Examiners' Report: Final Honour School of Mathematical and Theoretical Physics Part C and MSc in Mathematical and Theoretical Physics Trinity Term 2016

November 1, 2016

Part I

A. STATISTICS

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

  See Table 1.

	Numbers 2016	Percentages % 2016
Distinction	18	85.71
Pass	3	14.29
Fail	0	0
Total	21	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, except mini-projects for the Galactic and Planetary Dynamics course, were double-marked, after which

the two markers consulted in order to agree a mark between them. If the two markers were unable after discussion to agree a mark, the mark was decided by a third assessor. There were no cases which needed to be referred to a third assessor this year.

All written examinations, take-home exams and mini-project for the Galactic and Planetary Dynamics course, 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

D. Notice of examination conventions for candidates

Notices to candidates were sent on: 21st October 2015 (first notice), 11th November 2015 (second notice), 23rd February 2016 (third notice) and the 5th May 2016 (final notice).

The examination conventions for 2016 were 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	4.76
91	2	2	9.52
90	3	4	19.05
89	5	5	23.81
87	6	6	28.57
86	7	7	33.33
84	8	8	38.1
80	9	12	57.14
78	13	14	66.67
77	15	16	76.19
75	17	18	85.71
65	19	19	90.48
63	20	20	95.24
60	21	21	100

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

Table 3: Breakdown of results by gender

Class	Total		Female		Male	
	Number	%	Number	%	Number	%
Distinction	18	85.71	-	-	16	88.89
Pass	3	14.29	-	-	2	11.11
Fail	0	0	-	-	0	0
Total	21	100	3	100	18	100

Table 3 shows the performances of candidates broken down by gender.

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 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 paper

Paper	Number of Candidates	Avg USM	StDev USM
Advanced Fluid Dynamics	2	-	-
Advanced QFT	12	64.67	19.35
Algebraic Geometry	4	-	-
Algebraic Topology	2	-	-
Applied Complex Variables	2	-	-
Complex Systems	5	-	-
Critical Phenomena	5	-	-
Differential Geometry	4	-	-
Galactic and Planetary Dynamics	1	-	-
General Relativity I	9	69.67	11.9
General Relativity II	7	75	10.9
Geometric Group Theory	2	-	-
Geophysical Fluid Dynamics	2	-	-
Groups and Representations	17	86.29	14.53
High Energy Astrophysics	2	-	-
Homological Algebra	1	-	-
Introduction to Quantum Condensed Matter Physics	6	72.33	16.31
Kinetic Theory	3	-	-
Networks	2	-	-
Nonlinear Systems	2	-	-
Numerical Linear Algebra	1	-	-
Perturbation Methods	3	-	-
Quantum Condensed Matter Physics II	3	-	-
Quantum Field Theory	18	77.56	14.08
Scientific Computing I	11	84	11.2
Scientific Computing II	10	94.4	16.8
Stellar Astrophysics	1	-	-
Statistical Mechanics	2	-	-
Statistical Data Mining and Machine Learning	1	-	-
String Theory I	12	69.58	9.96
Supersymmetry and Supergravity	10	71.6	16.61
Viscous Flow	1	-	-
Dissertation	7	72.14	15.42

The number of candidates taking each homework completion course is shown in Table 5. In accordance with University guidelines, statistics are not given for papers where the number of candidates was five or fewer.

Table 5: Numbers taking each homework completion course

Paper	Number of Candidates	Percentage completing course
Astroparticle Physics	4	-
Beyond the Standard Model	3	-
Conformal Field Theory	13	92.3
Cosmology	5	-
Critical Phenomena	5	-
Group and Representations	17	100
Introduction to Gauge-String Duality	4	-
Non-perturbatic Methods in Quantum Field Theory	3	-
Quantum Condensed Matter Physics II	3	-
Quantum Field Theory in Curved Space Time	5	-
Stellar Astrophysics	1	-
Soft Matter Physics	2	-
String Theory II	6	100
The Standard Model	4	-
Topics in Soft and Active Matter Physics	1	-

D. Assessors' comments on sections and on individual questions

Advanced Fluid Dynamics

The facts of the question requiring pure algebra appeared doable but perhaps not as straight forward for the students as might have hoped. The more qualitative questions provided some opportunities for students to show physical insight opportunities that were, alas, not fully embraced by the candidates (this applies particularly to part d).

Advanced Quantum Field Theory

1a) Well done.

1b) Surprisingly, many had difficulty in squaring amplitude and computing trace.

2a) Reasonably well done but many did not take the hint about the gauge invariant terms and wasted time checking the invariance explicitly.

2b) Several failed to define time ordered product as path integral.

2c) Straightforward bookwork problem surprisingly 5 failed to produce adequate answer, suggesting poor preparation.

3a) This question cause the greatest difficulty suggest many had not revised this subject, possibly hoping to avoid it.

3b) Normalisation of eigenstates caused difficulty. Determination of electric charge poorly done.

3c) A straightforward bookwork problem but not done very well, possibly due to time pressure.

Geophysical Fluid Dynamics

Q1) Part (a) and first half of part (b) were done well, but with no further progress.

Q2) Solutions to parts (a) and (b) were mostly solid, barring occasional omissions/algebraic mistakes. Solutions either stalled in part (c) or progressed to part (d), dropping marks on the sketch and interpreting the competition between rotation and stratification.

Q3) Fairly solid progress through the question, with the main difficulties encountered in sketching the force balance in (a), deriving equation (2) and interpreting it in part (c), and the derivation of the final solution for the stream function.

Groups and Representations

Q1) A question on some standard concepts and on representations of finite Abelian groups. This question was attempted by 13 students with a high average of 23/25.

Q2) A question on representations of finite non-Abelian groups attempted by 12 students, again to a high standard with an average of 22/25.

Q3) This question covered the group SU(4) and its representations and was attempted by 12 students with a good average of 18/25.

Q4) A question on the group SO(7) and its representations attempted by 13 students, to a high standard with an average of 22/25.

Introduction to Quantum Condensed Matter Physics

Overall the quality of answers was very good.

Q1) This problem dealt with the application of the transfer matrix formalism to one dimensional models. The basic parts of the problem dealt with general formalism and were done very well. Some students had difficulties in applying the transfer matrix formalism to the Ising model on the lattice given.

Q2) Students showed a good understanding of how to apply the spin-wave formalism to the anisotropic Heisenberg chain. The identification of the ground states, explanation of spontaneous symmetry breaking, and derivation of the spin-wave Hamiltonian by means of the Holstein-Primakoff transformation were mostly done well.

Q3) This problem dealt with the path integral approach to the an-harmonic oscillator at finite temperatures. Students had few difficulties in answering the various questions.

Kinetic Theory

Q2) The question was perhaps on the easier/more standard side. Strong students with a good grasp of the mathematics of the subject appear to have done near perfectly well, while flagging maths led to weak performance. This said, the strong performers on maths also grasped the key physics points: that $K\lambda_{De} << 1$ allowed electric field to be computed purely from the ion distribution, that the wave was the sound wave, that it damped slowly because ions were cold while the wave propagated fast, etc. Overall conclusion is that some more challenging bits to stretch the strong harder would have not gone a miss, but good performance on this question is an adequate indication of a decent grasp of the core of the subject.

Q3)The question worked well in the sense that it started with a straightforward book work but required significant insight at the end in both maths and physics. The 3 parts with 5 marks all attracted full marks by some candidates. The highest score on the 10 mark piece was 7 and the lowest 1. The key point was missed by everyone: Φ, introduces a correlation between f_1 and g_1 but only through the term prop to $\delta g_0/\delta j$. the candidates seemed close to getting this and one had no idea. Only one candidate grasped the significance of F vanishing for non-uniform f_0 but G vanishing only if g_0 uniform.

Nonequilibrium Statistical Physics

There were two students in the end who took this exam. Both chose questions 1 and 3, to which they gave reasonable answers.

Quantum Condensed Matter Physics II

Question 1a was found difficult. Marks were awarded for indicating that the order parameter has quantum mechanical meaning similar to a wave function, although no one discussed ODLRO. The remainder of the question was mostly done well.

Question 2a-c were done perfectly by everyone. But 2e caused trouble when it was supposed to be easy classical physics.

Quantum Field Theory

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

Q1) The most problematic question in the whole exam. Students did not have difficulties in the first two parts of the question. Some of the candidates struggled, however, with the tensor calculus in part c). Many of them had problems with proper definitions of tensors η^{μ}_{ν} and δ^{μ}_{ν}. Part d) of the question turned out to be quite challenging for most, with only a couple of candidates solving it correctly. The common difficulty was to write down correct infinitesimal transformations of fields and the Lagrangian under the dilation transformation.

Q2) First three parts of the problem were solved correctly by most of candidates. In part d) few students struggled with the proof of Lorentz invariance. Additionally, not all candidates attempted the last part of the question.

Q3) One of the main difficulty was to find proper symmetry factors for Feynman diagrams. Also, some candidates did not write down all Feynman diagrams required in this question.

Q4) It was solved properly by most candidates. Apart from few typos in calculations, the most problematic part was the derivation of the β-function in part d) of the question.

C2.2 Homological Algebra

C3.1 Algebraic Topology

Question 1. There was one answer to this question receiving full marks.

- (a) In part (iii), there were some correct answers, though a number of candidates wrote down the first map they saw from A_n to C_{n+1}, namely $H\partial K$, where H and K were the two chain homotopies, without seeing that that map is not a chain homotopy.
- (b) Some candidates saw that the chain complex of the real projective plane provided a suitable example for both part (i) and part (ii).

- (c) Most candidates who attempted this part were able to compute the set of chain homotopy classes.

Question 2.

- (a) Most candidates did a reasonable job with this bookwork part.
- (b) Most candidates correctly set up the long exact sequence for the pair, but almost everyone failed to correctly identify the boundary map in the sequence as $1 - \det f$—the geometry of the mapping torus evidently has two components to the boundary attachment, corresponding to the identity and to the induced map of f, taken with opposite orientations.
- (c) Some candidates correctly identified whether M_f and M_g were manifolds, but no one determined whether there was a manifold homotopy equivalent to M_g, despite this being an immediate consequence of parts (a.i) and (b.ii).

Question 3. Note that this was a minor variation on a question that appeared in the exam last year, and in the exam the year before, and in the problem sheet this year. Candidates are encouraged to ensure they confidently know how to thoroughly do all problems from all the problem sheets and past exams in recent years.

- (a) All candidates gave a reasonable answer to this bookwork part.
- (b) A number of candidates correctly presented the CW structure, but there were a number of sloppy mistakes, for instance identifying each of the two halves of the boundary circle of M_2 with the whole diagonal circle of M_1. Most candidates correctly set up the Mayer–Vietoris sequence for computing the homology, and a few candidates managed to understand the geometry of the situation and therefore correctly identify the key map in the sequence as $(2, 1)$ (though some mixed up the two factors, leading to incorrect answers later). One or two candidates managed, more or less, to see through the key computation of $H_1(E)$.
- (c) Most candidates saw to apply the Universal Coefficient Theorem, but a combination of mistakes from part (b) and some incorrect Tor calculations, lead to few correct answers here.

C3.2 Geometric Group Theory

C3.3 Differentiable Manifolds

The last parts of all three questions caused difficulty for most candidates, but were all solved by some.

C3.4 Algebraic Geometry

All students chose Q1, and there was an almost even split between students choosing Q2 or Q3. Nobody attempted more than two questions. Average scores on the three questions were roughly equal, of a high standard: 18/25.

Q1) Failed attempts at (e) occurred from considering the ideal $(p_1, \ldots, p_m, r)$ instead of $(p_1, \ldots, p_m)$. In (f) students often pointed out that X was only unique up to isomorphism, but they did not justify why X as constructed was not unique.

Q2) There was a typo: *rational functions* should say *regular functions*, but nobody was confused by this, presumably because the symbols clarified the meaning. Several students erroneously stated that regular functions on U are a ratio of functions globally on all of U, rather than just locally.

Q3) A few students got confused in (c), and tried to set up a projection map (instead of considering the P^n that records the coefficients of the linear form). Some students forgot the standard example to the last part of (f).

B5.3 Viscous Flow

Question 1.

- Part (a): the book work aspects of this question were very well done.
- Parts (b)(i) and (b)(ii) were well done.
- In part (b)(iii) many candidates struggled to solve for $\hat{u}(\hat{y}, \hat{t})$. Hence few candidates were able to show that the stress on the plate is $\pi/4$ out of phase with the velocity far from the plate as $\hat{y} \to \infty$

Question 2.

- Part (a): the book work aspects of this question were very well done.

- In part (b)(i) some candidates were unable to deduce the form of $g(x)$. Some candidates struggled to give the form of the boundary conditions for $f(Y)$ and $H(Y)$.

Question 3.

- It was pleasing to see the majority of candidates giving correct answers to 3(a).
- Some candidates were unable to give the correct physical interpretation of the last three conditions in 3(b).
- Part (c) was well done in general.
- The majority of candidates struggled to show that no steady state solutions exist if $Q > Q_{max}$.

B5.6 Nonlinear Systems

Qn 1: Reasonably well answered overall. Only one or two candidates were able to find the approximate location of the homo-clinic orbit. Many people assumed initial conditions for part (b), where they should have been kept general.

Qn 2: Many candidates did not identify the first bifurcation in (a)(i) as a saddle-node. A few candidates got as far as (c)(i). No-one got (c)(ii).

Qn 3: Reasonably well answered by those candidates, who attempted this question.

SC4 Statistical Data Mining and Machine Learning

Question 1. Good understanding in (a). Logistic regression derivations in (b) did not pose serious difficulties but there was some misunderstanding apparent from (b-iii) where some treated Hessian matrix as a scalar. In part (c) on epsilon-insensitive regression, several students did not see how to set up constraints for the dual problem and used only two constraints. For others, there were mistakes on expressing primal variables in terms of dual variables in some cases, dual program still contained the weight vector.

Question 2. Part (a) on dimensionality reduction had a surprisingly large number of incorrect answers on the number of components in LDA. Part

(b) contained some basic derivations for LDA with two classes (on which students did well) but several struggled to show that generalized eigenvalue equation must be satisfied and some who did seem to have forgotten to show the second part of (b-iii). Part (c) was derivations for a kernel version of LDA on which there were some good solutions for (c-i) but part (c-ii) proved too difficult as it required getting the criterion into a Rayleigh quotient form.

Question 3. This question had a substantial bookwork component in (a) on which all students received perfect or nearly perfect marks. In (b), there were no difficulties with the first part, but when it came to applying the SVD result in (b-ii), only a few realised which matrix is being approximated with a low-rank one. Misconceptions of matrix algebra involved (projection matrices) was apparent from some of the answers.

E. Comments on performance of identifiable individuals

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F. Names of members of the Board of Examiners

Examiners:

Prof Xenia de la Ossa
Prof John Chalker
Prof Andre Lukas (Chair)
Prof Gordon Ogilvie
Prof James Sparks
Prof Dan Waldron

Assessors:

Dr Mariano Beguerisse
Prof James Binney
Dr Roberto Bondesan
Dr Andreas Braun
Dr Matthew Bullimore
Prof Philip Candelas
Prof Joe Conlon
Prof Graham Cotter
Prof Xenia de la Ossa
Prof Paul Dellar
Prof Christopher Douglas
Prof Fabian Essler
Prof Andrew Fowler
Prof Ramin Golestanian
Dr Andre Henriques
Prof Ian Hewitt
Prof Peter Howell
Prof Dominic Joyce
Prof Andre Lukas
Dr Tomasz Lukowski
Prof John Magorrian
Mr Hadrien Montanelli
Prof Irene Moroz
Prof Jim Oliver
Prof Felix Parra
Prof Philip Podsiadlowski

Prof Mason Porter
Prof Alexander Ritter
Prof Graham Ross
Prof Alex Schekochihin
Prof Steve Simon
Dr Richard Mikael Slevinsky
Prof Jared Tanner
Prof Mike Teper
Prof Sarah Waters
Prof Andrew Wells