REPORT OF THE CURRICULUM COMMITTEE

1. Easter term report

The Curriculum Committee met for one hour on 30 April 2018. We discussed the following proposals.

1.1. **IID Analysis of Functions.** We received a proposal from Clement Mouhot, the lecturer for the past three years, for some relatively minor changes to the schedule. We agree with the suggestion that the overlap between this course and other Part II courses (notably Probability & Measure and Linear Analysis) should be minimised to spend more time in lectures on the new material. However, we note that Claude Warnick, who will lecture next year, is hesitant to change the schedule before he has had a chance to lecture it as it currently is. Therefore, we do not recommend a change at this time, but will keep this under review for a possible update next year. In the mean time, we encourage the lecturer and responsible Part II examiner to limit the overlap with other Part II courses when setting exam questions.

1.2. **IIC Cosmology.** We received a proposal from David Tong, the lecturer next year, for a somewhat substantial change the schedule. This proposal was discussed and approved at the Easter term DAMTP staff meeting.

There were some concern that this course demands too much background in physics, and so is perhaps not suitable to be a C course. However, the exam takeup has been healthy recently, so we concluded that there is no immediate concern. Furthermore, we believe that the proposed changes would make the course more attractive, so we **recommend** that the proposal be implemented.

1.3. **IID Classical Dynamics.** We received a proposal from Gordon Ogilvie, the current lecturer, for some minor changes to the list of recommended books, essentially correct the publication details. The suggested changes are attached. We **recommend** implementing these changes.

1.4. **IIC Automata & Formal Languages.** We received a proposal from Maurice Chiodo, the current lecturer, to remove *homomorphisms* from the second paragraph of the schedule, and to make minor adjustments to the number of lecturers per topic. We **recommend** implementing these changes.

1.5. **IB Methods.** We received a proposal from Colm Caulfield, the current lecturer, to adjust the number of lecturers per topic, the main effect being to substantially increase the number of lectures on PDEs on bounded domains. There was a view that the proposed allocation of lectures would over-emphasise this part of the course. Since there would be a new lecturer next year anyway, the Committee does not recommend implementing these changes.

Date: 16 May 2019.

1.6. **IID Galois Theory.** We received a request from Pelham Wilson, the current lecturer, to clarify what the intended meaning of the second sentence of the final paragraph of the schedule. The Committee asked the Chair to consult various interested parties to suggest better wording.

While there seems some agreement among potential Galois Theory lecturers that the current wording is somewhat vague, no concrete proposal to change the wording has emerged in time to be included in next year's schedule. Proposals will be solicited to be considered at our Michaelmas term meeting.

1.7. **IA Vectors & Matrices.** We received a proposal from Stephen Cowley to include the *singular value decomposition* into the schedule. This proposal was motivated by a prior proposal to include SVD into the IB Linear Analysis schedule, which was considered by this committee during our Lent term meeting, but not accepted.

There was concern that the schedule is already full. Including the SVD without having ample time to discuss its applications seemed to us inappropriate. Furthermore, since the rigorous details of the proofs of the results presented in V & M are often not lectured, there was concern that the SVD would not be fully proven.

A natural application of the SVD is in least-squares approximation, which is discussed in IB Numerical Analysis. The Numerical Analysis lecturer has been invited to make a proposal to incorporate SVD into the schedule, but one has not been received in time to be considered for next year.

1.8. **IA Computational Projects.** We received a proposal from Stephen Cowley, the current lecturer, to move the lectures to the same day as the two (from next year) examinable Easter term courses. This move would encourage students attending Variational Principles and Optimisation to attend the Computational Projects lectures. We agreed and **recommend** that the proposed timetable is adopted if feasible.

While discussing these lectures, we noted that unlike the examinable lecture courses, there is not a prescriptive schedule of lectures. We believe that this is a good practice since it would be inappropriate to tie the lecturer's hands unnecessarily. However, we do recommend that the lectures do not repeat too much mathematical content from the examinable courses. Furthermore, the student members expressed the view that the basics of programming are straightforward to most maths students once they have read the Matlab manual, and therefore it was not necessary to dwell on this issue for too long.

We note that, while the basics of programming are straightforward, the art of debugging is challenging and students would benefit from some instruction in this area. Furthermore, student members expressed the view that many of their peers are concerned about how to write up their reports, and would benefit from more discussion of how to decide what to include in their reports and what to omit.

2. Annual report

The major changes recommended by this committee this academic year, and already accepted by the Faculty Board, are

(1) to remove IB Metric & Topological Spaces,
(2) to replace IB Analysis II with IB Analysis & Topology
(3) to lengthen IB Geometry to 24 lectures,

(4) to introduce IID Mathematics of Machine Learning.

Although we made the above recommendations, there were a few concerns that we intend to monitor in future years. Notably, we will check for overcrowding in the Lent term of IB (with the introduction of 8 new hours of lectures) and that the the new version of Geometry is suitably accessible and not too difficult. Furthermore, we monitor the Machine Learning course to ensure that there is an adequate number of supervisors.

As mentioned above, we intend to check with the new lecturer of Analysis of Functions to see if it necessary to change the wording of the schedule to address the overlap with Probability & Measure and Linear Analysis.

The Committee has noted that there is quite a bit of overlap between IA Vectors & Matrices and IB Linear Algebra. Both courses are crucially important, so any attempt to change their schedules must be done with circumspection. However, the student members have noted that these two courses are somewhat repetitive, describing Linear Algebra as 'fixing the mistakes from first year'. Therefore, we intend to give some thought about how to teach this material more efficiently.

We noted that the number of available lecturers and supervisors for Logic & Set Theory and Automata & Formal Languages is limited and is not expected to grow in the near future. We intend to give some thought about whether these courses should be replaced within the next few years. Since Automata is a C course, extra attention must be given to any proposed replacement.

Finally, as noted above, the Committee has some concerns about whether Cosmology is suitably mathematical (i.e. not so reliant on physical knowledge) to teach to mathematicians. We intend to continue to discuss whether Cosmology is serving it intended purpose as a C course, or whether at some future time it should be made a D course or retired altogether.

Michael Tehranchi (chair), Jonathan Evans, John Lister, Jack Button, Anthony Ashton, Richard Nickl, Balaji Krishna, Valentin Hübner, Aled Powell

Revision of Part II Cosmology

I would like to propose a revision of our Part II Cosmology course. The course splits into three sections. Below I describe the proposed changes to each section.

The Expanding Universe

The first part of the course is a traditional introduction to the physics of expanding spacetimes. It is straightforward material and needs little revision. I would like to add two small topics to the schedules which, combined, comprise roughly 1.5 extra lectures of material.

- The FRW metric. This is the fundamental equation of cosmology and we should probably mention it. Our students don't know GR but they should have little difficulty in understanding simple metrics as a way to measure distance.

- Discussion of the evidence for dark matter and dark energy.

Statistical Physics and Thermal History

This is, in my opinion, the most problematic part of the course. Understanding the early history of the universe requires knowledge of thermodynamics and statistical mechanics. Yet our students have neither. They haven't even seen the first law of thermodynamics. The current solution is to "review" a large chunk of thermodynamics and statistical mechanics in 3 lectures. (At least according to the schedules; in reality it usually takes longer.)

The new proposal makes no attempt to give a comprehensive review of statistical mechanics but teaches only those parts that are needed for cosmology. The Boltzmann distribution is introduced as the defining property of equilibrium systems, leaving its derivation to the later Statistical Physics course. Then we proceed slowly, deriving Maxwell-Boltzmann, blackbody and other necessary distributions, using the relevant concepts from cosmology as illustrations. This allows both a gentler introduction to the statistical mechanics ideas while, at the same time, showing their application in cosmology.

Structure Formation

This part of the course has been back and forth over the years, with a number of topics dropping in and out. Currently, the schedule covers Peeble's non-linear spherical collapse model, and then turns to stars. The latter is good material but it is rather disconnected from the rest of the course. Meanwhile, the non-linear collapse model isn't developed far enough (at least in the schedules) to tell an interesting story.

I propose to instead describe linear perturbations of the Euler equation. We will again go slowly, and study sound waves, the Jeans instability and the evolution of these instabilities in an expanding universe. This will, I hope, fit well with material covered in the fluids courses, although no knowledge from these courses will be assumed. It also has the advantage that it will connect with observations and the most exciting current ideas in cosmology.

Below I include the new proposed schedule, and the old schedule. I think that on the whole I have removed more than I've added. With this schedule, the length of the lecture notes is the same as my Classical Dynamics lecture notes, which I think is the right ballpark for a C course.

David Tong

COSMOLOGY (C) **24 lectures, Michaelmas term**

The Expanding Universe
Review of Newtonian gravity, gravitational potential, and spherical-shell theorem. The Cosmological Principle: homogeneity and isotropy. Derivation of Hubble's law. Scale factor of the universe. Hubble parameter. Kinematic effects, including redshift and horizons. [3]

Newtonian derivation of Friedmann and Raychaudhuri equations for perfect-fluid models. Origin of cosmological constant. Observational parameters: H, q, Ω. Possible worlds: open, closed, and flat models. Different epochs: radiation-, matter- and dark-energy-dominated eras. Einstein, Friedmann, Lemaître and De Sitter universes. Age of the universe. Luminosity distance. The acceleration of the universe. Inflation and problems of the standard cosmology [6]

Statistical physics
Introduction to standard-model particles, fermions and bosons. Summary of statistical physics: Thermodynamic variables and laws, density of states, fermion and boson distributions for mass, number and entropy densities in classical and relativistic limits. [3]

Thermal History
The Bose-Einstein distribution and the Planck blackbody spectrum. Evolution of temperature. Hydrogen recombination, photon decoupling, and the origin of the cosmic microwave background radiation. Conservation of entropy, neutrino temperature and the baryon-to-photon ratio. [4]

Origin of structure: galaxies, stars and black holes
Collapse of a spherically symmetric overdensity. Simple growing mode solution for small perturbations. Nonlinear accretion and virialisation. Galaxies and hierarchy of large-scale structures. [4]

Pressure support and hydrostatic equilibrium of stars. Qualitative evolution of stars. Fermi-Dirac distribution and electron degeneracy pressure. White dwarfs and collapse to neutron stars and black holes. [4]

Appropriate Books

J.D. Barrow *The Book of Universes.* Vintage 2012
E. Linder *First Principles of Cosmology.* Addison Wesley 1997
B. Ryden *Introduction to Cosmology.* Addison-Wesley 2003
E.Kolb and M.S.Turner *The Early Universe.* Addison-Wesley 1990 (Advanced text to consult for particular topics)
E.R. Harrison *Cosmology: The Science of the Universe.* CUP 2000

COSMOLOGY (C) **24 lectures, Michaelmas term**

The Expanding Universe

The Cosmological Principle: homogeneity and isotropy. The FRW metric and the scale factor of the universe. Hubble parameter and Hubble's law. Kinematic effects, including redshift and horizons. Luminosity distance [3]

Perfect fluids. Newtonian derivation of Friedmann and Raychaudhuri equations. Simple solutions including open, closed, and flat models. The cosmological constant. Einstein, Friedmann, Lemaître and de Sitter universes. Different epochs: radiation-, matter- and dark-energy-dominated eras. The energy budget today and observational parameters H and Ω. Age of the universe. Evidence for dark matter and dark energy. Problems of the standard cosmology and inflation. [8]

The Hot Universe

Introduction to statistical mechanics: the Boltzmann and Maxwell-Boltzmann distributions. Blackbody radiation and the cosmic microwave background. Chemical potential. Bose-Einstein and Fermi-Dirac distributions. Recombination and photon decoupling. Baryon-to-photon ratio. Ultra-relativistic particles. Evolution of temperature. Basics of nucleosynthesis. [7]

Structure Formation

Linear density perturbations. Sound waves, Jeans instability and the evolution of perturbations in an expanding spacetimes. Transfer function. Adiabatic, Gaussian perturbations and the Harrison-Zel'dovich spectrum. The observed power spectrum. Baryon acoustic oscillations. *Fluctuations in the cosmic microwave background*. [6]

Additional information - Curriculum Committee Matters - Easter Term report

Classical Dynamics

Proposed book list:

L.D. Landau and E.M. Lifshitz. Mechanics, 3rd ed. Butterworth-Heinemann 1976

V.I. Arnold. Mathematical methods of classical mechanics, 2nd ed. Springer 1989

H. Goldstein, C.P. Poole and J.L. Safko. Classical mechanics, 3rd ed. Pearson 2001

L.N. Hand and J.D. Finch. Analytical mechanics. CUP 1998

F. Scheck. Mechanics: from Newton's laws to deterministic chaos, 6th ed. Springer 2018

(i.e. alphabetise and update publication years)

Automata and Formal Languages

from Maurice Chiodo: I recommend the following changes to the schedule:

1. Delete the words " homomorphisms and" from the second paragraph (beginning "Regular languages and..."). It has not been possible to fit in homomorphisms into the teaching of this course, and it seems out of place. This is a minor change.

2. Adjust the lecture split of the three sections to 10-9-5 (instead of the current split of 9-9-6). Having given this course in an almost identical way for 2 years, that is the split that occurs.