the space is homotopy equivalent to the wedge of six circles. Inexplicably a number of candidates failed to apply Lefschetz Duality, despite the structure of the question indicating that was the appropriate tool.

Question 3. Most candidates attempted this question; the standard was high overall and included one perfect answer. (b) Most candidates correctly identified these cocycles, reflecting either good geometric understanding or good algebraic computation; a very small number of candidates unfortunately computed using the genus one rather than genus two surface. (c) Most candidates correctly computed the products, though only some fully identified the Poincare dual classes as simplicial cycles, for instance via the cap product.

C3.2 Geometric Group Theory

Q1 This was a basic question about presentations and algorithmic problems. All students attempted this. Part a.i was done well. Some students had difficulties with part a.ii. However most students solved this considering homomorphisms to $\mathbb{Z}_2$ or to a free group. Some used Tietze transformations giving lengthier proofs.

Surprising many candidates had difficulties with part bi. They failed to realize either that the presentation given was that of the quotient group G/F or they missed the fact the g is the identity in this quotient group iff $g \in F$.

Some students failed to do bii as they did not interpret correctly equality of words in G.

Quite a few candidates that did not do bi, bii went on to solve biii asuming the results of the previous part.

Some candidates had a valid idea of using homomorphisms for b.iv but mistakenly tried to list homomorphisms $G \to S_n$ rather than $S_n \to G$ which would have worked. Several students used a straightforward argument with words.

Q2 This was a question on amalgamated products and actions on trees attempted by most students.

Several candidates had difficulties with part a. They realized that it could be done using normal forms but they did not think of cyclically reduced normal forms. For the second part group actions on Trees were appropriately used, however several students claimed that H is free rather than a free product and many did not explain in detail why H is a free product.

In part b some candidates assumed that the tree T is finite - which was not assumed.

Quite a few candidates had the right geometric idea of constructing a translation axis and they got either partial or full credit for this when they gave a complete argument. Very few saw that commuting elements fix the same axis which was needed for the action of $\mathbb{Z}^3$ on T.

Some students realized that they could use the results of part b for c and got either partial or full credit for this part.

Q3It was on the last part of the course dealing with quasi-isometries and hyperbolic groups.

Candidates did well answering most parts that were either bookwork or close to bookwork.

They had the right idea on how to show that $G \times G$ has one end and got partial credit for this.

C3.3: Differentiable Manifolds

Question 1: A wide spread of marks. For (a), almost everyone who answered correctly reproduced a proof from the notes that was unnecessarily complex, as it also gave f = 1 near x.

Question 2: Again, a wide spread of marks. Some candidates tried incorrectly to use Cartans formula in (b). Parts (d) and (e) were found difficult, and noone used the hint in (e).

Question 3: Candidates did better on this question, as many of them were able to get close to full marks on (a)-(d). Noone answered (e) correctly. The answer I was hoping for was this: fix a base point $x0$. For any other point x in X, join $x0$ to x by a smooth path . The equation in (d) implies a second-order o.d.e. along on the coefficients i restricted to . Hence results on o.d.e.s imply i at x is determined by i and its first derivatives at x0, and this holds for all x in X.

C3.4: Algebraic Geometry

All students attempted Q1, and then the students split 50/50 on choosing Q2 or Q3.

Q1: In (d) there was some confusion among candidates trying to consider the two hypersurfaces given by the two defining equations, instead of noticing that Y was a subset of X, and noticing that X also contains the line given by the Z - axis.

Q2: Some slips in (a) caused by the fact that $dimX$ is $dimS(X)-1$ (the drop in 1 is caused by the presence of the irrelevant ideal). None of the candidates solved the second part of (b)(iv), one needed to consider the case when Q was a union of two lines.

Q3: In (a) candidates usually forgot to say that one picks and affine open neighbourhood of a point in the definition of regular function. In (b) most candidates just assumed that locally f, g belong to $K[x, y]$, instead of considering basic open sets where f,g live in a localisation of $K[x, y]$ and then passing to $K[x, y]$ by rewriting the fraction

C3.5: Lie Groups

Question 1

This question was about the exponential map and the relation between Lie algebra and Lie group homomorphisms.

The earlier parts of the question were generally well done, and candidates showed a good understanding of the generation lemma. Some answers were too sketchy in showing that exp was a local diffeomorphism around the identity. The last part (finding a Lie algebra homomorphism that did not integrate to a Lie group map) proved harder than expected, though a few candidates succeeded, either considering the group $SO(3)$ or S^1.

Question 2

This question was on representations of $SU(2)$ and characters,

Candidates understood the idea of restriction to a maximal torus but failed to take account of the Weyl-invariance. Surprisingly, nobody really got the decomposition of the tensor product in the final part, although it is an easy character calculation.

Question 3

This question was on Haar measure.

Candidates had a good grasp of the bookwork. The calculation in the final part, showing that a certain noncompact solvable group had essentially distinct left and right Haar measures and hence admitted no bi-invariant measure, proved more difficult but there were some very good answers here.

C4.1: Functional Analysis

The exam was taken by 14 MMath candidates and one MTP candidate. It is pleasing to see that advanced courses in pure analysis continue to attract significant interest, especially among high-calibre students.

Question 1. Part (a) was straightforward bookwork. In part (b)(iv) only the stronger candidates realised that they could apply the Hahn-Banach theorem to the zero subspace. Part (c) led to a variety of outcomes, with some candidates declining my invitation to consider the diagonal subspace of X^n and instead offering an inductive argument based on part (b).

Question 2. While part (a) was generally well done, the arguments given in part (b) were often rather sloppy. Most candidates coped reasonably well with (c), and even those who struggled in parts (i) and (ii) tended to spot that (iii) was something of a gift.

Question 3. Candidates generally had little difficulty with the bookwork in part (a). In part (b)(ii) some candidates failed to appreciate that proving boundedness of T required an application of the uniform boundedness principle (or something similar). Part (c) received only a small number of convincing answers. In particular, nobody saw how to take advantage of the fact that the norms of the functionals in question are Riemann sums.

C5.3: Statistical Mechanics

In its last year before its sabbatical after my five year tenure, and its probable future re-invention, this was perhaps the hardest exam that I have yet set.

The first question was the most standard, but the derivation of conservation laws from the Boltzmann equation caused some difficulties. The second question on condensation had been scampered through in lecture, and was algebraically intricate, but generally well done. The third, proving a lower bound for Boltzmanns H function, was also intricate but very well done.

C5.5: Perturbation Methods

Overall students performed well on the examination.

Question 1. A commonly attempted question, overall answered very well with the integrand singularity in the final part not derailing students, who typically noted it was integrable and proceeded with an approach based on Laplace's method. Marks were more usually lost by not accurately determining the order of the asymptotic corrections.

Question 2. This was rather unpopular and seriously attempted only by a very small minority, who did rather well and were well rewarded in the early stages, though matching the boundary layer at infinity did challenge most of the students.

Question 3. This was extremely popular, though managing the calculation complexity in final part did differentiate the attempts.

C5.6: Applied Complex Variables

- Q1: Part (a) was mostly done quite well but some candidates had errors with some of the intermediate mappings required and therefore ended up not being able to reproduce the given solution. Most candidates realised the mapping of the hodograph plane in part (b) was the same as that needed in part (a), but some stubbornly continued with their own incorrect mapping and therefore got quite stuck with part (c). Part (b) was well done apart from that. Part (c) caused the most difficulties, but a number of candidates obtained the correct expression.

- Q2: Some candidates did much more work than was required in part (a), using integral expressions for w itself as well as $w/\tilde{w}$; explanation of where the function H comes, even brief, was lacking in some cases. Part (b) was generally done well, although some candidates gave incorrect definitions of the square root (giving imaginary values on either side of the branch cut). Part (c) was found the most challenging, with only one or two candidates correctly calculating the contour integral round the large circle (most had it being zero, or made up more exotic expressions to try to arrive at the given solution in the case $c = 1$). Part (d) was done quite well, the connection to the earlier parts being noted.

- Q3: Part (a) was bookwork plus a standard application of the residue theorem; however it seemed to be found tricky by many candidates. Many tried to close the contour to find G_+ in the upper half plane rather than the lower half plane. Part (b) was mostly done very well; a surprising number of candidates failing to note that the required 'splitting' of the right hand side had already been achieved in (a). Part (c) was not completed correctly by any candidate, although a number came close. A common misconception was to discuss a 'residue' at the branch point.

C5.11: Mathematical Geoscience

Q1: This was the most popular question and was attempted by most candidates. It was mostly done well, although some candidates overly complicated the algebra of part (a) and surprisingly many made a hash of the non-dimensionalisation in part (b). Part (c) was well answered on the whole, although many candidates jumped straight to the quasi-steady evolution on the $O(1)$ timescale without discussing the initial transient evolution of p. No-one produced a completely satisfactory sketch of the evolution of $p(t)$.

Q2: This question was found to be the most challenging. Surprisingly many candidates struggled with the linear stability in part (a), which was almost identical to an example in lectures and on the problem sheets. The first part of (b) was well done, but most candidates would have benefited from thinking more graphically, and many attempts were much more involved than required. Part (c), which was new and certainly harder, was answered well be two or three candidates, although several others managed to explain the expression for the wavelength.

Q3: This question proved to be relatively straightforward. Part (a) and (b) were answered completely by most who attempted this question. Part (c) was new, and required some broader thinking, but it was mostly well done. Some explanations of the thermal boundary conditions were confused, with a number of candidates suggesting that the presence of the subglacial water layer makes the base insulating.

C6.1: Numerical Linear Algebra

This seems to have been a fair exam with most candidates gaining at least reasonable scores and several gaining high scores.

Q1 on orthogonalilies and the SVD was attempted by about 3/4 of the candidates and there were correspondingly a range of scores. There was some confusion over permutations in part (c) and very few made much headway on the final part (e), though some did correctly complete this.

Q2 on simple iteration and SOR was attempted by just less than 2/3 of the candidates and also attracted a range of scores. Many incorrectly assumed the eigenvalues of B to necessarily be read in part (b) and only a few correctly completed the final part (e).

Q3 on the conjugate gradient method contained the most bookwork but still several candidates put forward incorrect arguments for various parts. Only one or two were able to correctly answer the final part (b)(iv).

C7.4: Introduction to Quantum Information

Question 1
Parts (a) - (c) were bookwork with very few marks lost. Most students struggled with part (d) and calculating the action of the Grover iteration operator on the states. Good attempts at parts (e) and (f).

Question 2
Fairly well done question. Parts (a) and (b) were bookwork and posed no difficulty. Neither did part (c), though only a few candidates used stabiliser generators to prove it. In part (d) almost all students erroneously thought the state was entangled. Good attempts at (f) and (g). However, only a handful of students considered calculating the reduced density matrix in part (g).

Question 3
This was the most popular question on the paper, probably owing to the familiar bookwork in parts (a) and (b), but it also had the lowest average mark. Many students struggled with part (c). There were various attempts at part (d). Some candidates had the right idea but failed to spot the block structure of the matrix and got lost in the algebra of diagonalisation.

C7.5: General Relativity I

Hardly any of the students tried question 3 and those that did were unable to make progress on the final part. The answers for question 2 were generally very good, a few students even succeeded in deriving the Reissner-Nordstrom solution. Question 3 attracted many students as well, but few managed to solve the final part.

C7.6: General Relativity II

This exam was not particularly easy but students did very well.

Q1: This was not very popular despite the fact that this examiner thought it was the easiest. Q2: Most points where lost in part c of the question and in part b where students did not produce an accurate space time diagram.

Q3: Students were not able to obtain the answer for part c(i) correctly.

E. Comments on performance of identifiable individuals

Prizes

Removed from public version

F. Names of members of the Board of Examiners

Examiners:

Prof John Chalker
Prof Artur Ekert
Prof Andre Lukas (Chair)
Prof Gordon Ogilvie
Prof James Sparks
Prof Daniel Waldram

Assessors:

Prof Samson Abramsky
Prof Fernando Alday
Dr Jonathan Barratt
Prof Chris Beem
Prof James Binney
Dr Andreas Braun
Prof Philip Candelas
Dr Adam Caulton
Prof Bob Coecke
Prof Joseph Conlon
Prof Amanda Cooper-Sarkar
Dr Neave O'Clery
Prof Andrew Dancer
Prof Xenia de la Ossa
Dr Paul Dellar
Dr Amin Doostmohammadi
Prof Christopher Douglas
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