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(MATHEMATICS VALUES CHASE YEAR 01-10-2015 to 30-09-2016)

VEDIC MATHEMATICS
&
MODERN MATHEMATICS

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COURSE 05 PART – 2
CREATOR SPACE
(5-SPACE)
Fifth Week : Day 1

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Let us first revisit MA / M. Sc (mathematics courses) of University of Oxford

Syllabi

Below you will _nd syllabi for all courses in the programme, as listed in the table in Section 2. Note that the designated pre-requisites are only recommendations | they are not required as a conditions of enrolment in each course as some students may have already had adequate equivalent training during their Bachelor's degree or may choose to catch up via an independent autodidactic e_ort.

A.1 Michaelmas Term
Quantum Field Theory [24 hours]

FOUNDATIONAL COURSE.
Syllabus (written by J. Cardy, F. Essler, A. Lukas, A. Starinets). Classical _eld theory, Noether's theorem, canonical quantization, path integral formulation of quantum mechanics, path integrals in _eld theory: generating ntense ng, _nite temperature _eld theory, Feynman diagrams, Feynman rules, divergences and ntense ng ion, ntense ng ion and ntense ng ion group, scattering and S-matrices, response functions, path integrals for fermions.

Sequel: Advanced Quantum Field Theory for Particle Physics (HT), Conformal Field Theory (TT),

Quantum Field Theory in Curved Space-Time (TT)
Statistical Mechanics [16 hours] (Maths C6.2a). This course can be taken by students who have not studied this subject before (e.g., as Physics A1) but would like to be able to follow the more ntense ng courses o_ered in Hilary and Trinity that require familiarity with Statistical Mechanics.
Syllabus (from the 2012{13 Mathematics Handbook). Thermodynamics and Probability: microscopic versus macroscopic viewpoints, the laws of thermodynamics, temperature, entropy, free energy, etc. Clas-

sical Statistical Mechanics: ideal gas, Gibbs paradox, canonical and grand canonical ensembles, Liouville's
theorem and ergodicity, Maxwell relations. Nonequilibrium Statistical Mechanics: Boltzmann equation,
Boltzmann-Grad limit. Phase Transitions: order parameters, phase transitions, critical phenomena, Ising
model, Potts model, renormalization, symmetry breaking. Other Topics and Applications: This could vary
from year to year, but a good example would be Bose-Einstein condensates or statistical mechanics of
random graphs.

Introduction to Quantum Condensed Matter Physics [16 hours]

FOUNDATIONAL COURSE.
Part of this course is also o_ered as part of Physics C6.
Syllabus (written by J. Chalker and F. Essler). Second ntense ng i. Ideal Fermi and Bose gases in
second quantization. Weakly interacting Bose gas: Bogoliubov theory; superuidity. Weakly interacting
fermions: mean-_eld theory; Hartree-Fock approximation. Linear response theory.
10
Sequel: Quantum Condensed Matter Physics II (HT)
Nonequilibrium Statistical Physics [8 hours]

FOUNDATIONAL COURSE. Part of this course is also o_ered as part of Physics C6.

Syllabus (written by R. Golestanian). Stochastic Processes. Brownian motion; Langevin and Fokker-
Planck equations. Normal and anomalous di_usion. Brownian ratchets. Molecular motors.
Sequel: Soft Matter Physics (HT)
Kinetic Theory [24 hours]
FOUNDATIONAL COURSE.
Syllabus (written by J. Binney, P. Dellar, R. Golestanian, J. Magorrian, A. Schekochihin).

Part I: Basic Kinetic Theory of Gases. Liouville Theorem. BBGKY hierarchy and derivation of Boltzmann's
equation. H-theorem, Maxwell's distribution. Derivation of uid equations. Transport: viscosity and
thermal di_usvity. Onsager symmetries.

Part II: Plasma Kinetics (Charged Particles in Electromagnetic
Fields). Kinetics in an external _eld. Plasma: charged particles and self-consistent electromagnetic _elds.
Debye screening. Landau collision integral. Outline of the derivation of two-uid equations and magneto-
hydrodynamics. Collisionless plasma in electrostatic _eld. Dielectric permittivity, Landau damping, kinetic
instabilities, waves. Outline of the quasilinear theory and nonlinear approximations.

Part III: Kinetics of
Gravitating Objects. Self-gravitating kinetics and the resultant uid equations. Invariants of motion and
the Jeans theorem. Non-Maxwellian (collisionless) equilibria. Anisotropic distributions.

Part IV: Kinetics
of Quasiparticles. Phonons. UV catastrophe.
Sequels: Advanced Fluid Dynamics (HT), Plasma Physics (HT), Galactic and Planetary Dynamics
(HT)
Viscous Flow [16 hours] (Maths B6a). This course is particularly recommended to the students who

have not studied basic Fluid Dynamics (e.g., as Physics B1) and would like to be able to follow the more
ntense ng courses o_ered in Hilary and Trinity and requiring familiarity with this subject.
Syllabus (from the 2012{13 Mathematics Handbook). Euler's identity and Reynolds' transport theo-
rem. The continuity equation and incompressibility condition. Cauchy's stress theorem and properties of
the stress tensor. Cauchy's momentum equation. The incompressible Navier-Stokes equations. Vorticity.
Energy. Exact solutions for unidirectional ows; Couette ow, Poiseuille ow, Rayleigh layer, Stokes layer.
Dimensional analysis, Reynolds number. Derivation of equations for high and low Reynolds number ows.
Thermal boundary layer on a semi-in_nite at plate. Derivation of Prandtl's boundary-layer equations and
similarity solutions for ow past a semi-in_nite at plate. Discussion of separation and application to the
theory of ight. Slow ow past a circular cylinder and a sphere. Non-uniformity of the two dimensional
approximation; Oseen's equation. Lubrication theory: bearings, squeeze _lms, thin _lms; Hele-Shaw cell
and the Sa_man-Taylor instability.
Sequels: Advanced Fluid Dynamics (HT), Waves and Compressible Flow (HT)
General Relativity I [16 hours] (Maths C7.2a). FOUNDATIONAL COURSE. Some students may
have studied this subject before (for example, as Physics B5).
Syllabus (from the 2012{13 Mathematics Handbook). Review of Newtonian gravitation theory and
problems of constructing a relativistic ntense ng ion. Review of Special Relativity. The equivalence prin-
ciple. Tensor formulation of special relativity (including general particle motion, tensor form of Maxwell's
equations and the energy momentum-tensor of dust). Curved space time. Local inertial coordinates. Gen-
eral coordinate transformations, elements of Riemannian geometry (including connections, curvature and
geodesic deviation). Mathematical formulation of General Relativity, Einstein's equations (properties of the
energy-momentum tensor will be needed in the case of dust only). The Schwarzschild solution; planetary
motion, the bending of light, and black holes.
Sequels: General Relativity II (HT), Cosmology (HT), Quantum Field Theory in Curved Space-Time
(TT)

Perturbation Methods [16 hours] (Maths C6.3a). FOUNDATIONAL COURSE.
Syllabus (from the 2012{13 Mathematics Handbook). Asymptotic expansions. Asymptotic evaluation
of integrals (including Laplace's method, method of stationary phase, method of steepest descent). Reg-
ular and singular perturbation theory. Multiple-scale perturbation theory. WKB theory and semiclassics.
Boundary layers and related topics. Applications to nonlinear oscillators. Applications to partial di_erential
equations and nonlinear waves.
Sequel: Applied Complex Variables (HT)
Scienti_c Computing I [12 hours] Part of a 2-term 24-hour course, designed as an introduction to
computing for doctoral students.

Syllabus. See Maths Graduate Handbook. URL: http://www.maths.ox.ac.uk/courses/course/19944

Sequel: Scienti_c Computing II (HT)

Numerical Solutions to Di_erential Equations I [16 hours] (Maths B21a).

Syllabus (from the 2012{13 Mathematics Handbook). Development and analysis of numerical methods for initial value problems. Classical techniques for the numerical solution of ordinary di_erential equations.

The problem of sti_ness in tandem with the associated questions of step-size control and adaptivity: Initial value problems for ordinary di_erential equations: Euler, multistep and Runge-Kutta; sti_ness; error control and adaptive algorithms. Numerical solution of initial value problems for partial di_erential equations, in-cluding parabolic and hyperbolic problems: Initial value problems for partial di_erential equations: parabolic equations, hyperbolic equations; explicit and implicit methods; accuracy, stability and convergence, Fourier analysis, CFL condition.

Sequel: Numerical Solutions to Di_erential Equations II (HT)

Numerical Linear Algebra [16 hours] (Maths C12.1a).

Syllabus (from the 2012{13 Mathematics Handbook). Common problems in linear algebra. Matrix structure, singular value decomposition. QR factorization, the QR algorithm for eigenvalues. Direct solution methods for linear systems, Gaussian elimination and its variants. Iterative solution methods for linear systems. Chebyshev polynomials and Chebyshev semi-iterative methods, conjugate gradients, convergence analysis, preconditioning.

Groups and Representations [24 hours]

Syllabus (written by A. Lukas). Basics on groups, representations, Schur's Lemma, representations of _nite groups, Lie groups, Lie algebras, Lorentz and Poincare groups, SU(n), SO(n), spinor representations, roots, classi_cation of simple Lie algebras, weights, representations and Dynkin formalism.

Algebraic Topology [16 hours] (Maths C3.1a).

Syllabus (from the 2012{13 Mathematics Handbook). Chain complexes of free Abelian groups and their homology. Short exact sequences. Delta (and simplicial) complexes and their homology. Euler characteristic.

Singular homology of topological spaces. Relative homology and the Five Lemma. Homotopy invariance and excision (details of proofs not examinable). Mayer-Vietoris Sequence. Equivalence of simplicial and singular homology. Degree of a self-map of a sphere. Cell complexes and cellular homology. Application: the hairy ball theorem. Cohomology of spaces and the Universal Coe_cient Theorem (proof not examinable). Cup products. Knneth Theorem (without proof). Topological manifolds and orientability. The fundamental class of an orientable, closed manifold and the degree of a map between manifolds of the same dimension.

Poincar Duality (without proof).

Algebraic Geometry [16 hours] (Maths C3.4a).

Syllabus (from the 2012{13 Mathematics Handbook). A_ne algebraic varieties, the Zariski topology,

morphisms of a_ne varieties. Irreducible varieties. Projective space and general position points. Pro-
jective varieties, a_ne cones over projective varieties. The Zariski topology on projective varieties. The
projective closure of a_ne variety. Morphisms of projective varieties. Projective equivalence. Veronese
morphism: de_nition, examples. Veronese morphisms are isomorphisms onto their image; statement, and
proof in simple cases. Subvarieties of Veronese varieties. Segre maps and products of varieties, Categorical
products: the image of Segre map gives the categorical product. Coordinate rings. Hilbert's Nullstellensatz.
Correspondence between a_ne varieties (and morphisms between them) and _nitely generate reduced k-
algebras (and morphisms between them). Graded rings and homogeneous ideals. Homogeneous coordinate
rings. Categorical quotients of a_ne varieties by certain group actions. The maximal spectrum. Discrete
invariants projective varieties: degree dimension, Hilbert function. Statement of theorem de_ning Hilbert
polynomial. Quasi-projective varieties, and morphisms of them. The Zariski topology has a basis of a_ne
open subsets. Rings of regular functions on open subsets and points of quasi-projective varieties. The ring
of regular functions on an a_ne variety in the coordinate ring. Localisation and relationship with rings of
regular functions. Tangent space and smooth points. The singular locus is a closed subvariety. Algebraic re-
formulation of the tangent space. Di_erentiable maps between tangent spaces. Function _elds of irreducible
quasi-projective varieties. Rational maps between irreducible varieties, and composition of rational maps.
Birational equivalence. Correspondence between dominant rational maps and homomorphisms of function
_elds. Blow-ups: of a_ne space at appoint, of subvarieties of a_ne space, and general quasi-projective
varieties along general subvarieties. Statement of Hironaka's Desingularisation Theorem. Every irreducible
variety is birational to hypersurface. Re-formulation of dimension. Smooth points are a dense open subset.

A.2 Hilary Term

Advanced Quantum Field Theory for Particle Physics [24 hours]

Prequel/pre-requisite: Quantum Field Theory (MT)

Syllabus (written by X. de la Ossa, G. Ross). Quantum Electrodynamics: Introduction, photon
propagator, scalar electrodynamics (Feynman rules, radiative corrections), canonical quantization, fermions
(fermions propagator, path integral and Feynman rules), spinor electrodynamics, sample calculations (scat-
tering in spinor electrodynamics), beta function in QED. Non-Abelian Quantum Field Theory: SU(N) local
gauge theory, path integral, gauge _xing, BRST, spontaneous symmetry breaking, anomalies, introduction
to the standard model.

Sequels: The Standard Model (TT), Beyond the Standard Model (TT), Non-perturbative Methods in
Quantum Field Theory (TT)

String Theory I [16 hours]

Pre-requisite: Quantum Field Theory (MT)

Syllabus (written by P. Candelas). String actions, equations of motion and constraints, open and

closed strings | boundary conditions, Virasoro algebra, ghosts and BRS, physical spectrum, elementary
consideration of D branes, Veneziano amplitude.
Sequels: String Theory II (TT), Introduction to Gauge-String Duality (TT)
Supersymmetry and Supergravity [24 hours]
Pre-requisite: Quantum Field Theory (MT)
Syllabus (written by J. Conlon). Motivations for supersymmetry, spinor algebras and representations,
supersymmetry algebra and representations, extended supersymmetry and BPS states, super_elds, SUSY
_eld theories, non-renormalisation theorems, SUSY breaking, the MSSM and its phenomenology, rescaling
anomalies, NSVZ beta function, basic properties of supergravity.
13
Advanced Fluid Dynamics [16 hours]
Prequels: Kinetic Theory (MT), Viscous Flow (MT)
Pre-requisites: basic familiarity with uid equations and stress tensors as provided, e.g., by Kinetic
Theory (MT).
Syllabus (written by P. Dellar, A. Schekochihin, J. Yeomans). Introduction to the dynamics of uids
with stress tensors more complex than the viscous and Euler momentum uxes.

Part I: Magnetohydrody-
namics. MHD equations: Maxwell stress, magnetic pressure and tension, ux freezing, magnetic di_usion,
magnetic reconnection, Zeldovich rope dynamo. Conservation laws. Helicity, Taylor relaxation, force-free
solutions. Simple MHD equilibria. MHD waves, Elsasser variables and Elsasser solutions. Lagrangian MHD,
Cauchy solution, action principle. Energy principle, instabilities: sausage, kink, interchange (overview). Bra-
ginskii stress tensor.

Part II: Non-Newtonian uids. Stokes ow, reciprocity and minimal dissipation, forces
and torques on rigid bodies. Stokeslets, the Oseen tensor, multipole expansions. Microscopic bead-spring
models of polymers, derivation of upper convected Maxwell model. Properties of viscoelastic uids: normal
stress di_erences, rheological ows, die swell, rod climbing, elastic waves, elastic instabilities, analogies with
MHD. Liquid crystals and active suspensions.
Sequels: Astrophysical Fluid Dynamics (TT), Advanced Plasma Physics (TT), Topics in Soft and
Active Matter Physics (TT), Turbulence (TT)
Soft Matter Physics [16 hours]
Prequel/pre-requisite: Nonequilibrium Statistical Physics (MT)
Syllabus (written by R. Golestanian, A. Louis, J. Yeomans). Polymers: statics and dynamics. Mem-
branes. Liquid Crystals and topological defects. Colloids: dispersion interactions and transport. Di_usion-
reaction processes and pattern formation. Self-assembly.
Sequel: Topics in Soft and Active Matter Physics (TT)
Nonlinear Systems [16 hours] (Maths B8b).
Syllabus (from the 2012{13 Mathematics Handbook).

Part I: Bifurcations and Nonlinear Oscillators. Bifurcation theory: standard codimension one examples (saddle-node, Hopf, etc.), normal forms and

codimension two examples (brie y). Non-conservative oscillators: Van der Pol's equation, limit cycles.
Conservative oscillators (introduction to Hamiltonian systems): Du_ng's equation, forced pendulum. Syn-
chronization: synchronization in non-conservative oscillators, phase-only oscillators (e.g., Kuramoto model).

Part II: Maps. Stability and periodic orbits, bifurcations of one-dimensional maps. Poincar_e sections and
_rst-return maps.

Part III: Chaos in Maps and Di_erential Equations. Maps: logistic map, Bernoulli
shift map, symbolic dynamics, two-dimensional maps (examples could include Henon map, Chirikov-Taylor
[\standard"] map, billiard systems). Di_erential equations: Lyapunov exponents, chaos in conservative
systems (e.g., forced pendulum, Henon-Heiles), chaos in non-conservative systems (e.g., Lorenz equations).

Part IV: Other topics. Topics will vary from year to year and could include: dynamics on networks, solitary
waves, spatio-temporal chaos, quantum chaos.

Quantum Condensed Matter Physics II [24 hours]

Prequel/pre-requisite: Introduction to Quantum Condensed Matter Physics (MT)

Syllabus (written by J. Chalker and F. Essler). Phase transitions: transfer matrix methods, sponta-
neous symmetry breaking in the Ising model, Landau theory of phase transitions. Fermi liquid theory. BCS
theory of superconductivity. Strong interactions: Mott insulators. Ferromagnetism and antiferromagnetism,
Holstein-Primako_ transformation. Quantum Hall e_ect: integer and fractional QHE; fractional statistics.
Disorderd systems: random potential and localization.

Sequels: Advanced Quantum Condensed Matter Physics (TT), Topics in Quantum Condensed Matter
Physics (TT)

Networks [16 hours] (Maths C6.2b, to start in 2013-14)

Pre-requisite: Maths C6.2a or another undergraduate course in Statistical Mechanics.

Syllabus (written by M. Porter). Introduction and basic concepts. Small worlds. Toy models of
network formation. Additional summary statistics and other useful concepts. Random graphs. Community
structure and mesoscopic structure. Dynamics on (and of) networks. Additional topics.

Sequel: Complex Systems (TT)

Waves and Compressible Flow [16 hours] (Maths B6b).

Prequels: Viscous Flow (MT), Kinetic Theory (MT)

Syllabus (from the 2012{13 Mathematics Handbook). Equations of inviscid compressible ow including
ow relative to rotating axes. Models for linear wave propagation including Stokes waves, internal gravity
waves, inertial waves in a rotating uid, and simple solutions. Theories for Linear Waves: Fourier Series,
Fourier integrals, method of stationary phase, dispersion and group velocity. Flow past thin wings. Nonlinear
Waves: method of characteristics, simple wave ows applied to one-dimensional unsteady gas ow and

shallow water theory. Shock Waves: weak solutions, Rankine{Hugoniot relations, oblique shocks, bores and
hydraulic jumps.
Sequels: Geophysical Fluid Dynamics (TT), Astrophysical Fluid Dynamics (TT), Turbulence (TT)
Plasma Physics [16 hours]
Prequel: Kinetic Theory (MT)
Pre-requisite: Kinetic Theory (MT) or a basic introductory course in Plasma Physics.
Syllabus (written by F. Parra).

Part I: Magnetised plasmas. Particle motion in magnetic _eld,
adiabatic invariants. Drift kinetics, drift waves and instabilities. Kinetic MHD and CGL (double-adiabatic)
equations. Two-uid (Braginskii) equations, MHD.

Part II: Plasma waves. Cold plasma dispersion relation.
Hot-plasma dispersion relation for electrostatic waves. Hot-plasma dispersion relation for electromagnetic
waves. Landau, Barnes (transit-time) and cyclotron damping. Quasilinear theory.
Sequel: Advanced Plasma Physics (TT)
Galactic and Planetary Dynamics | Celestial Mechanics for the 21st Century [16 hours]
Prequel/pre-requisite: Kinetic Theory (MT)
Syllabus (written by J. Magorrian). Introduction to prototypical systems: Galactic disk, globular
clusters, protoplanetary disks. Characteristic length and time scales. Collisionless approximation. Deriva-
tion of Jeans and virial equations. Simple applications: need for closure relations. Orbits: integrals of
motion, orbit families. Introduction to action-angle variables: tori. Jeans' theorem. Simple equilibrium
models. Disc dynamics: winding problem; wave mechanics of discs; bars. Interactions between stellar sys-
tems. Dynamical friction. Tidal shocks. Disk heating mechanisms. Collisional systems. Negative speci_c
heat and gravothermal catastrophe. Fokker{Planck equation. Application to globular clusters.
Stellar Astrophysics [16 hours] Part of this course is also o_ered as part of Physics C1.
Syllabus (written by P. Podsiadlowski).

Part I: Modern Topics in Stellar Astrophysics. Late stages
of stellar evolution; massive stars; supernovae, millisecond pulsars, hypernovae, gamma-ray bursts; compact
binaries; the origin of elements, chemical evolution of the Universe.

Part II: Accretion discs, Theory and Applications. Accretion disc theory, thin and thick discs; disc instabilities (thermal instability, gravitational
instabilities [Toomre criterion]); optically thin advection-dominated ows, super-Eddington accretion.
Sequels: Astrophysical Fluid Dynamics (TT), High-Energy Astrophysics (TT), Astroparticle Physics
(TT)
15
General Relativity II [16 hours] (Maths C7.2b, revised)
Prequel: General Relativity I (MT)
Pre-requisite: General Relativity I (MT) or equivalent.
Syllabus (written by X. de la Ossa). Lie derivative and isometries, linearised GR and the metric of
an isolated body, Schwarzschild solution and extensions, Eddington-Finkelstein coordinates and Kruskal

extension, Penrose diagrams, area theorem, stationarity, axisymmetric metrics and orthogonal transitivity,
the Kerr solution and its properties, interpretation as rotating black hole, gravitational waves, the Einstein
_eld equations with matter, energy momentum tensor for a perfect uid, equations of motion from the con-
servation law, cosmological principle, homogeneity and isotropy, cosmological models, Friedman-Robertson
Walker metric and solutions, observational consequences.

Cosmology [16 hours]

Pre-requisite: General Relativity I (MT) or equivalent.

Syllabus (written by P. Candelas, P. Ferreira). Einstein _eld equations and the Friedman equations,
universe models, statistics of expanding background, relativistic cosmological perturbations, observations,
from the Hubble ow to the CMB.

Applied Complex Variables [16 hours] (Maths C6.3b).

Prequel: Perturbation Methods (MT)

Syllabus (from the 2012{13 Mathematics Handbook). Review of core complex analysis, especially
continuation, multifunctions, contour integration, conformal mapping and Fourier transforms. Riemann
mapping theorem. Schwarz-Christo_el formula. Solution of Laplace's equation by conformal mapping onto
a canonical domain. Applications to inviscid hydrodynamics: ow past an aerofoil and other obstacles
by conformal mapping; free streamline ows of hodograph plane. Unsteady ow with free boundaries in
porous media. Application of Cauchy integrals and Plemelj formulae. Solution of mixed boundary value
problems motivated by thin aerofoil theory and the theory of cracks in elastic solids. Reimann-Hilbert
problems. Cauchy singular integral equations. Transform methods, complex Fourier transform. Contour
integral solutions of ODE's. Wiener-Hopf method.

Scienti_c Computing II [12 hours] Part of a 2-term 24-hour course, designed as an introduction to
computing for doctoral students.

Prequel/pre-requisite: Scienti_c Computing I (MT)

Syllabus. See Maths Graduate Handbook. URL: http://www.maths.ox.ac.uk/courses/course/19944

Numerical Solutions to Di_erential Equations II [16 hours] (Maths B21b).

Prequel: Numerical Solutions to Di_erential Equations I (MT)

Syllabus (from the 2012{13 Mathematics Handbook). Numerical methods for boundary value prob-
lems. Numerical techniques for the approximation of boundary value problems for second-order ordinary
di_erential equations. Boundary value problems for ordinary di_erential equations: shooting and _nite dif-
ference methods. Finite di_erence schemes for elliptic boundary value problems. Introduction to the theory
of direct and iterative algorithms for the solution of large systems of linear algebraic equations which arise
from the discretisation of elliptic boundary value problems. Boundary value problems for PDEs: _nite dif-
ference discretisation; Poisson equation. Associated methods of sparse numerical algebra: sparse Gaussian
elimination, iterative methods.

Di_erential Geometry [16 hours]

Syllabus (written by X. de la Ossa, P. Candelas, A. Dancer, J. Sparks). Manifolds, tangent and
 ntense n spaces, di_erential forms and co-homology, Riemannian manifolds, _bre bundles (also principal
bundles and vector bundles), connections on _ber bundles, characteristic classes, index theorems.
16
Geometric Group Theory [16 hours] (Maths C3.2b).
Syllabus (from the 2012{13 Mathematics Handbook). Free groups. Group presentations. Dehn's
problems. Residually _nite groups. Group actions on trees. Amalgams, HNN-extensions, graphs of groups,
subgroup theorems for groups acting on trees. Quasi-isometries. Hyperbolic groups. Solution of the word
and conjugacy problem for hyperbolic groups. If time allows: Small Cancellation Groups, Stallings Theorem,
Boundaries.
A.3 Trinity term
Conformal Field Theory [16 hours]
Prequel/pre-requisite: Quantum Field Theory (MT)
Syllabus (written by J. Cardy). Scale invariance and conformal invariance in critical behaviour, the
role of the stress tensor, radial
 ntense ng i and the Virasoro algebra, CFT on the cylinder and torus,
height models, loop models and Coulomb gas methods, boundary CFT and Schramm-Loewner evolution,
perturbed conformal _eld theories: Zamolodchikov's c-theorem, integrable perturbed CFTs: S-matrices and
form factors.
Introduction to Gauge-String Duality [16 hours]
Prequel: String Theory I (HT)
Pre-requisite: Quantum Field Theory (MT)
Syllabus (written by A. Starinets). Duality in lattice statistical mechanics and quantum _led theory
(an overview), black hole thermodynamics and black hole entropy, D-branes, the AdS-CFT correspondence,
main recipes of gauge-string duality, gauge-string duality at _nite temperature and density, uid mechanics,
black holes and holography, transport in strongly correlated systems from dual gravity, gauge-string duality
and condensed matter physics, modern developments.
String Theory II [16 hours
Prequel/pre-requisite: String Theory I (HT)
Syllabus (written by P. Candelas). Superstring action, super-Virasoro algebra, RNS model and GSO
projection, physical spectrum, type I, IIA, IIB and heterotic strings, D-branes, string dualities.
The Standard Model [16 hours]
Prequel/pre-requisite: Advanced Quantum Field Theory for Particle Physics (HT)
Syllabus (written by X. de la Ossa, G. Zanderighi).

Part I. Weak interactions, weak decays, non-renormalizable Fermi four-point interactions (violation of unitarity), SU(2)_UY (1) gauge symmetry, sponta-
neous symmetry breaking (masses of gauge bosons), custodial symmetry and Yukawa masses, axial anomaly
cancellation, accidental symmetries, renormalizability and power counting, neutrino masses (see-saw mech-
anism), Higgs phenomenology,

Part II. Strong interaction, SU(3) symmetry, Lagrangian, color identities,

beta-function and asymptotic freedom, infrared divergences and infrared safety, e+e ! hadrons, R-ratio,
parton model (failure with radiative corrections), parton distribution functions, dimensional ntense ng ion,
subtraction procedures for calculations of cross-sections, hadron collider phenomenology: event shapes, jets,
benchmark processes (Drell-Yan, heavy quarks etc.).
Beyond the Standard Model (16 lectures, TT)
Prequel/pre-requisite: Advanced Quantum Field Theory for Particle Physics (HT)
Syllabus (written by J. March-Russell). SM precision tests, avour physics, neutrino physics, strong
CP and axions, hierarchy problem, motivations for susy/technicolour/warped extra dimensions and their
basic phenomenology, introduction to grand uni_ed theories.
17
Non-perturbative Methods in Quantum Field Theory [16 hours]
Prequel/pre-requisite: Advanced Quantum Field Theory for Particle Physics (HT)
Syllabus (written by M. Teper). Lattice Field Theory: Motivation and applications, gauge _elds on
a lattice and continuum limit(s), strong coupling calculations: con_nement and mass gap, fermions on a
lattice. Markovian Monte Carlo: Metropolis, heat bath, hybrid Monte Carlo, lightest glueball masses and
their continuum limit, calculating the hadron spectrum, the running coupling. Solitons: kinks in D=1+1
scalar QFT, a no-go theorem and its limitations, vortices in D=2+1 scalar QFT (KT phase transition),
vortices in D=2+1 gauge+scalar QFT, solitonic `strings' in D=3+1 gauge+scalar QFT (Meissner e_ect and
magnetic con_nement), textures, domain walls, homotopy groups, monopoles in the D=3+1 Georgi-Glashow
model. Instantons: ntense n in D=1+1 Quantum Mechanics, Abelian-Higgs model in D=1+1: the dilute
gas approximation, n-vacua and theta-vacua, Wilson loops and linear con_nement, SU(2) gauge _elds in
D=3+1: the dilute gas calculations, n-vacua (Chern-Simons) and theta-vacua, SU(N) and intertwined theta-
vacua, fermions and index theorems, anomalies and chiral symmetry breaking (Banks-Casher) in QCD,
anomalies, sphalerons and the baryon asymmetry in SM.
Advanced Quantum Condensed Matter Physics [8 hours]
Prequel/pre-requisite: Introduction to Quantum Condensed Matter Physics (MT), Quantum Con-
densed Matter Physics II (HT)
Syllabus (written by F. Essler). From particles to _elds: phonons and self-interacting scalar _eld
theory. Weakly interacting electron gas: perturbation theory, Dyson equation, Hartree-Fock and random-
phase approximations.
Topics in Quantum Condensed Matter Physics [8 hours]
Prequel/pre-requisite: Quantum Condensed Matter Physics II (HT)
Syllabus (written by F. Essler). This is a reading course. Under the guidance of the course ntense n,
students will give presentations based on key papers in quantum condensed matter theory. Some examples of
the topics for these presentations are: Kramers-Wannier duality for the Ising model. Feynman's wavefunction

approach to superuid helium. The Haldane conjecture for integer quantum spin chains. Quantum friction.
Homotopy and defects. Renormalisation group for Fermi liquids. The Kondo e_ect and scaling. Fractional
statistics.
Complex Systems [16 hours]
Prequel: Networks (HT)
Pre-requisite: Maths C6.2a or another undergraduate course in Statistical Mechanics.
Syllabus (written by M. Porter). Percolation, fractals, self-organised criticality, and power laws.
Stochastics and generative models: random walks, preferential attachment, master equations. Dynami-
cal systems on networks: includes models of epidemics, social inuence, voter models, etc. and how they
are a_ected by network architecture. Agent-based models. Numerical methods: Monte Carlo, simulated
annealing, etc.
Critical Phenomena [16 hours]
Pre-requisites: Quantum Field Theory (MT), Statistical Mechanics (MT) or equivalent.
Syllabus (written by J. Cardy). Phase transitions in simple systems. Mean _eld theory and its
limitations (Landau theory). Basic theory of the RG. Scaling and crossover behaviour. Perturbative RG
and the epsilon-expansion. Relation to the _eld-theoretic RG. Some applications: low-dimensional systems,
random magnets, polymer statistics, critical dynamics.
Topics in Soft and Active Matter Physics [8 hours]
Prequels: Soft Matter Physics (HT), Advanced Fluid Dynamics (HT)
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Pre-requisites: Soft Matter Physics (HT)
Syllabus (written by R. Golestanian, A. Louis, J. Yeomans). This is a reading course. Under the
guidance of the course ntense n, students will give presentations based on key papers in soft condensed
matter theory. Some examples of the topics for these presentations are: Active nematics and active gels.
Wetting, spreading and contact line dynamics. Hydrodynamics of microswimmers: Stokes equation, scallop
theorem, multipole expansion, active suspensions. Fluctuations and response.
Turbulence [16 hours]
Prequels: Kinetic Theory (MT), Viscous Flow (MT), Advanced Fluiod Dynamics (HT), Waves and
Compressible Flow (HT)
Pre-requisite: basic familiarity with uid equations as provided, e.g., by Kinetic Theory (MT), Maths
B6a or an equivalent undergraduate course (e.g., Physics B1).
Syllabus (written by A. Schekochihin). Kolmgorov 1941 theory and general philosophy of turbulent
cascades (Obukhov). Turbulent di_usion, mixing of a scalar. General framework of mean-_eld theory,
closures (basic idea, not detailed exposition). Kinematics of turbulence: correlation functions. Exact laws
(Kolmogorov's 4/5 and Yaglom's 4/3). Intermittency: basic ideas; re_ned similarity (Kolmogorov 1962);
She-Leveque theory. Turbulence in systems with waves: introduction to weak turbulence theory. Critically
balanced turbulence in wave-supporting systems: general idea and the example of rotating turbulence.
Restoration of Kolmogorov symmetries. Time-permitting: MHD turbulence, turbulent dynamo.

Geophysical Fluid Dynamics [16 hours]
Prequel: Waves and Compressible Flow (HT)
Pre-requisite: basic familiarity with uid equations as provided, e.g., by Kinetic Theory (MT), Maths
B6a or an equivalent undergraduate course (e.g., Physics B1).
Syllabus (written by D. Marshall). Rotating frames of reference, Rossby number, geostrophic and hy-
drostatic balance, thermal wind relation, pressure coordinates. Shallow water and reduced gravity models, f
and beta-planes, conservation laws for energy and potential vorticity (relation to particle ntense ng symme-
try?), inertia-gravity waves, equations for nearly geostrophic motion, Rossby waves, Kelvin waves. Linearised
equations for a strati_ed, incompressible uid, internal gravity waves, vertical modes. Quasigeostrophic ap-
proximation: quasigeostrophic potential vorticity equation and Rossby waves solutions, vertical propagation
and trapping. Barotropic and baroclinic instability, necessary conditions for instability of zonal ow, Eady
model of baroclinic instability, qualitative discussion of frontogenesis. Wave-mean ow interaction, trans-
formed Eulerian mean, Eliassen-Palm ux, non-acceleration theorem. Angular momentum and Held-Hou
model of Hadley circulations. Applications to Mars and slowly-rotating planets. Giant planets: Multiple
jets, stable eddies and free modes. Ekman layers, spin-down and upwelling. Sverdrup balance and ocean
gyres, western ntense_cation, simple models for the vertical structure of ocean circulation. Energetics and
simples models of the meridional overturning circulation.

Advanced Plasma Physics [16 hours]
Prequel: Plasma Physics (HT)
Pre-requisites: Plasma Physics (HT), Advanced Fluid Dynamics (HT)
Syllabus (written by F. Parra).

Part I: Resistive MHD. Tearing modes. Magnetic Reconnection. Part
II: Drift kinetics in curved magnetic _elds: neoclassical transport.

Part III: Drift-wave modes in curved magnetic _elds: ion-temperature-gradient (ITG) instabilities, trapped electron modes (TEM), etc.

Astrophysical Fluid Dynamics [16 hours]
Prequels: Advanced Fluid Dynamics (HT), Waves and Compressible Flow (HT)
Pre-requisite: Advanced Fluid Dynamics (HT) and/or a standard course in Fluid Dynamics.
Syllabus (written by S. Balbus).

Part I: Basic Equations. Review of Euler and Navier-Stokes equations.
E_ects of radiation. Heating and cooling processes. MHD. Ion-electron uid equations.

Part II: Basic Dynamics. Rotating Frames Gravitational tides and indirect potentials. Vorticity and _eld freezing. Taylor-
Proudman theorem. Local Equations for discs and spheres.

Part III: Waves and Instabilities. Eulerian and Langrangian perturbations. Classic waves: sound, density (in discs), gravity/inertial, MHD (slow,
Alfvn, fast). Classic instabilities: gravitational, Rayleigh-Taylor, Schwarzschild-Parker, Kelvin-Helmholtz,
Rayleigh and magnetorotational, thermal. Transport by correlated uctuations.

Part IV: Astrophysical Flows. Shock Waves, Taylor-Sedov blast-wave solution. Bondi accretion, Parker winds. Classical accretion
disc theory. Solar rotation. Growth of cosmological perturbations.

Part V: Elementary Turbulence Theory.
Scaling and Kolmogorov arguments. Kinematic and MHD Dynamos.
High-Energy Astrophysics [16 hours]
Prequel: Stellar and Atomic Astrophysics (HT)
Syllabus (written by G. Cotter). Physics of interactions between high-energy particles and radiation
(synchrotron, inverse-Compton, thermal Bremsstrahlung). Relativistic jets.
Astroparticle Physics [16 hours]
Pre-requisites: Quantum Field Theory (MT), General Relativity I (MT)
Syllabus (written by S. Sarkar). The Universe observed, constructing world models, reconstructing our
thermal history, decoupling of the cosmic microwave background, primordial nucleosynthesis. Dark matter: astrophysical phenomenology, relic particles, direct and indirect detection. Cosmic particle accelerators,
cosmic ray propagation in the Galaxy. The energy frontier: ultrahigh energy cosmic rays and neutrinos.
The early Universe: constraints on new physics, baryo/leptogenesis, ination, the formation of large-scale
structure, dark energy.
Quantum Field Theory in Curved Space-Time [16 hours]
Prequels/pre-requisites: Quantum Field Theory (MT), General Relativity I (MT)
Syllabus (written by A. Starinets). Non-interacting quantum _elds in curved space-time (Lagrangians,
coupling to gravity, spinors in curved space-time, global hyperbolicity, Green’s functions, canonical quanti-
zation, choice of vacuum) Quantum _elds in Anti de Sitter space. Quantum _elds in an expanding universe.
Unruh e_ect. Casimir e_ect. Black hole thermodynamics. Hawking radiation. Interacting quantum _elds
in curved space-time. E_ective action, heat kernel and renormalization. Holographic principle.

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