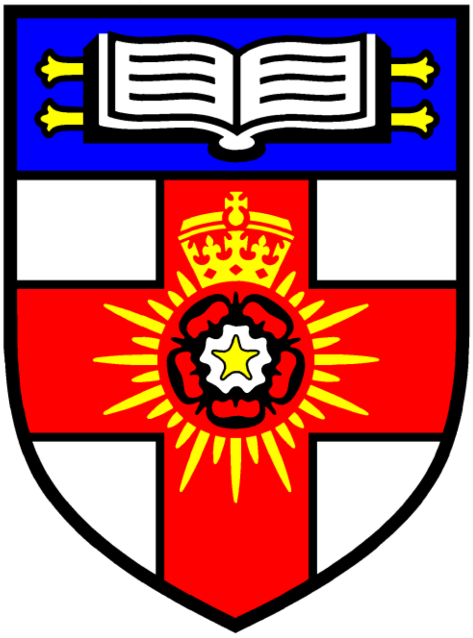
University of London

MSci Intercollegiate Planning Board



Physics MSci

Student Handbook

Intercollegiate taught courses for 2013-2014 session

This version is correct as at 09 Oct. 13

Contents

Courses and Teachers

Each course has a code number used by the Intercollegiate MSci board, shown at the left hand side. Colleges use local codes for the courses they teach. The *number* is usually the same as the MSci code, but some are different; beware! Local course codes are shown at the right hand side.

All courses are a half course unit (15 credits). In QMUL language, they are a full course unit.

The list shows the course title and the term in which it is taught. Also indicated is the course teacher and the college from where he/she comes.

No.	**Course Title**	**Term**	**Teacher**		**Local no**
4201	Math Methods for Theoretical Physics ~	1	Prof S. Sarkar	KCL	7CCP4201
4205	Lie Groups and Lie Algebras €	1	Dr. A. Recknagel	KCL+	7CCMMS01
4211	Statistical Mechanics	2	Prof. B. Cowan	RHUL§	PH4211
4215	Phase Transitions	1	Prof. M. Dove	QMUL	PHY7017U/P
4226	Advanced Quantum Theory	1	Dr A. Olaya-Castro	UCL	PHASM426
4242	Relativistic Waves & Quantum Fields	1	Prof. G. Travaglini	QMUL	PHY7004U/P
4245	Advanced Quantum Field Theory	2	Prof. A Brandhuber	QMUL	PHY7007U/P
4261	Electromagnetic Theory	1	Prof. B. Carr	QMUL	PHY7005U/P
4319	Formation and Evolution of Stellar Clusters	1	Dr. I. Ferreras	UCL	PHASM319
4421	Atom and Photon Physics	1	Dr. C. Faria	UCL	PHASM421
4425	Advanced Photonics	2	Prof. A. Zayats	KCL	7CCP4126
4427	Quantum Computation and Communication	2	Prof. J. Oppenheim	UCL	PHASM427
4431	Molecular Physics	2	Prof. A. Shluger	UCL	PHASM431
4442	Particle Physics	1	Dr. R. Nichol	UCL	PHASM442
4450	Particle Accelerator Physics	1	Dr. P. Karataev	RHUL§	PH4450
4472	Order and Excitations in Condensed Matter	2	Prof N Skipper	UCL	PHASM472
4473	Theoretical Treatments of Nano-systems	2	Dr. R. D'Agosta	KCL	7CCP4473
4475	Physics at the Nanoscale	1	Prof. V. Petrashov	RHUL	PH4475
4476	Electronic Structure Methods	2	Dr. A. Misquita	QMUL	PHY7016U/P
4478	Superfluids, Condensates and Superconductors	1	Prof. J. Saunders	RHUL	PH4478
4501	Standard Model Physics and Beyond	2	Prof. Mavromatos	KCL	7CCP4501
4512	Nuclear Magnetic Resonance	2	Dr. C. P. Lusher	RHUL*	PH4512

4515	Computing and Statistical Data Analysis	1	Prof. G. Cowan	RHUL	PH4515
4534	String Theory and Branes €	2	Prof. P. West	KCL+	7CMMS34
4541	Supersymmetry & Gauge Symmetry €	2	Dr S Schafer-Nameki	KCL+	7CMMS41
4600	Stellar Structure and Evolution	1	Dr. S. Vorontsov	QMUL	PHY7009U/ ASTM109
4601	Cosmology	1$	Prof. J.E.Lidsey	QMUL	PHY7010U/ ASTM108
4602	Relativity and Gravitation #	1	Dr. A. G. Polnarev	QMUL	PHY7006U/ P
4604	General Relativity and Cosmology	2	Prof. N. Mavromatos	KCL	7CCP4630
4605	Astroparticle Cosmology	2	Prof. M. Sakellariadou	KCL	7CCP4600
4630	Planetary Atmospheres	2	Prof. A. Coates	UCL	PHASM312
4640	Solar Physics	2	Dr. L van Driel Gesztelyi	UCL	PHASM314
4650	Solar System	1	Prof. C. Murray	QMUL	PHY7011U/ ASTM001
4660	The Galaxy	2	Dr. W Sutherland	QMUL	PHY7012U/ ASTM002
4670	Astrophysical Plasmas	2$	Prof. D. Burgess	QMUL	PHY7014U/ ASTM116
4680	Space Plasma and Magnetospheric Physics	2	Dr. C. Owen	UCL	PHASM465
4690	Extrasolar Planets & Astrophysical Discs	2$	Dr. Y. Tsapras	QMUL	PHY7013U/ ASTM735
4702	Environmental Remote Sensing	1	Prof M Wooster	KCL†	7SSG5029
4800	Molecular Biophysics	2	Dr. B. Hoogenboom	UCL	PHASM800
4810	Theory of Complex Networks #	1	Dr. M. Urry	KCL+	7CCMCS02
4820	Equilibrium Analysis of Complex Systems	1	Dr. I. Perez Castillo	KCL+	7CCMCS03
4830	Dynamical Analysis of Complex Systems	2	Dr. A. Annibale	KCL+	7CCMCS04
4840	Mathematical Biology	2	Dr. R. Kuehn	KCL+	7CCMCS05
4850	Elements of Statistical Learning #	2	Dr. M. Urry	KCL+	7CCMCS06

Students will undertake one or more project-related courses in accordance with practice at their own colleges.

Note: greyed-out courses will not run this session

§ Course taught over VideoCon network – sites at UCL, QMUL and RHUL
$ Course taught at QMUL in the *evening* this session.
* Course taught at RHUL in Egham, also available over VideoCon at QMUL
# Course unavailable to UCL students for syllabus reasons
~ Course unavailable to RHUL students for syllabus reasons
\+ Course taught by the *Mathematics* department of KCL

In the interest of balance students will ordinarily take no more than *three* KCL maths courses.
†Course taught by the *Geography* department at KCL
€ Course content is mathematically demanding

Web and Email Addresses

You can communicate with most of the course teachers using email. And some courses have their own web pages. Address details are given in the following table.

No.	Course and web address	Teacher email address
4201	Math Methods for Theoretical Physics	sarben.sarkar@kcl.ac.uk
4205	Lie Groups and Lie Algebras http://www.mth.kcl.ac.uk/courses	andreas.recknagel@kcl.ac.uk
4211	Statistical Mechanics http://personal.rhul.ac.uk/UHAP/027/PH4211/	b.cowan@rhul.ac.uk
4215	Phase Transitions http://ph.qmul.ac.uk/intranet/undergraduates/module?id=132	martin.dove@qmul.ac.uk
4226	Advanced Quantum theory	a.olaya@ucl.ac.uk
4242	Relativistic Waves & Quantum Fields http://ph.qmul.ac.uk/intranet/undergraduates/module?id=46	g.travaglini@qmul.ac.uk
4245	Advanced Quantum Field Theory http://ph.qmul.ac.uk/intranet/undergraduates/module?id=46	a.brandhuber@qmul.ac.uk
4261	Electromagnetic Theory http://ph.qmul.ac.uk/intranet/undergraduates/module?id=45	b.j.carr@qmul.ac.uk
4319	Formation and Evolution of Stellar Clusters	ipf@mssl.ucl.ac.uk
4421	Atom and Photon Physics	c.faria@.ucl.ac.uk
4425	Advanced Photonics	a.zayats@kcl.ac.uk
4427	Quantum Computation and Communication	j.oppenheim@ucl.ac.uk
4431	Molecular Physics	a.shluger@ucl.ac.uk
4442	Particle Physics http://www.hep.ucl.ac.uk/~markl/teaching/4442	rjn@hep.ucl.ac.uk
4450	Particle Accelerator Physics	pavel.karataev@rhul.ac.uk
4472	Order & Excitations in Cond. Matt.	n.skipper@ucl.ac.uk
4473	Theoretical Treatments of Nano-systems http://www.kcl.ac.uk/kis/schools/phys_eng/physics/courses/CourseList/CP4473.htm	roberto.dagosta@kcl.ac.uk
4475	Physics at the Nanoscale	v.petrashov@rhul.ac.uk
4476	Electronic Structure Methods http://ph.qmul.ac.uk/intranet/undergraduates/module?id=133	a.j.misquitta@qmul.ac.uk
4478	Superfluids, Condensates and Superconductors	j.saunders@rhul.ac.uk
4501	Standard Model Physics and Beyond	nikolaos.mavromatos@kcl.ac.uk
4512	Nuclear Magnetic Resonance	c.lusher@rhul.ac.uk
4515	Computing & Statist. Data Analysis http://www.pp.rhul.ac.uk/~cowan/stat_course.html	g.cowan@rhul.ac.uk
4534	String Theory and Branes http://www.mth.kcl.ac.uk/courses	peter.west@kcl.ac.uk
4541	Supersymmetry and Gauge Symmetry http://www.mth.kcl.ac.uk/courses	sakura.schafer-nameki@kcl.ac.uk
4600	Stellar Structure and Evolution http://ph.qmul.ac.uk/intranet/undergraduates/module?id=83	S.V.Vorontsov@qmul.ac.uk

4601	Cosmology http://ph.qmul.ac.uk/intranet/undergraduates/module?id=84	J.E.Lidsey@qmul.ac.uk
4602	Relativity and Gravitation http://ph.qmul.ac.uk/intranet/undergraduates/module?id=81	A.G.Polnarev@qmul.ac.uk
4604	General Relativity and Cosmology	nikolaos.mavromatos@kcl.ac.uk
4605	Astrophysical Cosmology	Mairi.sakellariadou@kcl.ac.uk
4630	Planetary Atmospheres http://www.mssl.ucl.ac.uk/teaching/UnderGrad/4312.html	ajc@mssl.ucl.ac.uk
4640	Solar Physics http://www.mssl.ucl.ac.uk/~lvdg/	lvdg@mssl.ucl.ac.uk
4650	Solar System http://ph.qmul.ac.uk/intranet/undergraduates/module?id=85	c.d.murray@qmul.ac.uk
4660	The Galaxy http://ph.qmul.ac.uk/intranet/undergraduates/module?id=87	w.j.sutherland@qmul.ac.uk
4670	Astrophysical Plasmas http://ph.qmul.ac.uk/intranet/undergraduates/module?id=88	d.burgess@qmul.ac.uk
4680	Space Plasma and Magnetospheric Physics http://www.mssl.ucl.ac.uk/teaching/UnderGrad/4665.html	ajc@mssl.ucl.ac.uk
4690	Extrasolar Planets and Astrophysical Discs http://ph.qmul.ac.uk/intranet/undergraduates/module?id=86	y.tsapras@qmul.ac.uk
4702	Environmental Remote Sensing	martin.wooster@kcl.ac.uk
4800	Molecular Biophysics	b.hoogenboom@ucl.ac.uk
4810	Theory of Complex Networks http://www.mth.kcl.ac.uk/courses	matthew.urry@kcl.ac.uk
4820	Equilibrium Analysis of Complex Systems http://www.mth.kcl.ac.uk/courses	isaac.perez castillo@kcl.ac.uk
4830	Dynamical Analysis of Complex Systems http://www.mth.kcl.ac.uk/courses	alessia.annibale@kcl.ac.uk
4840	Mathematical Biology http://www.mth.kcl.ac.uk/courses	reimer.kuehn@kcl.ac.uk
4850	Elements of Statistical Learning http://www.mth.kcl.ac.uk/courses	matthew.urry@kcl.ac.uk

Programme Strands

The table below gives a coherent base of courses for your registered programme and specialization interests. It is strongly recommended that you choose one of these programme strands, and then select other courses to make up your full complement.

You should also note that some courses, particularly the more mathematical ones may require a high degree of mathematical ability – certainly more than would be contained in a standard single-honours Physics programme. Such courses would be appropriate for some joint degrees.

	Recommended Courses	
Strand	**Term 1**	**Term 2**
Particle Physics	PH4226: Advanced Quantum Theory PH4442: Particle Physics PH4515: Computing and Statistical Data Analysis PH4242: Relativistic Waves and Quantum Fields	
Condensed Matter	PH4226: Advanced Quantum Theory PH4475: Physics at the Nanoscale	PH4211: Statistical Mechanics PH4472: Order and Excitations in Condensed Matter PH4512: Nuclear Magnetic Resonance
Theoretical Physics	PH4226: Advanced Quantum Theory PH4261: Electromagnetic Theory	PH4211: Statistical Mechanics PH4242: Relativistic Waves and Quantum Fields PH4245: Advanced Quantum Field Theory
General list / Applied Physics	PH4226: Advanced Quantum Theory	PH4211: Statistical Mechanics

Teaching and Examination Arrangements

Teaching Term Dates: Courses are taught in eleven-week terms. For the session 2013-2014 the teaching dates are:

First term Monday 30 September – Friday 13 December 2013
Second term Monday 13 January – Friday 28 March 2014

Note: these teaching dates may not be the same as your College terms!

Some courses – particularly Astro courses at QMUL and Maths courses at KCL might run according to the home College's term dates. QMUL Astro courses, for example, start in the week beginning 23 September and the week beginning 6 January in term two. You should check dates with the course leader.

MSci Administrative contact points at each College

KCL: James French, james.french@kcl.ac.uk, telephone 020 7848 2823
QMUL: Susan Benedict, s.benedict@qmul.ac.uk, telephone 0207 882 6962
RHUL: Gill Green, gill.green@rhul.ac.uk, telephone 01784 443506
UCL: Dr. Dan Browne, d.browne@ucl.ac.uk, telephone 020 7679 3602

Registration

If you are taking courses at another College, it is very important that you fill out a course registration form from that College (i.e. you must fill out a UCL form for UCL taught courses, a KCL form for KCL taught courses and so on). If you do not fill out these types of form for all of your courses at other colleges you will not have a place in the examination hall. It is not enough to inform your home College of your selection. You must complete the registration forms and submit them through your own College administrator by the date specified by each College:

KCL: Beginning of October 2013
QMUL: 25 January 2014
RHUL: 30 September 2013 (undergraduates), 31 October 2013 (postgraduates)
UCL: Beginning of October 2013

If you drop a course at another College you should inform both your own College and the administrative contact point at the College that runs the course.

Class locations

The timetable gives details of room locations; this is published separately from the Handbook and it is also available on the Intercollegiate MSci web pages http://www.rhul.ac.uk/physics/informationforcurrentstudents/msci4thyear/msci4thyear.htm.

Most courses are taught in lecture rooms at UCL. The exceptions are:

Courses taught at KCL

4201 Mathematical Methods for Theoretical Physics
4205 Lie Groups and Lie Algebras
4425 Advanced Photonics
4501 Standard Model Physics and Beyond
4534 String Theory and Branes
4541 Supersymmetry & Gauge Symmetry
4605 Astroparticle Cosmology
4792 Environmental Remote Sensing
4810 Theory of Complex Networks
4820 Equilibrium Analysis of Complex Systems
4830 Dynamical Analysis of Complex Systems
4840 Mathematical Biology
4850 Elements of Statistical Learning
4603 General Relativity and Cosmology

Courses taught at QMUL

4215 Phase Transitions
4476 Electronic Structure Methods
4600 Stellar Structure and Evolution
4601 Cosmology
4602 Relativity and Gravitation
4650 Solar System
4660 The Galaxy
4670 Astrophysical Plasmas
4690 Extrasolar Planets and Astrophysical Discs

Some of these QMUL courses will be taught in the evening; *check pages 3-4 and the timetable for details.*

Courses taught over VideoCon network – sites at UCL, QMUL and RHUL

4211 Statistical Mechanics
4450 Particle Accelerator Physics

Courses taught at RHUL – Egham campus and *available over VideoCon at QMUL*

4512 Nuclear Magnetic Resonance

Coursework policy

Some courses have coursework associated with them and others do not. The details are given in the Course Descriptions below.

Examination arrangements

The examinations period for all Colleges will run between 12 May and 30 May.
Queen Mary’

UCL Students: You will sit UCL and RHUL examinations at UCL. You will sit KCL examinations at KCL and QMUL examinations at QMUL.

KCL Students: You will sit KCL and RHUL examinations at KCL. You will sit UCL examinations at UCL and QMUL examinations at QMUL.

QMUL Students: You will sit QMUL and RHUL examinations at QMUL. You will sit UCL examinations at UCL and KCL examinations at KCL.

RHUL students: You will sit all your examinations at RHUL.

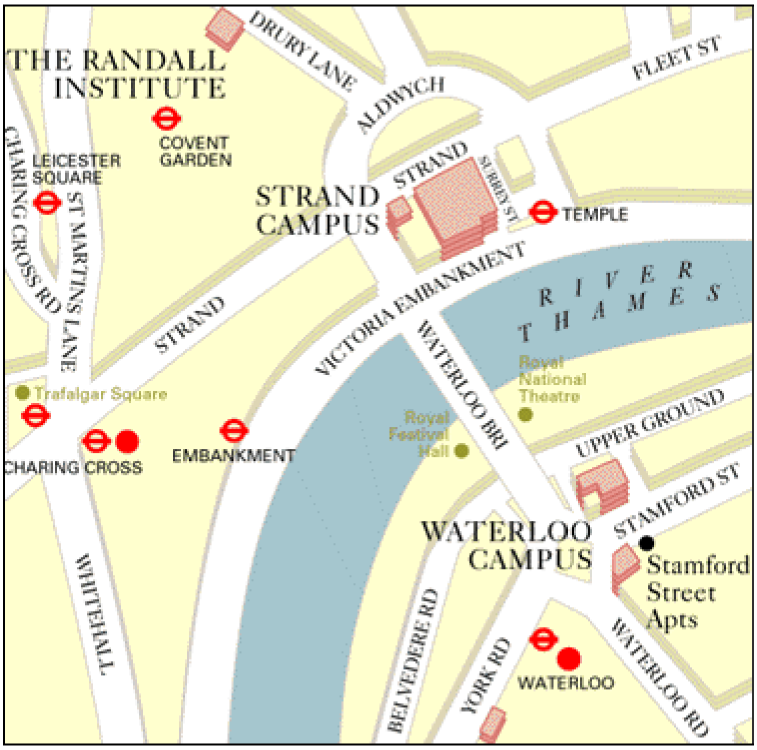
The college responsible for the examination is given in column 5 of the table on pages 3 and 4.

Computer and Library facilities at UCL

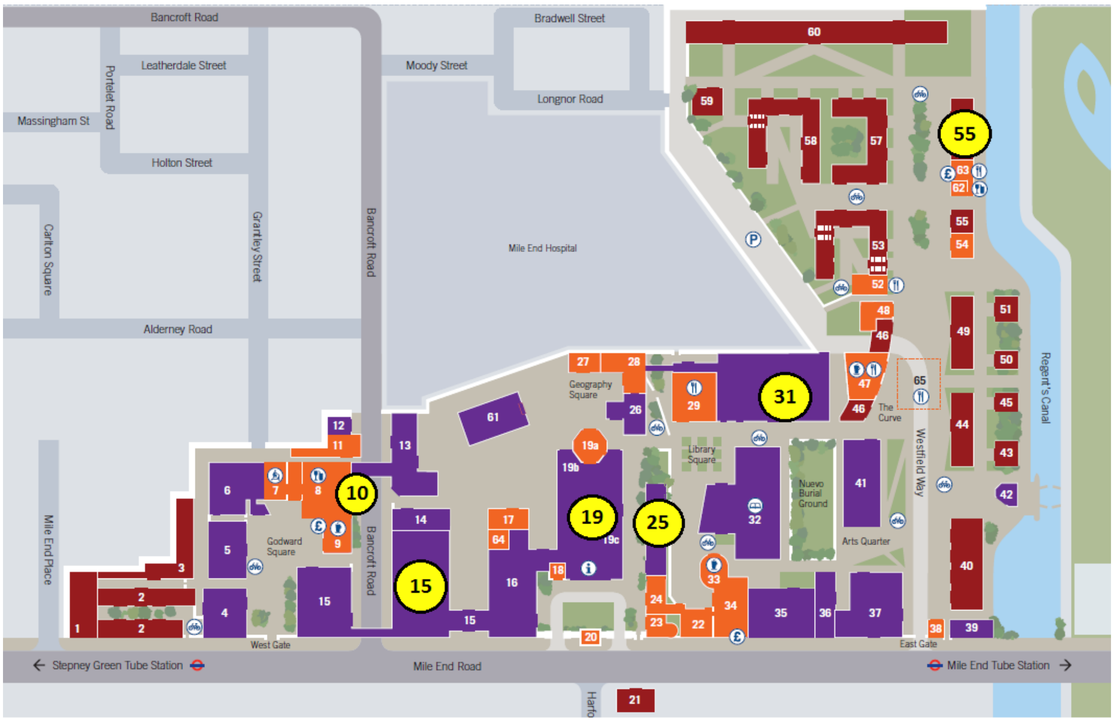
Registration on any UCL course will get you automatic library access, a UCL computer account and a UCL security card. This takes about a week from UCL receiving your signed form and submitting it to their Exam section. The Exam section then set all this up and will notify you when it is done.

College and Class Locations

King's College, Strand. London, WC2.



Queen Mary University of London, Mile End Road, London E1**.**



Bancroft Road Teaching Rooms	10
Engineering Building	15
Queens' Building ⓘ	19
G.O. Jones Building	25
The Bancroft Building	31
France House	55

Stepney Green tube station is on the District and Hammersmith & City lines. Turn left out of the station and walk along the Mile End road for approximately 5 minutes until you reach the East Gate on your left.

Mile End tube station is on the Central line. Turn left out of the station, cross over the junction, go under the bridge and along Mile End road for approximately 2 minutes. You will see the East Gate on the opposite side of the road.

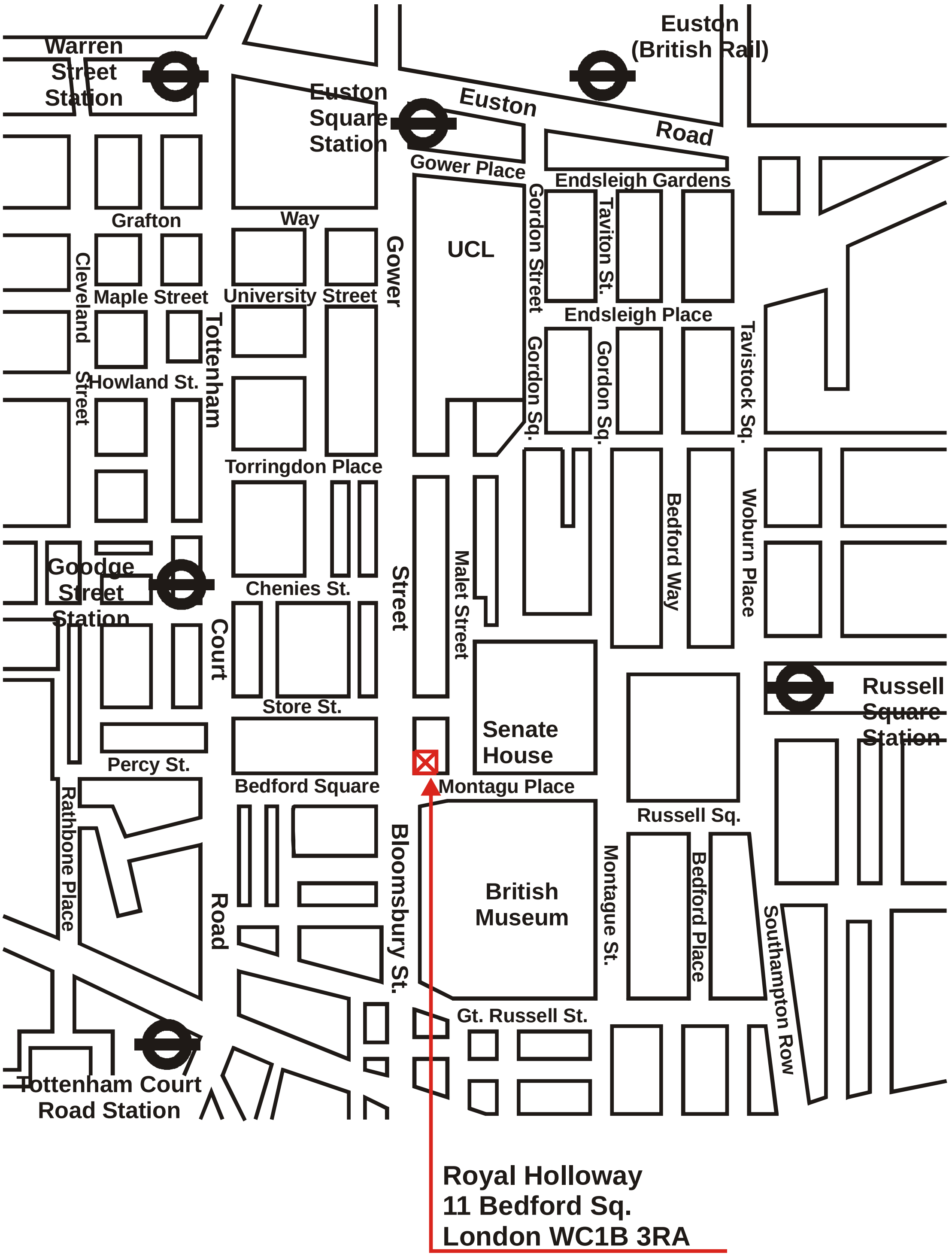
The East Gate will be recognisable by a big 'Queen Mary' banner on the wall next to it.

Students may obtain a campus map from the Physics Department admin office on the second floor of the GO Jones Building in Rooms 110.

Please note the Francis Bancroft Building has been renamed the Bancroft Building.

Royal Holloway University of London, central London base.

11 Bedford Square and Senate House.



On arrival students must sign in at the front desk of the building before proceeding to their class.

Royal Holloway University of London, Egham campus

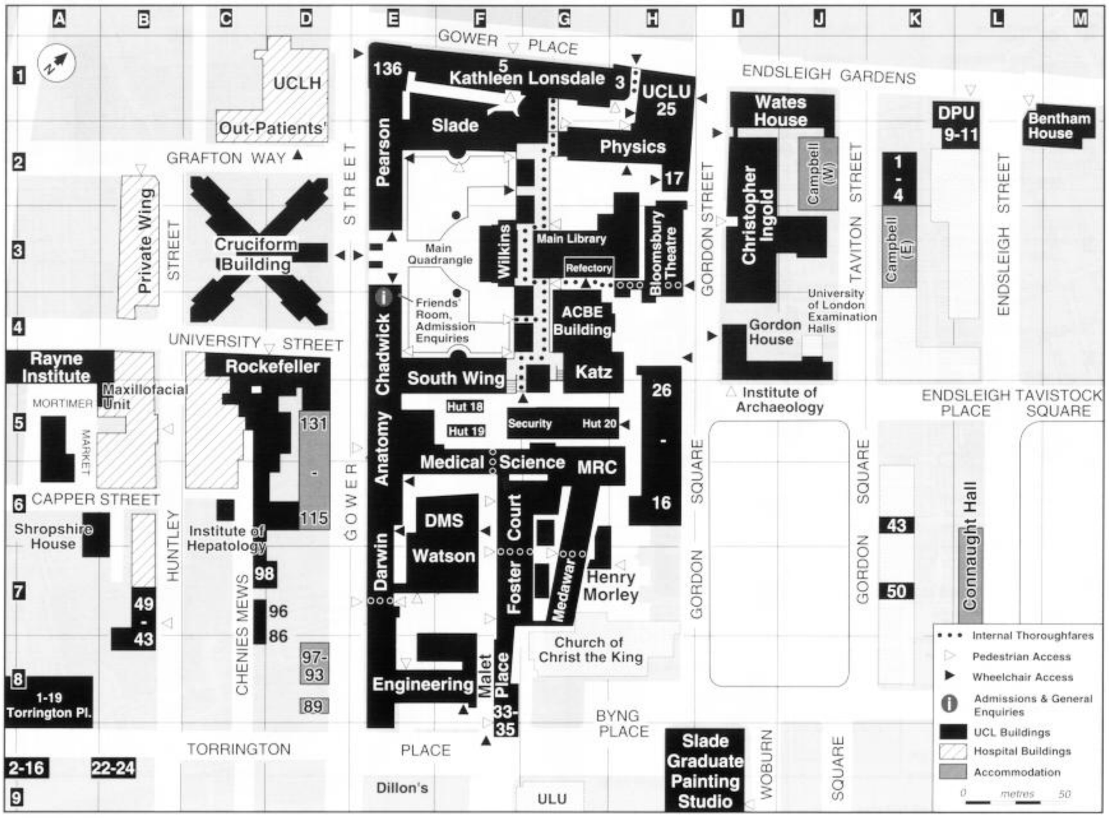
By Rail: There are frequent services from London Waterloo to Egham station (35 minutes); Woking to Egham (35 minutes, change at Weybridge) and Reading to Egham (40 minutes). Services at weekends, especially those on Sunday, are less frequent than on weekdays.

From Egham station by Bus: There is a College bus service that carries students and visitors directly from Egham station to the bus stop on Campus. The bus timetable is available on http://www.rhul.ac.uk/forstudents/campuslife/collegebusservice.aspx.

From Egham station by Foot: The College is just over a mile from Egham Station, about 20 minutes walk. Turn right out of the station along Station road and walk about 100 yards to the T-Junction and the traffic lights. Turn left at the junction and follow the road up to the large roundabout; go left up Egham Hill (south-west direction). It is easiest to enter by the gate before the foot bridge over the road and follow the path to the Physics Department – buildings 21 and 22.

By Road: The College is on the A30, 20 miles from central London and about a mile south-west of the town of Egham. It is 2 miles from junction 13 of the M25 (London Orbital). After leaving the motorway take the A30 west, signposted to Bagshot and Camberley (not Egham). At the first roundabout, take the second exit; at the second roundabout, again take the second exit and continue on the A30 up Egham Hill. The College is on the left at the top of the hill. There are footbridges across the road at the pedestrian and main entrances.

University College, Gower Street, London WC1



Entrance to the UCL campus is from Gower Street into the Main Quadrangle and then into the appropriate building. UCL-based lectures can take place in lecture theatres across UCL's Bloomsbury Campus. Detailed downloadable maps and a routefinder - which can give you detailed walking directions to any lecture theatre - can be found at http://www.ucl.ac.uk/maps .

Course Details

4201 Mathematical Methods for Theoretical Physics

Aims and Objectives

This course introduces mathematical techniques which are crucial to the formulation and solution of fundamental theories in Physics. It is biased towards the application of mathematics to solve problems, rather than the development of rigorous mathematics. It assumes competence in the use of mathematics covered in previous mathematical courses given in the first and second years. On finishing the course, students should be able to solve physics problems through complex analysis, the calculus of variations, and extend the definition of special functions to the complex plane.

Syllabus outline

Functions of a complex variable: limits, continuous and differentiable functions; Cauchy-Riemann equations for an analytic function $f(z)$; physical significance of analytic functions; properties of power series, definition of elementary functions using power series; complex integral calculus, contour integrals, upper bound theorem for contour integrals; Cauchy-Goursat theorem; Cauchy integral representation, Taylor and Laurent series, singularities and residues; residue theorem and its applications. Properties of the gamma function $\Gamma(z)$. Bessel functions; series solution of the Bessel differential equation; definition of $J_n(z)$ and $Y_n(z)$; recurrence relations for $J_n(z)$; zeros of $J_n(z)$; orthogonality properties of Bessel functions; solution of the wave equation in plane polar coordinates. Classical mechanics; constraints and generalised co-ordinates; D'Alembert's principle; Lagrange equations of motion; conservation laws; Hamilton's equation of motion; conservation laws and Poisson brackets. Calculus of variation; method of Lagrange multipliers; functionals; Euler-Lagrange equation; minimum surface energy of revolution; properties of soap films; Hamilton's principle in classical dynamics; multiple integral problems and field equations.

4205 Lie Groups and Lie Algebras

Aims and objectives:
This course gives an introduction to the theory of Lie groups, Lie algebras and their representations. Lie groups are essentially groups consisting of matrices satisfying certain conditions (e.g. that the matrices should be invertible, or unitary, or orthogonal). They arise in many parts of mathematics and physics. One of the beauties of the subject is the way that methods from many different areas of mathematics (algebra, geometry, analysis) are all brought in at the same time. The course should enable you to go on to further topics in group theory, differential geometry, string theory and other areas.

Syllabus:
Examples of Lie groups and Lie algebras in physics. Matrix Lie groups, matrix Lie algebras, the exponential map, BCH formula. Abstract Lie algebras, examples: sl(2), sl(3), Poincare algebra. Representations of Lie algebras, sub-representations, Schur's Lemma, tensor products. Cartan-Weyl basis, classification of simple Lie algebras (without proof).

Web page: See http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures per week

Prerequisites:
Note – A high level of mathematical ability is required for this course
Basic knowledge of vector spaces, matrices, groups, real analysis.

Assessment:
One two-hour written examination at the end of the academic year.
Assignments:
Exercises in the course notes. Solutions will be provided.

Books:
There is no book that covers all the material in the same way as the course, but the following may be useful:

- Baker, Matrix groups, Springer, 2002
- J. Fuchs, C. Schweigert, Symmetries, Lie algebras and representations, CUP 1997
- J. Humphreys, Introduction to Lie Algebras and Representation Theory, Springer, 1972
- H. Jones, Groups, Representations and Physics, IoP, 1998

4211 Statistical Mechanics

Course taught over VideoCon network – sites at UCL, QMUL and RHUL

The Methodology of Statistical Mechanics (5 lectures)

- Relationship between statistical mechanics and thermodynamics – emergence.
- Review of equilibrium statistical mechanics.
- The grand canonical ensemble. Chemical potential. The Bose and Fermi distribution functions.
- The classical limit, phase space, classical partition functions.

Weakly Interacting Systems (7 lectures)

- Non-ideal systems. The imperfect gas and the virial expansion, Mayer's f function and cluster integrals. (2 lectures)
- The second virial coefficient for the hard sphere, square-well and Lennard-Jones potentials. (2 lectures)
- Throttling and the Joule-Kelvin coefficient. (1 lecture)
- The van der Waals gas as a mean field paradigm. (2 lectures)

Strongly Interacting Systems (13 lectures)

- The phenomenology of phase transitions, definitions of critical exponents and critical amplitudes. (2 lectures)
- Scaling theory, corresponding states. (2 lectures)
- Introduction to the Ising model. Magnetic case, lattice gas and phase separation in alloys and Bragg-Williams approximation. Transfer matrix method in 1D. (3 lectures)
- Landau theory. Symmetry breaking. Distinction between second order and first order transitions. Discussion of ferroelectrics. (3 lectures)
- Broken symmetry, Goldstone bosons, fluctuations, scattering, Ornstein Zernike, soft modes. (3 lectures)

Dissipative Systems (5 lectures)

- Fluctuation-dissipation theorem, Brownian motion, Langevin equation, correlation functions. (5 lectures)

Books:
B. Cowan, "Topics in Statistical Mechanics", 2005, Imperial College Press.
R. Bowley & M. Sánchez, "Introductory Statistical Mechanics", 1999, OUP
Other books and publications will be referred to by the lecturer.
Course notes and other material available on the course web pages at
http://personal.rhul.ac.uk/UHAP/027/PH4211/

Assessment:
Written examination of 2½ hours contributing 90%, coursework contributing 10%.

4215 Phase Transitions

Aims and objectives:
Phase transitions are ubiquitous in condensed matter physics, and their existence gives rise to many important properties that are exploited in many physics-based technologies, including electronics, sensors and transducers. Many of the most important phase transitions are found in materials that are more complex than the simple materials that traditionally are covered in condensed matter physics teaching. The aim of this module is to expose students to the wealth of physics contained within the study of phase transitions, and equip students with the skills required to manipulate the theory and analyse associated data.

Syllabus:
The course is divided into 9 topics, some of which span more than one session.

Topic 1: Phenomenology
How we define a phase transition; Experimental observations and implications of phase transitions on properties; Various types of phase transitions; Quantification via an order parameter; Qualitative form of free energy and implications; Role of susceptibility.

Topic 2. Magnetic phase transitions
Origin of magnetic moments in materials (review); Curie law for paramagnetic materials; Magnetic interactions; Different types of magnetic order; Definition of mean field theories; Curie-Weiss model for ferromagnetism; Extension for antiferromagnetism; Comparison with experimental and simulation data, and critique of the model.

Topic 3. Landau theory
Expected shape of free energy curves above and below the phase transition, with separate contributions from potential energy and entropy term; Model for second-order phase transition and predictions (order parameter, heat capacity, susceptibility, and order parameter vs field at the phase transition; Connection with predictions from mean field theory; Model for first-order phase transition, noting tricritical as the in-between case; Coupling to strain; Worked examples and comparison with experiment data (including $PbTiO_3$).

Topic 4. Role of symmetry
Review of point symmetry, with examples of loss of symmetry at phase transitions; Symmetry of strain and its relationship from the symmetry associated with the order parameter; Translational symmetry with some examples (starting with the rotational perovskite structure).

Topic 5. Soft modes and displacive phase transitions
Phenomenology of ferroelectric phase transitions, extended to other displacive phase transitions; Lyddane-Sachs-Teller relation for dielectric constant implies transverse optoc mode frequency falling to zero at the phase transition; Review phonon dispersion relations, and role of potential energy surface in the space of normal mode coordinates in determining phonon frequency; Note that unstable modes give rise to negative squared frequencies, hence suggestion of soft modes; Experimental data; Renormalised phonon theory to describe origin of soft mode; Phonon theory of thermodynamics of low-temperature phase; Phi-4 model, described with very simple mean-field solution; Rigid unit mode model, giving insights into a) why materials can deform easily, b) what determines the transition temperature, c) why mean field theory works, d) structural disorder in high-temperature phase.

Topic 6. Order-disorder phase transitions
Different types of order-disorder phase transitions, including atom ordering, orientational disorder, liquid crystals, H-bonding transitions, fast ion conductors; Bragg-Williams model as

adaptation of Curie-Weiss model, comparison with experiments; Beyond Bragg-Williams: cluster variation model; Monte Carlo methods.

Topic 7. Critical point phenomena
Phenomena: critical point exponents, universality, role of dimensions; Predictions of critical point exponents for different models; Correlation functions and role of correlation lengths; Scaling arguments giving rise to scaling relations between critical exponents; Introduction to renormalisation group theory.

Topic 8. The three traditional states of matter
Liquid-gas phase diagram; Van der Waal equation of state and relation to mean-field theories; Theories of melting; Polymorphism in the solid state and reconstructive phase transitions; In-between states: orientational disorder, fast ion conductors, liquid crystals.

Topic 9. Role of composition and pressure
Compositional phase diagrams for liquid/solid solutions, exsolution, eutectics; Phase diagrams of metals, including steels; High-pressure phase transitions and phase diagrams, including ice; Clausius-Clapeyron relation and explanation of shapes of solid-state phase diagrams.

Teaching arrangements:
Lectures, 33 hours delivered in 11 sessions of 3 hours each.

Prerequisites:
Condensed Matter Physics course

Assessment:
Examination 2.5 hours 90%, coursework 10%.

Books:

Dove, Structure and Dynamics (Oxford University Press)
Yeomans, Statistical Mechanics of Phase Transitions (Oxford University Press)
Fujimoto, The Physics of Structural Phase Transitions (Springer)

4226 Advanced Quantum Theory

This course aims to:

- review the basics of quantum mechanics so as to establish a common body of knowledge for the students from the different Colleges on the Intercollegiate MSci. programme;
- extend this, by discussing these basics in more formal mathematical terms;
- explore the WKB approximation, as a method for studying tunnelling and quantum wells;
- explore advanced topics in the dynamics of quantum systems; including time-dependent perturbation theory, and the dynamics of open quantum systems;
- provide students with the techniques and terminology which they can apply in specialist courses and in their research projects.

Syllabus: (Approximate allocation of lectures is shown in brackets below)

Formal quantum mechanics [10.5 hours]
[Partly revision] Abstract vector spaces; norm, inner product, basis, linear functionals, operators, column vector and matrix representations of abstract vectors and operators, Dirac notation, Hermitian and unitary operators, projectors. Expectation values.
Postulates of quantum mechanics.
Representations of continuous variables, position and momentum.
Compound systems, tensor product, entanglement.
Statistical state preparation and mixed states, density operator formalism, density operators to describe sub-systems of entangled systems

Advanced wave mechanics - WKB approximation [4.5 hours]
WKB Ansatz and derivation of WKB approximation wave-functions. The failure of these wave-functions at classical turning points. The role of connection formulae. Application to quantum wells and quantum tunnelling in one-dimension.

Atoms, light and their interaction [3 hours]
[Revision of] Quantum Harmonic oscillator, Wave equation and quantisation of light. Optical cavities and concept of a light mode. Two-level atom and dipole approximation. Rotating Wave Approximation and Jaynes-Cummings model.

Advanced topics in time-dependence 1 - Unitary Evolution [3 hours]
Unitary evolution under the Schrödinger equation, Split operator method and Tsuzuki-Trotter decomposition. Heisenberg picture, Interaction picture. Example: Jaynes-Cummings model in the interaction picture.

Advanced topics in time-dependence 2) - Time-dependent perturbation theory [6 hours]
Dirac's method as application of interaction picture. Time-dependent perturbation theory. First-order time-dependent perturbation theory. Higher-order time-dependent theory. Examples: constant perturbation and harmonic perturbation. Fermi's Golden Rule with examples of its application.

Advanced topics in time-dependence 3) - Open quantum systems [6 hours]
Von Neumann equation for density matrices. Interaction with enviroment. Evolution of a sub-system. Markov approximation.
Abstract approach to non unitary evolution. Completely positive maps. Kraus operators.
Master equations. Lindblad form, derivation from Kraus operator Ansatz. Quantum trajectories and jump operators. Example: Damped quantum harmonic oscillator.

Books:
Those which are closest to the material and level of the course are (in alphabetical order)

- B.H. Bransden and C.J.Joachain, *Introduction to Quantum Mechanics*, Longman (2nd Ed, 2000),) (available at a discount from the physics departmental Tutor),
- C.Cohen-Tannoudji, B.Diu and F.Laloe, *Quantum Mechanics*, (2 Vols) Wiley,
- S.Gasiorowicz, *Quantum Physics,* Wiley, (1996)
- F.Mandl, *Quantum Mechanics*, Wiley (1992)
- E.Merzbacher, *Quantum Mechanics*, (3rd Ed.) Wiley, (1998)
- M. Peskin and D. V. Schroeder, *An Introduction to Quantum Field Theory* Addison Wesley
- J. J. Sakurai, *Modern Quantum Mechanics*, Addison Wesley, (2010)

John Preskill (Caltech) *Lecture notes on Quantum Computation*,
Chapter 2, "States and Ensembles"
http://www.theory.caltech.edu/people/preskill/ph229/notes/chap2.pdf
Chapter 3, "Measurement and evolution"
http://www.theory.caltech.edu/people/preskill/ph229/notes/chap3.pdf

Assessment: Examination of 2½ hours duration contributing 90%, coursework 10%.

Prerequisites:
Students will be expected to have attended and passed their department's introductory and intermediate quantum mechanics course. For example, at UCL these will be PHAS2222: Quantum Physics and PHAS3226: Quantum Mechanics.

The following topics will be assumed to have been covered:

- Introductory material: states, operators and time-independent Schrödinger equation, the Born interpretation of the wave function, transmission and reflection coefficients, Dirac notation
- Harmonic oscillator: energy eigenvalues, ladder operators
- Time-independent perturbation theory: including the non-degenerate and degenerate cases and its application to the helium atom ground state, Zeeman effect and spin-orbit interactions.

This is a theory course with a strong mathematical component to this course, and students should feel confident in their ability to learn and apply new mathematical techniques.

4242 Relativistic Waves and Quantum Fields

Classical field theories, Special Relativity and Quantum Mechanics (part revision):

Elements of Classical field theories: variational principle, equations of motion and Noether theorem.

Short introduction to Special Relativity: 4-vector notation, Lorentz transformations, Lorentz invariance/covariance.

Quantum Mechanics: Schroedinger equation, wavefunctions, operators/observables, symmetries and conservation laws in QM, Fock space for non-relativistic theories

Relativistic Wave equations:

Klein-Gordon equation: plane wave solutions, positive and negative energy solutions.

Dirac equation: Gamma matrices in 4D (Dirac, Weyl and Majorana representations); Gamma matrices in 2D and 3D; Lorentz transformations and covariance of Dirac equation: non-relativistic limit, Dirac equation in an electromagnetic field; discrete symmetries: C & P & T symmetry

Quantum Field Theory:

Scalar fields: canonical quantisation and Fock space interpretation of the free complex and real Klein-Gordon field; vacuum energy; Causality, commutators and time ordered products, the Feynman propagator; Dyson expansion; S-matrix, tree-level scattering amplitudes; examples of an interacting scalar theory with three flavours; Wick's theorem.
Quantisation of Dirac fermions: spin-statistics connection.

Prerequisites: a 3rd year quantum mechanics course; familiarity with the Lagrangian formalism and with the four vector notation in Special Relativity

Books:

F. Mandl and G. Shaw, *Quantum Field Theory*, John Wiley and Sons Ltd
M. Peskin, D. Schroeder, *An Introduction to Quantum Field Theory*, Addison Wesley
L.H. Ryder, *Quantum Field Theory*, Cambridge University Press

Assessment:
Written examination of 2½ hours contributing 90%, coursework contributing 10%.

4245 Advanced Quantum Field Theory

Building on the fundamental concepts of Quantum Field Theory introduced in 4242 Relativistic Waves and Quantum Fields, this course will cover the following topics:

1 Classical Field Theory and Noethers Theorem, Quantisation of free spin 0, 1/2 and 1 fields (revision)

2 Perturbation Theory and Feynman Diagrams:
Dyson formula and the S-matrix, in and out states, evaluation of S-matrix elements using Wick's theorem and LSZ reduction formula, formulation in terms of Feynman diagrams (part revision)

3 Quantum Electrodynamics
Feynman diagrams for QED, simple scattering processes at tree level such as $e^- e^-$ and $e^- e^+$ scattering, cross sections, spin sums

4 Renormalisation:
Renormalisation of φ^4 and QED at one-loop level, regularisation (dimensional and Pauli-Villars), Running coupling, corrections to electron anomalous moment

5 If time permits:
Elements of non-Abelian gauge theories, path integrals and ghosts, anomalies, modern, twistor inspired methods to calculate amplitudes.

Four sessions will be devoted to a discussion of coursework problems and their solutions.

Prerequisites: 4242 Relativistic Waves and Quantum Fields

Books:
F. Mandl and G. Shaw, *Quantum Field Theory*, John Wiley and Sons Ltd
L.H. Ryder, *Quantum Field Theory*, Cambridge University Press
J. Bjorken and S. Drell, *Relativistic quantum mechanics* and *Relativistic quantum fields*, McGraw-Hill
S. Weinberg, *The Quantum Theory of Fields*, Volume I, Cambridge University Press

Assessment:
Written examination of 2½ hours contributing 90%, coursework contributing 10%.

4261 Electromagnetic Theory

- Revision of laws of electromagnetism *in vacuo*, displacement current, Maxwell's equations *in vacuo*, charge and current density sources, energy theorems, fluxes of energy and momentum. (2 hours)

- Polarization and magnetization, **D** and **H** fields, linear media, boundary conditions on the fields in media, Maxwell stress tensor, concept of macroscopic fields as space averages of molecular fields, Lorentz local field argument, the Clausius-Mossotti relation. (3 hours)

- Maxwell's equations in media, Homogeneous wave equation *in vacuo* and in media, concept of frequency dependent dielectric function $\varepsilon(\omega)$, properties of real and imaginary parts of $\varepsilon(\omega)$, causality, Kramers-Krönig relation. (3 hours)

- Scalar and vector potentials, gauge transformations, inhomogeneous wave equation, the retarded solution to the wave equation, radiation from a Hertzian dipole with discussion of near and far fields, formula for power radiated, qualitative discussion of magnetic dipole and electric quadrupole radiation. (4 hours)

- Scattering of a plane wave by a single slowly moving charged particle, total and differential scattering cross-sections, optical theorem, scattering from a medium with space-varying dielectric constant, scattering from an assemblage of polarizable particles, Rayleigh-Smoluchowski-Einstein theory of why the sky is blue – critical opalescence. (5 hours)

- Lorentz transformations, charge and current density as a 4-vector, the potential 4-vector, tensors and invariants, the relativistic field tensor $F^{\mu\nu}$, Lorentz transformation properties of current density and potential 4-vectors and of the free vacuum **E** and **B** fields, tensor form of Maxwell's equations, covariant formulation of energy and momentum theorems, energy-momentum tensor. (5 hours)

- Liénard-Wiechert potentials for a moving charged particle derived from a delta-function source, fields for a uniformly moving charged particle in the non-relativistic and ultra-relativistic limits, radiation from accelerated charges, the cases of velocity and acceleration parallel and perpendicular, Larmor formula for radiated power, bremsstrahlung and synchrotron radiation as examples. (5 hours)

- Maxwell theory as a Lagrangian field theory, the free field as an ensemble of oscillators. (3 hours)

Prerequisites:

The course assumes a knowledge of the electromagnetism topics as detailed in the Institute of Physics Recommended Core. These comprise:

- Electrostatics: the electric field **E**
- Charge. Coulomb's law, Gauss's flux theorem
- Electrostatic potential; Poisson's and Laplace's equations
- The field and potential of a point charge and an electric dipole
- Capacitance and stored energy
- Magnetostatics: the magnetic field **B**
- Electric currents; the Biot-Savart law, Ampère's circuital theorem
- The field of a linear current and of a magnetic dipole/current loop
- Lorentz force law, force on current-carrying conductors
- Motion of particles in electric and magnetic fields
- Electrodynamics: Faraday's law, Lenz's law and induction
- Inductance and stored magnetic energy
- Maxwell's equations and electromagnetic waves
- The electromagnetic spectrum
- The Poynting vector
- Fields in media: **D** and **H**; permittivity, permeability and dielectric constant: basic ideas, related to their microscopic origins
- Energy storage in media

In addition the following knowledge in mathematics and physics are assumed:

- Taylor series.
- Div, Grad and Curl, Surface and Volume integrals, Gauss and Stokes theorems.
- The complex representation of harmonically varying quantities.
- Fourier transforms.
- The one-dimensional wave equation.
- Matrix multiplication and familiarity with indices.
- Contour integration up to Cauchy's theorem (this is used only in the discussion of the Kramers-Krönig relation)
- From special relativity the explicit form of the simple Lorentz transformation between frames in relative motion along a single coordinate direction.
- It is desirable but not necessary that students have met the Lagrangian formulation of particle mechanics.
- We do not assume that students have met the concept of Green's functions before.

Books:

J D Jackson, *Classical Electrodynamics*, J Wiley
H C Ohanian, *Classical Electrodynamics*, Allyn and Bacon

Assessment:

Written examination of 2½ hours contributing 90%, coursework contributing 10%.

4319 Formation and Evolution of Stellar Systems

Aims of the Course
This course aims to:

- give a detailed description of the structure, physical characteristics, dynamics and mechanisms that determine the kinematic structure, origin and evolution of clusters and galaxies;
- discuss applications, including stellar clusters within the Galaxy, spiral and elliptical galaxies and clusters of galaxies, with emphasis given to the interpretation of observational data relating to the Milky Way.

Objectives
After completing this course students should be able to:

- identify the dynamical processes that operate within star clusters, galaxies and clusters of galaxies;
- explain the observed characteristics of stellar motions within the Milky Way;
- use this information to elucidate the internal structure of the Galaxy;
- be able to discuss the dynamical structure and observational appearance of clusters and external galaxies;
- understand how these objects have formed and are evolving.

Methodology and Assessment
30 lectures and 3 problem class/discussion periods.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks
- *Stellar Dynamics* (I.R. King, W.H. Freeman, 1996)
- Galaxies: *Structure and Evolution* (R.J. Tayler, Cambridge Univ. Press, 1993)

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below).

The observational properties of galaxies and clusters   [1 lecture]
    Historical introduction
    Galaxy and cluster classification
    Observational overview
    The theoretical problem.

The mathematical foundations of stellar dynamics   [3 lectures]
    Stellar dynamics.
    The equations of motion.
    The Collisionless Boltzmann Equation (CBE)
    The solution of the CBE.

- Time-independent solution of the CBE
- Jeans’ theorem.
- Using the distribution function

The Milky Way I: Individual motions [3 lectures]
- Galactic coordinates and the Local Standard of Rest
- Galactic rotation in the solar neighbourhood
- The determination of Oort's constants
- Differential motion and epicyclic orbits
- Motion perpendicular to the galactic plane

The Milky Way II: The Collisionless Boltzmann Equation [3 lectures]
- The CBE in galactic coordinates
- The third integral
- Probing deeper into the Galaxy
- The Oort substitution
- The Jeans' equations
- The density distribution from individual orbits

Evolution of dynamical systems [4 lectures]
- Relaxing assumptions
- Two-body encounters and collisions
- The relaxation timescale
- The relative importance of close and distant encounters
- Comparison with crossing time and age
- The Fokker-Planck equation
- Dynamical friction
- The Kolmogorov-Feller equation
- The virial theorem
- Applications of the virial theorem

Stellar clusters [4 lectures]
- Introduction
- Entropy
- Evaporation of clusters
- Models of globular clusters
- Tidal forces in globular clusters
- Dynamical evolution of clusters
- Other long-term evolutionary effects
- The importance of binaries

Prerequisites

PHAS3136 - Cosmology and Extragalactic Astronomy

4421 Atom and Photon Physics

Interaction of Light with atoms (single photon) (4 lectures)
1 Processes – excitation, ionization, auto-ionization
2 A and B coefficients (semi classical treatment)
3 Oscillator strengths and *f*-sum rule
4 Life times – experimental methods. (TOF and pulsed electron)
5 Review of selection rules
6. Photo-ionization – synchrotron radiation

L.A.S.E.R (3 lectures)
1 Line shapes $g(\nu)$; Pressure, Doppler, Natural
2 Absorption and Amplification of radiation
3 Population inversion; spontaneous and stimulated emission
4 YAG and Argon ion lasers
5 Tunable radiation – dye and solid
6 Mode structure

Chaotic Light and Coherence (2 lectures)
1 Line broadening
2. Intensity fluctuations of chaotic light
3 First order correlation functions
4. Hanbury Brown Twiss experiment

Laser Spectroscopy (3 lectures)
1 Optical pumping – orientation and alignment
2 Saturation absorption spectroscopy
3 Lamb shift of H(1S) and H(2S)
4 Doppler-Free spectroscopy

Multi-Photon Processes (3 lectures)
1 Excitation, ionization, ATI
2 Laser field effects – pondermotive potential – Stark shifts – Harmonic Generation
3 Pump and Probe Spectroscopy
4 Multi-photon interactions via virtual and real states
5 Two photon decay of hydrogen (2S–1S)
6 Simultaneous electron photon interactions

Light Scattering by Atoms (3 lectures)
1 Classical Theory
2 Thompson and Compton scattering
3 Kramers-Heisenberg Forumlae
4 (Rayleigh and Raman scattering)

Electron Scattering by Atoms (4 Lectures)

1 Elastic, inelastic and super-elastic
2 Potential scattering
3 Scattering amplitude – partial waves
4 Ramsauer-Townsend Effect – Cross Sections
5 Resonance Structure

Coherence and Cavity Effects in Atoms (4 lectures)

1 Quantum beats – beam foil spectroscopy
2 Wave packet evolution in Rydberg states
3 Atomic decay in cavity
4. Single atom Maser

Trapping and Cooling (4 lectures)

1 Laser cooling of atoms
2 Trapping of atoms
3 Bose condensation
4 Physics of cold atoms – Atomic Interferometry

Books:
A Thorne, "Spectrophysics", (Chapman and Hall)
J Wilson and J F B Hawkes, "Opto Electronics", (Prentice Hall)

Assessment: Examination of 2½ hours duration contributing 90%, coursework 10%.

4425 Advanced Photonics

Module pre-requisites

Electromagnetism and optics at a typical second year level is essential. Quantum mechanics and condensed matter physics at a typical third year level is desirable but not essential.

Syllabus outline

Summary of those aspects of quantum theory, optics and materials science as applied in photonics. A survey of the main types of photonic applications and concepts. Optical fibres and communication systems. Basic understanding of physics of subwavelength light manipulation (silicon photonics, photonic crystals, plasmonics, metamaterials). Modern applications of photonics (information processing, optical data storage, biophotonics and sensing, energy).

Aims and Objectives

The aim of the course is to provide a comprehensive overview of theoretical and practical aspects of major modern photonic technologies with special emphasis on novel trends and applications of nanophotonics.

The students should be exposed to modern concepts in photonics, understand main physics principles behind modern photonic technologies, such as optical communications, nanophotonics, plasmonics, metamaterials, biosensing and bio-imaging and their applications in everyday life.

The successful student should be able to:

Demonstrate comprehension of the concepts of photonics. Apply these concepts to a range of physical situations, solving simplified model problems

Show the linking of the basic and advanced concepts within the above subject area problem formulation and solving (both numerical and symbolic), written and verbal communication skills, group work

4427 Quantum Computation and Communication

Aims:
The course aims to

- provide a comprehensive introduction to the emerging area of quantum information science.
- acquaint the student with the practical applications and importance of some basic notions of quantum physics such as quantum two state systems (qubits), entanglement and decoherence.
- train physics students to think as information scientists, and train computer science/mathematics students to think as physicists.
- arm a student with the basic concepts, mathematical tools and the knowledge of state of the art experiments in quantum computation & communication to enable him/her embark on a research degree in the area.

Objectives:
After learning the background the student should

- be able to apply the knowledge of quantum two state systems to any relevant phenomena (even when outside the premise of quantum information)
- be able to demonstrate the greater power of quantum computation through the simplest quantum algorithm (the Deutsch algorithm)
- know that the linearity of quantum mechanics prohibits certain machines such as an universal quantum cloner.

After learning about quantum cryptography the student should

- be able to show how quantum mechanics can aid in physically secure key distribution
- be knowledgeable of the technology used in the long distance transmission of quantum states through optical fibers.

After learning about quantum entanglement the student should

- be able to recognize an entangled pure state
- know how to quantitatively test for quantum non-locality
- be able to work through the mathematics underlying schemes such as dense coding, teleportation, entanglement swapping as well their simple variants.
- know how polarization entangled photons can be generated.
- be able to calculate the von Neumann entropy of arbitrary mixed states and the amount of entanglement of pure bi-partite states.

After learning about quantum computation the student should

- know the basic quantum logic gates
- be able to construct circuits for arbitrary multi-qubit unitary operations using universal quantum gates

- be able to describe the important quantum algorithms such as Shor's algorithm & Grover's algorithm.

After learning about decoherence & quantum error correction the student should

- be able to describe simple models of errors on qubits due to their interaction with an environment
- be able to write down simple quantum error correction codes and demonstrate how they correct arbitrary errors.
- be able to describe elementary schemes of entanglement concentration and distillation.

After learning about physical realization of quantum computers the student should

- be able to describe quantum computation using ion traps, specific solid state systems and NMR.
- be able to assess the merits of other systems as potential hardware for quantum computers and work out how to encode qubits and construct quantum gates in such systems.

Methodology and Assessment

The course consists of 30 lectures of course material which will also incorporate discussions of problems and question and answer sessions. Two hours of revision classes are offered prior to the exam. Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Syllabus:

Background [3]: The qubit and its physical realization; Single qubit operations and measurements; The Deutsch algorithm; Quantum no-cloning.
Quantum Cryptography [3]: The BB84 quantum key distribution protocol; elementary discussion of security; physical implementations of kilometers.
Quantum Entanglement [8]: State space of two qubits; Entangled states; Bell's inequality; Entanglement based cryptography; Quantum Dense Coding; Quantum Teleportation; Entanglement Swapping; Polarization entangled photons & implementations; von-Neumann entropy; Quantification of pure state entanglement.
Quantum Computation [8]: Tensor product structure of the state space of many qubits; Discussion of the power of quantum computers; The Deutsch-Jozsa algorithm; Quantum simulations; Quantum logic gates and circuits; Universal quantum gates; Quantum Fourier Transform; Phase Estimation; Shor's algorithm; Grover's algorithm.
Decoherence & Quantum Error Correction [4]: Decoherence; Errors in quantum computation & communication; Quantum error correcting codes; Elementary discussion of entanglement concentration & distillation.
Physical Realization of Quantum Computers [4]: Ion trap quantum computers; Solid state implementations (Kane proposal as an example); NMR quantum computer.

4431 Molecular Physics

1. Atomic Physics (2 lectures)
Brief recap of atomic physics: *n*, *l*, *m*, *s*; He atom, orbital approximation, exchange.

2. Molecular electronic structure (8 lectures):
The molecular Hamiltonian and the Born-Oppenheimer approximation.
Electronic structure, ionic and covalent bonding, Bonding in H_2^+ and H_2. Muon catalysed fusion. Dissociation and united atom limits. Long range forces.

3. Nuclear motion (6 lectures)
Vibrational structure: harmonic motion and beyond, energy levels and wavefunctions Rotational structure: rigid rotor and energy levels Energy scales within a molecule: ionisation and dissociation. Nuclear spin effects. Labeling schemes for electronic, vibrational and rotational states.

4. Molecular spectra (7 lectures):
Microwave, infrared and optical spectra of molecules. Selection rules, Franck-Condon principle. Experimental set-ups. Examples: the CO_2 laser, stimulated emission pumping experiment. Raman spectroscopy. Ortho-para states. Absorption spectra of simple diatomics (eg O_2 and NO, N_2). Simple poly-atomics (ozone, water).

5. Molecular processes (7 lectures):
Collisions with electrons. Elastic and inelastic collisions. Dissociation, dissociative attachment and dissociative recombination. Resonances and negative ions. Experimental techniques. Theoretical models (briefly).

Prerequisites: Quantum Physics (year 2/3), Atomic Physics (year 2/3), some previous experience of basic molecular physics would be helpful but is not a requirement.

Books:
P W Atkins and R S Friedman, *Molecular Quantum Mechanics*, (Oxford University)
B H Bransden and C J Joachain, *Physics of Atoms and Molecules,* (Longman, 1983)
C.W. Banwell and E. McGrath, *Fundamentals of Molecular Spectroscopy*, 4th Edition, (McGraw-Hill, 1994)

Assessment:
Examination of 2½ hours duration contributing 90%, coursework 10%.

4442 Particle Physics

Prerequisites

Students should have taken the UCL courses: Quantum Mechanics PHAS3226 and Nuclear and Particle Physics PHAS3224 or the equivalent and additionally have familiarity with special relativity, (four-vectors), Maxwell's equations (in differential form) and matrices.

Aims of the Course

This course aims to:

- introduce the student to the basic concepts of particle physics, including the mathematical representation of the fundamental interactions and the role of symmetries;
- emphasise how particle physics is actually carried out with reference to data from experiment which will be used to illustrate the underlying physics of the strong and electroweak interactions, gauge symmetries and spontaneous symmetry breaking.

Objective*s*

On completion of this course, students should have a broad overview of the current state of knowledge of particle physics. Students should be able to:

- state the particle content and force carriers of the standard model;
- manipulate relativistic kinematics (Scalar products of four-vectors);
- state the definition of cross section and luminosity;
- be able to convert to and from natural units;
- state the Dirac and Klein-Gordon equations;
- state the propagator for the photon, the W and the Z and give simple implications for cross sections and scattering kinematics;
- understand and draw Feynman diagrams for leading order processes, relating these to the Feynman rules and cross sections;
- give an account of the basic principles underlying the design of modern particle physics detectors and describe how events are identified in them;
- explain the relationship between structure function data, QCD and the quark parton model;
- manipulate Dirac spinors;
- state the electromagnetic and weak currents and describe the sense in which they are ‘unified';
- give an account of the relationship between chirality and helicity and the role of the neutrino;
- give an account of current open questions in particle physics;

Methodology and Assessment

The course consists of 30 lectures of course material which will also incorporate discussions of problem sheets and question and answer sessions.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

- *Introduction to Elementary Particles:* D. Griffiths
- *Quarks and Leptons:* F.Halzen and A.D.Martin.
- *Introduction to High Energy Physics (4th ed):* D.H. Perkins.

Syllabus

Broken down into eleven 2.5 hr sessions.

1. Introduction, Basic Concepts

Particles and forces. Natural units. Four vectors and invariants. Cross sections & luminosity. Fermi's golden rule. Feynman diagrams and rules.

2. Simple cross section Calculation from Feynman Rules

Phase space. Flux. Reaction rate calculation. CM frame. Mandelstam variables. Higher Orders. Renormalisation. Running coupling constants.

3. Symmetries and Conservation Laws

Symmetries and Conservation Laws. Parity and C symmetry. Parity and C-Parity violation, CP violation.

4. Relativistic Wave Equations without interactions

From Schrodinger to Klein Gordon to the Dirac Equation; Dirac Matrices; Spin and anti-particles; Continuity Equation; Dirac observables.

5. Relativistic Maxwell’s equations & Gauge Transformations

Maxwell's equations using 4 vectors; Gauge transformations; Dirac equation + EM, QED Lagrangians.

6. QED & Angular Distributions

QED scattering Cross Section calculations; helicity and chirality; angular distributions; forward backward asymmetries

7. Quark properties, QCD & Deep Inelastic Scattering

QCD - running of strong coupling, confinement, asymptotic freedom. Elastic electron-proton scattering. Deep Inelastic scattering. Scaling and the quark parton model. Factorisation. Scaling violations and QCD. HERA and ZEUS. Measurement of proton structure at HERA. Neutral and Charged Currents at HERA; Running of strong coupling; Confinement; QCD Lagrangian;

8. The Weak Interaction-1

Weak interactions; The two component neutrino. V-A Weak current. Parity Violation in weak interactions. Pion, Muon and Tau Decay.

9. The Weak Interaction-2

Quark sector in electroweak theory; GIM mechanism, CKM matrix; detecting heavy quark decays.

10. The Higgs and Beyond The Standard Model

Higgs mechanism; alternative mass generation mechanisms; SUSY; extra dimensions; dark matter; Neutrino oscillations and properties.

11.Revision & problem sheets

4450 Particle Accelerator Physics

- Introduction: history of accelerators, basic principles including centre of mass energy, luminosity, accelerating gradient.
- Characteristics of modern colliders; LEP, LHC, b-factories.
- Transverse motion, principles of beam cooling.
- Strong focusing, simple lattices.
- Circulating beams, synchrotron radiation.
- Longitudinal dynamics.
- Multipoles, non-linearities and resonances.
- Radio Frequency cavities, superconductivity in accelerators.
- Applications of accelerators; light sources, medical uses.
- Future: ILC, neutrino factories, muon collider, laser plasma acceleration.

Books
E. Wilson, *An Introduction to Particle Accelerators* OUP
S.Y. Lee *Accelerator Physics* World Scientific (2nd Edition).

Assessment
Written examination of 2½ hours contributing 90%, coursework contributing 10%.

Prerequisites
Second year level electromagnetism.

4472 Order and Excitations in Condensed Matter

Syllabus
The allocation of topics to sessions is shown below. Each session is approximately three lectures.

Atomic Scale Structure of Material (session 1): The rich spectrum of condensed matter; Energy and time scales in condensed matter systems; Crystalline materials: crystal structure as the convolution of lattice and basis; Formal introduction to reciprocal space.

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Magnetism: Moments, Environments and Interactions (session 2) Magnetic moments and angular momentum; diamagnetism and paramagnetism; Hund's rule; Crystal fields; Exchange interactions

Order and Magnetic Structure (session 3) Weiss model of ferromagnetism and antiferromagnetism; Ferrimagnetism; Helical order; Spin Glasses; Magnetism in Metals; Spin-density waves; Kondo effect

Scattering Theory (sessions 4 and 5) X-ray scattering from a free electron (Thomson scattering); Atomic form factors; Scattering from a crystal lattice, Laue Condition and unit cell struture factors; Ewald construction; Dispersion corrections; QM derivation of cross-section; Neutron scattering lengths; Coherent and incoherent scattering

Excitations of Crystalline Materials (session 6) Dispersion curves of 1D monoatomic chain (revision); Understanding of dispersion curves in 3D materials; Examples of force constants in FCC and BCC lattices; Dispersion of 1D diatomic chain; Acoustic and Optic modes in real 3D systems; Phonons and second quantization; Anharmonic interactions

Magnetic Excitations (session 7) Excitations in ferromagnets and antiferromagnets; Magnons; Bloch $T^{3/2}$ law; Excitations in 1, 2 and 3 dimension; Quantum phase transitions

Sources of X-rays and Neutrons (session 8) Full day visit to RAL. Neutron Sources and Instrumentation. Synchrotron Radiation. Applications of Synchrotron Radiation

Modern Spectroscopic Techniques (session 9)
Neutron scattering: triple-axis spectrometer, time-of-flight, polarized neutrons
X-ray scattering: X-ray magnetic circular dichroism, resonant magnetic scattering, reflectivity

Phase transitions and Critical Phenomena (session 10) Broken symmetry and order parameters in condensed matter. Landau theory and its application to structural phase transitions, ferromagnetism, etc. Ising and Heisenberg models. Critical exponents. Universality and scaling

Local Order in Liquids and Amorphous Solids (session 11) Structure of simple liquids; Radial distribution function; Dynamics: viscosity, diffusion; Modelling; Glass formation; Simple and complex glasses; Quasi-crystals

Textbooks

Main texts: Structure and Dynamics: An Atomic View of Materials, Martin T. Dove (OUP); Magnetism in Condensed Matter, Stephen Blundell (OUP)
Additional texts: Elements of Modern X-ray Physics, Jens Als-Nielsen and Des McMorrow (Wiley); Introduction to the Theory of Thermal Neutron Scattering, G.L. Squires (Dover)

Assessment

Examination of 2½ hours duration contributing 90%, coursework 10%.

Prerequisites

UCL's PHYS3C25 – Solid State Physics, or an equivalent from another department

4473 Theoretical Treatments of Nano-systems

Overall aim of the course:
An increasing amount of science and technology is nowadays concerned with processes at the nanometer scale, typically involving functionalized structures like particles and molecules. Time scales of picoseconds are the natural ones to describe the vibrational/conformational properties of these systems, and the relevant steps of their synthesis/assembly mechanisms. Such a high time/size resolution poses extremely demanding constraints to experimental techniques.

A detailed theoretical description and quantum-based numerical modelling have thus become indispensable tools in modern research on this systems, as guides for interpreting the experimental observations and, increasingly, as independent complementary investigation tools, capable of quantitative predictions. The relevant physics at the nanoscale is quantum mechanics, and quantum approaches must be used to provide the potential energy surfaces and the structural/configurational properties which are at the basis of classical molecular dynamics techniques and phase-space descriptions.

This course provides an introduction to the rapidly growing area of atomistic-based theoretical modelling in nano-science, based on fundamental quantum theory. The course introduces the physics of many-electron systems with a particular focus on symmetry properties and on the simplifying assumptions which must be used to successfully model functional nanosized systems. While a main goal of the course is to provide a theoretical background on the structure and quantum behaviour of matter at the nano-scale, examples of applications given during the course involve modern concepts on the nano-scale behaviour of functional materials, and provide an accessible introduction to some of the main theoretical techniques used to model processes involving surfaces, interfaces, clusters, and macromolecules.

Objectives:
On successfully completing this course, a student should:

- Be familiar with the fact that the physical properties of complex nano-systems can be described within a coherent quantum mechanical framework, in particular that the many-electron QM problem can be attacked by mean-field techniques of different levels of complexity

- Understand how this theoretical description can be used as a basis for modelling tools yielding accurate quantum-based potential energy surfaces and inter-atomic force models, and thus is capable of quantitative predictions at the nanometer/picosecond size- and time- scales.

Topics:
(1) **Foundations: mean-field modelling of many electron systems**.
The many-body problem: the general Schroedinger equation problem. The particle exchange operator, symmetry of a two-body wave function with spin. Wavefunction classes constructed from spin orbitals. Reminder of perturbation theory.

Reminder of variational techniques. Example: the virial theorem for Coulombic systems. Variational minimum obtained through self-consistency: derivation of a simple self-consistent Hartree equation for the Helium ground state. Correlation energy. Many electrons: symmetry of the many body wave function under particle exchange. Pauli principle and Slater determinants. The general Hartree-Fock method (outline), electronic correlation in many electron systems. Modern self-consistent approaches: elements of Density Functional Theory.

(2) **Potential energy surfaces and molecular dynamics**.
Quantum molecules: the hamiltonian operator, the Born-Oppenheimer approximation, degrees of freedom of the electronic energy, reminder of the molecular roto-vibration spectrum. The Hellman-Feynman theorem and the concept of classical interatomic force-field. The Verlet Algorithm and First-Principles Molecular Dynamics. Classical potentials, the problem of transferability.

Modelling free energy barriers via thermodynamic integration. Classical dynamics and stochastic processes. Modelling the diffusion of point defects in crystalline solids. The central limit theorem and the evolution of a distribution function. The diffusion coefficient. Derivation of Fick's laws. Examples and exercises.

(3) **Electronic structure, symmetry, case studies**.
Approximate representations for the electronic structure of large molecular systems, derivation of a simple tight-binding scheme (LCAO in the nearest neighbour approximation). The case of aromatic n-rings: model energy multiplets in aromatic systems: HOMO and LUMO levels and the prediction of STM images in negative/positive bias.

The connection between finite and infinite systems: the infinite 1D periodic solid and direct calculation of a model band structure. Bloch states, the Bloch theorem in Born-Von Karman periodic conditions. Other notable symmetries.

If time allows, case study (updated each year), e.g. self-assembly of 2D nanostructures. Construction of a classical force-field and molecular dynamics.

Reading List
1. B. H. Bransden and C. J. Joachain, “Physics of Atoms and Molecules”, Prentice Hall (2002) ISBN: 058235692X
2. M. Finnis, “Interatomic Forces in Condensed Matter”, Oxford University Press (2003) ISBN: 0198509774
3. M. P. Allen and D. J. Tildesley, “Computer Simulations of Liquids”, Clarendon Press (1989) ISBN: 0198556454
4. D. Frenkel and B. Smit, “Understanding Molecular Simulations”, Academic Press (2001) ISBN: 0122673514

Assessment:
One three-hour examination contributing 100% of the total marks.

Pre-requisites:
CP3221 Spectroscopy and Quantum Mechanics, or equivalent

4475 Physics at the Nanoscale

Overall aim of the course:
Today an increasing amount of science and technology is concerned with processes at the nano-scale, typified by structures of the order of 10-1000 nanometre in dimension. At this scale, physics is determined by quantum processes. This course provides an introduction to the rapidly growing area of nano-science. Already, nano-structures are “familiar” to us in the structure of the current generation of computer chips, and the applications of nano-structures are predicted to contribute to the new technologies of this century. The course introduces the physics and technology of nano-structures, discusses their special properties, methods of fabricating them, and some of the methods of analysing them.

Objectives:
On successfully completing this course, a student should:

- Appreciate the difference between the physics on the classical (macro-) scale and on the quantum (nano-) scale.
- Understand the properties of nanostructures in ‘zero’, one and two dimensions.
- Understand the fabrication and characterisation of nano-devices.

Topics:

Miniaturisation, Moore’s law, electronics, microelectronics, nanoelectronics.
Single electronics.

Coulomb blockade. Single Electron Transistor (SET). Applications of SET. Cooper-pair box.

Overview of key electron transport properties of metals / semiconductors:

Electron energy spectrum, energy bands, density of electron states. Effective mass. Fermi surface. Landau quantization and the role of electron scattering, Dingle temperature. De Haas-van Alphen and Shubnikov-de Haas effects.

Quantum interference of conduction electrons.

Weak localisation, spin-orbit scattering and anti-localisation. Aharonov-Bohm effect. Mesoscopic regime. h/e and $h/2e$ quantum oscillations. Universal conductance fluctuations.

Josephson effect in superconductors and Josephson quantum bits.

Flux and phase qubits. Read-out using Superconducting Quantum Interference Devices (SQUIDs) and Hybrid nano-interferometers.

Semiconductor nano-science
Electrons in a two-dimensional layer:

Density of electron states in low dimensional conductors. GaAs/AlGaAs structures. Quantum Hall effect.

Electrons in a one-dimensional system: formation in GaAs/AlGaAs.

Density of states. Diffusive and ballistic conduction. Quantised conduction.

Electrons in a zero-dimensional system: Quantum dots
Carbon nanoelectronics.

Carbon nanotubes. Graphene.

'Top down' fabrication:

PVD thin layer deposition techniques by thermal and e-beam evaporation, laser ablation. Chemical vapour deposition (CVD) and MOCVD, plasma-assisted deposition, ion-implanted layers, epitaxial processes.

Nano-lithography:

Resolution limits. Electron-beam lithography. Proximity effect. Negative and positive lithographic processes. Electron beam resists. Ion beam etching and RIBE. Plasma-assisted etching. Alignment and self-alignment, Dolan technique. Focussed ion beam (FIB) nanotechnology, ion-beam lithography.

Nano-analysis:

SEM- and STEM-based methods. X-ray and electron spectroscopy. Scanning tunneling microscopy. Atomic force microscopy and other scanning probe-based methods, including scanning near field optical microscopy.

'Bottom up' fabrication:

Scanning probe based nano-technology, molecular manufacturing. Self-organised nano-structures.

Clean-room environment.

Books/references

Marc J. Madou, *Fundamentals of Microfabrication, The Science of Miniaturization*, 2nd ed, CRC Press, LLC (2002).

S. Washburn and R. A. Webb, *Quantum transport in small disordered samples from the diffusive to the ballistic regime*, Rep. Prog. Phys. 55, 1311-1383 (1992).

Michel Devoret and Christian Glattli, *Single-electron transistors*, Phys. World. Sep 1, 1998.

Assessment:

Examination of 2½ hours duration contributing 90%, coursework 10%.

Pre-requisites:

Quantum mechanics and Condensed matter physics at a typical second year level is essential. Condensed matter physics at a typical third year level is desirable but not essential.

4476 Electronic Structure Methods

Aims and objectives:

Electronic structure methods – that is, computational algorithms to solve the Schrodinger equation – play a very important role in physics, chemistry and materials science. These methods are increasingly treated on equal footing with experiment in a number of areas of research, a sign of their growing predictive power and increasing ease of use. We now rely on electronic structure methods to understand experimental data, improve force-fields for use in more accurate and predictive simulations, and to achieve an understanding of processes not accessible to experiment. But which of the many available methods do we choose? How do we assess them? What are their strengths and weaknesses? This module aims to answer some of these and other questions: 1) To provide a detailed and understanding of modern electronic structure methods. 2) To give our students the experience of using them to solve various problems through the computational laboratory. 3) To achieve a high level of understanding of the strengths and weaknesses, both in the class (theory) and in the lab. 4) To develop a competence with using modern and widely used programs.

Syllabus:

This course will cover the fundamental theoretical ideas in modern electronic structure theory. Some of these are:

- Hartree-Fock theory
- Correlated methods like Moller-Plesset perturbation theory, configuration interaction and coupled-cluster theory.
- Density-Functional theory
- Intermolecular perturbation theory

The theoretical material will be complemented with a computational larboratory using state-of-the-art programs (NWChem and others) with the aim of aiding the development of a practical understanding of the methods, their strengths and their weaknesses.

Teaching arrangements:

Lectures, 33 hours delivered in 11 sessions of 3 hours each.

Prerequisites:

Intermediate Quantum Mechanics and Mathematical Methods for Physicists. Some knowledge of using Unix/Linux systems will be handy, but is not essential.

Assessment:

Examination 2.5 hours 80%, coursework 20%

Books:

1) Modern Quantum Chemistry by Szabo and Ostlund.

2) Molecular Electronic Structure Theory by Helgaker, Jorgensen and Olsen.

3) Electronic Structure by Richard Martin.

4) A Chemist's Guide to Density Functional Theory by Koch and Holthausen

5) Electronic Structure Calculations for Solids and Molecules by Jorge Kohanoff

4478 Superfluids, Condensates and Superconductors

This course will not be available this session

The extraordinary properties of Superfluids, Superconductors and Bose-Einstein condensates are fascinating manifestations of macroscopic quantum coherence: the fact that the low temperature ordered state is described by a macroscopic wavefunction.

We will study quantum fluids, the superfluidity of liquid ^{4}He and liquid ^{3}He, Bose-Einstein Condensation in dilute gases, metallic superconductivity, as well as the different techniques for achieving low temperatures. It is hoped to emphasize the conceptual links between these very different physical systems. Important developments in this subject were recognised by Nobel prizes in 2003, 2001, 1997, 1996, 1987, 1978, 1973, 1972, 1962 and 1913, which is one measure of its central importance in physics.

Introduction and review of quantum statistics.
The statistical physics of ideal Bose and Fermi gases.
Superfluid ^{4}He and Bose-Einstein condensation.
Phase diagram. Properties of superfluid ^{4}He. Bose-Einstein condensation in ^{4}He. The two-fluid model and superfluid hydrodynamics. Elementary excitations of superfluid ^{4}He. Breakdown of superfluidity. Superfluid order parameter: the macroscopic wavefunction. Quantization of circulation and quantized vortices. Rotating helium.
Bose-Einstein condensation in ultra-cold atomic gases
Cooling and trapping of dilute atomic gases. BEC. Interactions. Macroscopic quantum coherence. Rotating condensates and vortex lattices. The atom laser.
Liquid ^{3}He; the normal Fermi liquid.
Phase diagram. Properties of normal ^{3}He. Quasiparticles. Landau theory of interacting fermions.
Liquid solutions of ^{3}He and ^{4}He.
Isotopic phase separation. Spin polarised ^{3}He.
The properties of quantum fluids in two dimensions
Two dimensional Fermi systems. The superfluidity of 2D ^{4}He; the Kosterlitz-Thouless transition.
Achieving low temperatures
^{3}He-^{4}He dilution refrigerator. Adiabatic demagnetisation of paramagnetic salts. Nuclear adiabatic demagnetisation. Pomeranchuk cooling.
Measurement of low temperatures
Thermal contact and thermometry at tremperatures below 1K.
Superfluid ^{3}He.
Superfluid ^{3}He as a model p-wave superfluid. Discovery and identification of the superfluid ground states. ^{3}He-A, the anisotropic superfluid.
Superconductivity
Review of the basic properties of superconductors. Meissner effect. Type I and type II superconductors. Pairing in conventional and unconventional superconductors. Survey of recent advances in novel superconductors.
The Josephson effects.
Josephson effects in superconductors, superfluid ^{4}He and superfluid ^{3}He.
Prerequisites:

This course requires knowledge of base level thermodynamics and statistical physics at year 2/3 level and quantum mechanics at typical year 2 level. A background in solid state physics and superconductivity as covered in a typical year 3 condensed matter course is desirable but not essential.

Books:
Course notes, popular articles, scientific articles and review articles, web based material.
J F Annett, *Superconductivity, Superfluids and Condensates*, Oxford University Press (2004)
Tony Guénault, *Basic Superfluids,* Taylor and Francis (2003)
D R Tilley and J Tilley, *Superfluidity and Superconductivity* Adam Hilger.
P M^{c}Clintock, D J Meredith and J K Wigmore, *Matter at Low Temperatures* 1984, Blackie. (Out of print).
J Wilks and D S Betts, *An Introduction to Liquid Helium* 1987, Oxford (out of print).

Assessment:
Written examination of 2½ hours contributing 80%, coursework and essays contributing 20%.

4501 Standard Model Physics and Beyond

Aims and Objectives:
To introduce the student to the Standard Model of Particle Physics, and its minimal supersymmetric extensions. In particular the course will discuss the constituents of the Standard Model and the underlying Lie group structure, within the framework of gauge invariant quantum field theory, which will be introduced to the student in detail, discuss the physical mechanism for mass generation (Higgs), consistently with gauge invariance, and finally present an introduction to (minimal) Supersymmetric Extensions of the Standard Model. In the latter respect, we shall also discuss implications of supersymmetry for astroparticle physics issues, in particular dark matter (provided by the supersymmetric partners) and how astrophysical observations can constrain such particle physics models.

Prerequisites
Level 2/3 nuclear physics
4242 Relativistic Waves and Quantum Fields or equivalent
4205 Lie Groups and Lie Algebras. or equivalent
Familiarity with tensors, e.g a General Relativity course, is highly desirable.

4512 Nuclear Magnetic Resonance

Course taught at RHUL – Egham campus and *available over VideoCon at QMUL*

This course will introduce students to the principles and methods of nuclear magnetic resonance. It will apply previously learned concepts to magnetic resonance. Students should appreciate the power and versatility of this technique in a variety of applications.

- Introduction: static and dynamic aspects of magnetism, Larmor precession, relaxation to equilibrium, T_1 and T_2, Bloch equations.

- Pulse and continuous wave methods: time and frequency domains. Manipulation and observation of magnetisation, 90° and 180° pulses, free induction decay.

- Experimental methods of pulse and CW NMR: the spectrometer, magnet. Detection of NMR using SQUIDs.

- Theory of relaxation: transverse relaxation of stationary spins, the effect of motion. Spin lattice relaxation.

- Spin echoes: 'violation' of the Second Law of Thermodynamics, recovery of lost magnetisation. Application to the measurement of T_2 and diffusion.

- Analytical NMR: chemical shifts, metals, NQR.

- NMR imaging: Imaging methods. Fourier reconstruction techniques. Gradient echoes. Imaging other parameters.

Books: B P Cowan, Nuclear Magnetic Resonance and Relaxation, CUP, 1st ed. 1997 and 2nd ed. 2005.
Journal and web references given during course.

Prerequisites: 2nd year-level electromagnetism and quantum mechanics

Assessment:
Written examination of 2½ hours contributing 90%, coursework contributing 10%.

4515 Computing and Statistical Data Analysis

This course aims to introduce students to programming techniques using the C++ language on a Unix platform. It will also introduce students to techniques of probability and statistical data analysis and they will study applications of data analysis using C++ based computing tools.

- Introduction to C++ and the Unix operating system.
- Variables, types and expressions.
- Functions and the basics of procedural programming.
- I/O and files.
- Basic control structures: branches and loops.
- Arrays, strings, pointers.
- Basic concepts of object oriented programming.
- Probability: definition and interpretation, random variables, probability density functions, expectation values, transformation of variables, error propagation, examples of probability functions.
- The Monte Carlo method: random number generators, transformation method, acceptance-rejection method.
- Statistical tests: significance and power, choice of critical region, goodness-of-fit.
- Parameter estimation: samples, estimators, bias, method of maximum likelihood, method of least squares, interval estimation, setting limits, unfolding.

Books: R. Miller, An Introduction to the Imperative Part of C++, www.doc.ic.ac.uk/~wjk/C++Intro.
W. Savitch, Problem Solving with C++: The Object of Programming, 4th Ed., Addison-Wesley, 2003.
G D Cowan, Statistical Data Analysis, Clarendon Press, 1998.
R J Barlow, Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences, John Wiley, 1989.

Prerequisites: none

Assessment:
Written examination of 2½ hours contributing 70%, coursework contributing 30%.

4534 String Theory and Branes

Aims and Objectives:
The main aim of the course is to give a first introduction to string theory which can be used as a basis for undertaking research in this and related subjects.

Syllabus:
Topics will include the following: classical and quantum dynamics of the point particle, classical and quantum dynamics of strings in spacetime, D-branes, the spacetime effective action, and compactification of higher dimensions.

Web page: http://www.mth.kcl.ac.uk/courses-10-11/

Teaching Arrangements:
Two hours of lectures each week

Prerequisites:
Note – A high level of mathematical ability is required for this course
The course assumes that the students have an understanding of special relativity and quantum field theory. In addition the student should be familiar with General Relativity, or be taking the Advanced General Relativity course concurrently.
4205 Lie Groups and Lie Algebras would be helpful

Assessment:
The course will be assessed by a two-hour written examination at the end of the academic year.

Assignments:
During the lectures problems will be given and complete solutions will be made available. It is crucial that students work through these problems on their own.

Reading List:
The lecture notes taken during the lectures are the main source. However, some of the material is covered in:

- Green, Schwarz and Witten: String Theory 1, Cambridge University Press.
- B. Zwiebach: A First Course in String Theory, Cambridge University Press.

4541 Supersymmetry and Gauge Symmetry

Aims and objectives:
This course aims to provide an introduction to two of the most important concepts in modern theoretical particle physics; gauge theory, which forms the basis of the Standard Model, and supersymmetry. While gauge theory is known to play a central role in Nature, supersymmetry has not yet been observed but nevertheless forms a central pillar in modern theoretical physics.

Syllabus:
Maxwell's equations as a gauge theory. Yang-Mills theories. Supersymmetry. Vacuum moduli spaces, extended supersymmertry and BPS monopoles.

Web page: http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures each week

Prerequisites:
Note – A high level of mathematical ability is required for this course
Students should be familiar with quantum field theory, special relativity as well as an elementary knowledge of Lie algebras.

Assessment:
The courses will be assessed by a two hour written examination at the end of the academic year.

Assignments:
During the lectures problems will be given and complete solutions will be made available. It is crucial that students work through these problems on their own.

Books:
The lecture notes taken during the lectures are the main source but see also

- D. Bailin and A. Love: Supersymmetric Gauge Field Theory and String Theory, Taylor and Francis.
- L. Ryder: Quantum Field Theory, Cambridge University Press
- P. West: Introduction to Supersymmetry, World Scientific

4600 Stellar Structure and Evolution

Course outline

Stars are important constituents of the universe. This course starts from well known physical phenomena such as gravity, mass conservation, pressure balance, radiative transfer of energy and energy generation from the conversion of hydrogen to helium. From these, it deduces stellar properties that can be observed (that is, luminosity and effective temperature or their equivalents such as magnitude and colour) and compares the theoretical with the actual. In general good agreement is obtained but with a few discrepancies so that for a few classes of stars, other physical effects such as convection, gravitational energy generation and degeneracy pressure have to be included. This allows an understanding of pre-main sequence and dwarf stages of evolution of stars, as well as the helium flash and supernova stages.

Syllabus – Topics covered include:

- Observational properties of stars, the H-R diagram, the main sequence, giants and white dwarfs.
- Properties of stellar interiors: radiative transfer, equation of state, nuclear reactions, convection.
- Models of main sequence stars with low, moderate and high mass.
- Pre- and post-main sequence evolution, models of red giants, and the end state of stars.

The course includes some exposure to simple numerical techniques of stellar structure and evolution; computer codes in Fortran.

Prerequisites: some knowledge of Fluids, Electromagnetism, Stellar Structure

Books: Course Notes available + R Kippenhahn and A Weigert - Stellar Structure and Evolution Springer

Assessment: Written examination of 3 hours contributing 100%

4601 Cosmology

Course outline

Cosmology is a rapidly developing subject that is the focus of a considerable research effort worldwide. It is the attempt to understand the present state of the universe as a whole and thereby shed light on its origin and ultimate fate. Why is the universe structured today in the way that it is, how did it develop into its current form and what will happen to it in the future? The aim of this course is to address these and related questions from both the observational and theoretical perspectives. The course does not require specialist astronomical knowledge and does not assume any prior understanding of general relativity.

Syllabus

- Observational basis for cosmological theories.
- Derivation of the Friedmann models and their properties.
- Cosmological tests; the Hubble constant; the age of the universe; the density parameter; luminosity distance and redshift.
- The cosmological constant.
- Physics of the early universe; primordial nucleosynthesis; the cosmic microwave background (CMB); the decoupling era; problems of the Big Bang model.
- Inflationary cosmology.
- Galaxy formation and the growth of fluctuations
- Evidence for dark matter.
- Large and small scale anisotropy in the CMB.

Prerequisites: Knowledge of Newtonian Dynamics and Gravitation, and Calculus.

Books:

Assessment: Written examination of 3 hours contributing 100%

4602 Relativity and Gravitation

- Introduction to General Relativity.
- Derivation from the basic principles of Schwarzschild.
- Solution of Einstein's field equations.
- Reisner-Nordstrom, Kerr and Kerr-Neuman solutions and physical aspects of strong gravitational fields around black holes.
- Generation, propagation and detection of gravitational waves.
- Weak general relativistic effects in the Solar System and binary pulsars.
- Alternative theories of gravity and experimental tests of General Relativity.

Prerequisites: knowledge of Relativity

Books:

Assessment: Written examination of 3 hours contributing 100%.

4604 General Relativity and Cosmology

This course will not be available this session

Syllabus outline

Mathematical tools for handling curved space. Metric. Geodesics. Principle of equivalence, experimental confirmations. Cosmology, Robertson-Walker solution, the Big Bang. Einstein’s field equations, Schwarzchild solution, observed effects, black holes.

Aims and Objectives

The aim of this optional course is to provide a first treatise on general relativity and cosmology, as a prerequisite for those students who would like to continue further studies in mathematical or theoretical particle physics. The structure of the course is aimed at the mathematically advanced students, and skills in mathematics are essential, given that a substantial part of the course deals with tensors and other advanced mathematical concepts, such as elements of differential geometry. Some techniques used in this course, such as Lagrange equations, are also taught in greater detail in other third year courses, such as mathematical methods.

4605 Astroparticle Cosmology

Syllabus outline

The module will focus on cosmology and gravitational and high energy physics in the context of early universe. Students will study and gain an understanding of Einstein's field equations and gravitational dynamics; homogeneous isotropic spaces; anisotropic and inhomogeneous spaces; physics of the very early universe; the Planck era.

Aims and Objectives

Students completing this module will have a deep and systematic understanding of knowledge in cosmological principles in the early universe and can work with theoretical knowledge like Einstein's field equations. A comprehensive understanding of Newtonian theory, General Relativity and other specialised methodologies. Students will develop critical awareness can undertake analysis of complex areas of knowledge communicating the outcome effectively. A level of conceptual understanding that will allow her/him critically to evaluate research, advanced scholarship and methodologies and argue alternative approaches

A student will be able to competently undertake research tasks with minimum guidance.

The successful student on this module will have an independent learning ability required for continuing professional study.

4630 Planetary Atmospheres

Comparison of the Planetary Atmospheres (2 lectures)
The radiative energy balance of a planetary atmosphere; the competition between gravitational attraction and thermal escape processes. The factors which influence planetary atmospheres; energy and momentum sources; accretion and generation of gases; loss processes; dynamics; composition.
Atmospheric structure (7 lectures)
Hydrostatic equilibrium, adiabatic lapse rate, convective stability, radiative transfer, the greenhouse effect and the terrestrial planets.
Oxygen chemistry (3 lectures)
Ozone production by Chapman theory; comparison with observations; ozone depletion and the Antarctic ozone hole.
Atmospheric temperature profiles (3 lectures)
Troposphere, stratosphere, mesosphere, thermosphere and ionosphere described; use of temperature profiles to deduce energy balance; internal energy sources; techniques of measurement for remote planets.
Origin of planetary atmospheres and their subsequent evolution (3 lectures)
Formation of the planets; primeval atmospheres; generation of volatile material; evolutionary processes; use of isotopic abundances in deducing evolutionary effects; role of the biomass at Earth; consideration of the terrestrial planets and the outer planets.
Atmospheric Dynamics (4 lectures)
Equations of motion; geostrophic and cyclostrophic circulation, storms; gradient and thermal winds; dynamics of the atmospheres of the planets; Martian dust storms, the Great Red Spot at Jupiter.
Magnetospheric Effects (1 lecture)
Ionisation and recombination processes; interaction of the solar wind with planets and atmospheres; auroral energy input.
Atmospheric loss mechanisms (1 lecture)
Exosphere and Jeans escape; non thermal escape processes; solar wind scavenging at Mars.
Observational techniques (3 lectures)
Occultation methods from ultraviolet to radiofrequencies; limb observation techniques; in-situ probes.
Global warming (3 lectures)
Recent trends and the influence of human activity; carbon budget for the Earth; positive and negative feedback effects; climate history; the Gaia hypothesis; terraforming Mars.

Books:
J. W. Chamberlain and D. M. Hunten, “Theory of Planetary Atmospheres” Academic Press.
M. Salby, “Introduction to Atmospheric Physics”, Academic Press.
J. T. Houghton, “The Physics of Atmospheres”, Cambridge University Press.

Assessment:
Examination of 2½ hours duration contributing 90%, coursework 10%.

4640 Solar Physics

1. **Introduction**
Presentation of the syllabus and suggested reading, a list of solar parameters and a summary of the topics to be treated during the course. (1)

2. **The Solar Interior and Photosphere**
Stellar Structure and Evolution. Life history of a star. Equations and results. Conditions for Convection. Arrival of the Sun on the Main Sequence. Nuclear fusion reactions. The Standard Solar Model. Neutrino production and Detection – the neutrino problem. Solar Rotation. Photospheric models and observations. Fraunhofer lines. Chemical composition. Convection and Granulation. Waves and oscillations – Helioseismology or probing the SunUs interior. (12)

3. **Solar Magnetic Fields/Solar Activity**
Sunspot observations – structure, birth and evolution. Spot temperatures and dynamics. Observations of faculae. Solar magnetism – Sunspot and Photospheric fields. Active Region manifestations and evolution. Solar Magnetic Cycle – Observations and Dynamics. Babcock dynamo model of the solar cycle. Behaviour of flux tubes. Time behaviour of the Sun's magnetic field. (4)

4. **The Solar Atmosphere - Chromosphere**
Appearance of the Chromosphere – Spicules, mottles and the network. Observed spectrum lines. Element abundances. Temperature profile and energy flux. Models of the Chromosphere. Nature of the Chromosphere and possible heating mechanisms. (4)

5. **The Solar Atmosphere - Corona and Solar Wind**
Nature and appearance of the corona. Breakdown of LTE. Ionization/ recombination balance and atomic processes. Spectroscopic observations and emission line intensities. Plasma diagnostics using X-ray emission lines. Radio emission. Summary of coronal properties. Discovery of the solar wind. X-ray emission and coronal holes. In-situ measurements and the interplanetary magnetic field structure. Solar wind dynamics. Outline of the Heliosphere. (6)

6. **Solar Flares.**
Flare observations throughout the solar atmosphere. Thermal and non-thermal phenomena. Particle acceleration and energy transport. Gamma-ray production. Flare models and the role of magnetic fields. (3)

Assessment:
Examination of 2½ hours duration contributing 90%, coursework 10%.

4650 Solar System

Course outline

As the planetary system most familiar to us, the Solar System presents the best opportunity to study questions about the origin of life and how enormous complexity arise from simple physical systems in general. This course surveys the physical and dynamical properties of the Solar System. It focuses on the formation, evolution, structure, and interaction of the Sun, planets, satellites, rings, asteroids, and comets. The course applies basic physical and mathematical principles needed for the study, such as fluid dynamics, electrodynamics, orbital dynamics, solid mechanics, and elementary differential equations. However, prior knowledge in these topics is not needed, as they will be introduced as required. The course will also include discussions of very recent, exciting developments in the formation of planetary and satellite systems and extrasolar planets (planetary migration, giant impacts, and exoplanetary atmospheres).

Syllabus

- General overview/survey.
- Fundamentals: 2-body problem, continuum equations.
- Terrestrial planets: interiors, atmospheres.
- Giant planets: interiors, atmospheres.
- Satellites: 3-body problem, tides.
- Resonances and rings.
- Solar nebula and planet formation.
- Asteroids, comets and impacts.

Assessment: Written examination of 3 hours contributing 100%

Book: C.D. Murray and S.F. Dermott, Solar System Dynamics, Cambridge University
Press.

4660 The Galaxy

Course outline

The course considers in detail the basic physical processes that operate in galaxies, using our own Galaxy as a detailed example. This includes the dynamics and interactions of stars, and how their motions can be described mathematically. The interstellar medium is described and models are used to represent how the abundances of chemical elements have changed during the lifetime of the Galaxy. Dark matter can be studied using rotation curves of galaxies, and through the way that gravitational lensing by dark matter affects light. The various topics are then put together to provide an understanding of how the galaxies formed.

Syllabus

- Introduction: galaxy types, descriptive formation and dynamics.
- Stellar dynamics: virial theorem, dynamical and relaxation times, collisionless Boltzmann equation, orbits, simple distribution functions, Jeans equations.
- The interstellar medium: emission processes from gas and dust (qualitative only), models for chemical enrichment.
- Dark matter - rotation curves: bulge, disk, and halo contributions.
- Dark matter - gravitational lensing: basic lensing theory, microlensing optical depth.
- The Milky Way: mass via the timing argument, solar neighbourhood kinematics, the bulge, the Sgr dwarf.

Assessment: Written examination of 3 hours contributing 100%

References: Shu for some basic material, Binney & Merrifield and Binney & Tremaine for some topics, plus full course notes.

4670 Astrophysical Plasmas

- The plasma state as found in astrophysical contexts.
- Particle motion in electromagnetic fields, cyclotron motion, drifts and mirroring, with application to the radiation belts and emission from radio galaxies.
- Concepts of magnetohydrodynamics (MHD); flux freezing and instabilities.
- The solar wind, including MHD aspects, effects of solar activity, and impact on the terrestrial environment.
- Magnetic reconnection; models and application to planetary magnetic storms and stellar flares and coronal heating.
- Shock waves and charged particle acceleration.

Assessment: Examination of 2½ hours duration contributing 90%, coursework 10%.

4680 Space Plasma and Magnetospheric Physics

Introduction [1]
Plasmas in the solar system, solar effects on Earth, historical context of the development of this rapidly developing field
Plasmas [3]
What is a plasma, and what is special about space plasmas; Debye shielding, introduction to different theoretical methods of describing plasmas
Single Particle Theory [6]
Particle motion in various electric and magnetic field configurations; magnetic mirrors; adiabatic invariants; particle energisation
Earth's Radiation Belts [3]
Observed particle populations; bounce motion, drift motion; South Atlantic Anomaly; drift shell splitting; source and acceleration of radiation belt particles; transport and loss of radiation belt particles
Introduction to Magnetohydrodynamics [3]
Limits of applicability; convective derivative; pressure tensor; continuity equation; charge conservation and field aligned currents; equation of motion; generalised Ohm's law; frozen-in flow; magnetic diffusion; equation of state; fluid drifts; magnetic pressure and tension
The Solar Wind [3]
Introduction, including concept of heliosphere; fluid model of the solar wind (Parker); interplanetary magnetic field and sector structure; fast and slow solar wind; solar wind at Earth; coronal mass ejections
The Solar Wind Interaction with Unmagnetised Bodies [2]
The Moon; Venus, Comets
The Solar Wind and Magnetised Bodies (I) [4]
Closed Magnetosphere Model
The ring current, boundary currents; shape of the magnetopause; corotation; convection driven by viscous flow
The Solar Wind and Magnetised Bodies (II) [3]
Open Magnetosphere Model, Steady State
Magnetic reconnection; steady state convection; currents and potentials in an open magnetosphere; the magnetotail; the plasmasphere; the aurorae
The Solar Wind and Magnetised Bodies (III) [2]
Open Magnetosphere Model, Non-Steady State
Phases of a substorm; Substorm current systems and unanswered questions about substorms; magnetic storms; dayside reconnection.

Books: M.Kivelson and C.T.Russell, Introduction to space physics, Cambridge University Press, W.Baumjohann and R.Treumann, Basic space plasma physics, Imperial College Press

Assessment: Written Examination, 2½ hours, contributing 90%, coursework 10%.

Prerequisites: While the course is essentially self-contained, some knowledge of basic electromagnetism and mathematical methods is required. In particular it is assumed that the students are familiar with Maxwell's equations and related vector algebra.

4690 Extrasolar Planets and Astrophysical Discs

Course outline

Ever since the dawn of civilisation, human beings have speculated about the existence of planets outside of the Solar System orbiting other stars. The first bona fide extrasolar planet orbiting an ordinary main sequence star was discovered in 1995, and subsequent planet searches have uncovered the existence of more than one hundred planetary systems in the Solar neighbourhood of our galaxy. These discoveries have reignited speculation and scientific study concerning the possibility of life existing outside of the Solar System.

This module provides an in-depth description of our current knowledge and understanding of these extrasolar planets. Their statistical and physical properties are described and contrasted with the planets in our Solar System. Our understanding of how planetary systems form in the discs of gas and dust observed to exist around young stars will be explored, and current scientific ideas about the origin of life will be discussed. Rotationally supported discs of gas (and dust) are not only important for explaining the formation of planetary systems, but also play an important role in a large number of astrophysical phenomena such as Cataclysmic Variables, X-ray binary systems, and active galactic nuclei. These so-called accretion discs provide the engine for some of the most energetic phenomena in the universe.

The second half of this module will describe the observational evidence for accretion discs and current theories for accretion disc evolution.

4702 Environmental Remote Sensing

Teaching Assistants: Tom Smith & Jinda Sae-Jung

Module Structure
Lectures every 2 weeks and Practical Classes every 2 weeks.
All are run in the 1st semester at King’s, check the MSci website for details.

Module Outline
Week 1, Lecture 1: Introduction to EMR and Spectroscopy
Week 2, Practical 1: Introduction to Spectral Measurements
Week 3, Lecture 2: Principles of Optical Remote Sensing from Space
Week 4, Practical 2: Introduction to Spectral Datasets, Data Display and ENVI
Week 5, Lecture 3: Multispectral Sensors and Image Classification
Week 6, Practical 3a: Image Calibration, Annotation and Vegetation Indices
Practical 3b: Image Classification and Change Detection
Week 7, Lecture 4: Thermal Remote Sensing
Week 8, Practical 4: Thermal Remote Sensing of Vegetation Fires and Water Surface Temperatures
Week 9, Lecture 5: Image Processing
Week 10, Practical 5: Image Registration, Overlays and Output

Assessment
This course is assessed via two methods:
(a) 3 x multiple choice online quizzes - each worth 10% (undertaken after Lectures 3, 4 and 5 and covering the previous lecture)
(b) 1 x CW project (3000 words and worth 70%).
[In addition there will be two formative (non-assessed) pieces - a "practice" online quiz and a coursework project proposal]

Books
- Jensen, J. R. Remote Sensing of Environment – An Earth Resource perspective. (Prentice Hall, 2000).
- Lillesand, T. and Kiefer, R. Remote Sensing and Image Interpretation. (New York: Wiley, 2007 or earlier edition)

Websites
NASA Remote Sensing Tutorial   http://rst.gsfc.nasa.gov/
NASA Earth Observatory http://earthobservatory.nasa.gov

Additional Useful Explanatory Websites
- http://www.astronomynotes.com/light/s1.htm
- http://www.crisp.nus.edu.sg/~research/tutorial/rsmain.htm
- http://landsathandbook.gsfc.nasa.gov/handbook/handbook_site_map.hml
- http://speclab.cr.usgs.gov/PAPERS.refl-mrs/
- http://speclab.cr.usgs.gov/PAPERS/tetracorder/
- http://earthobservatory.nasa.gov/Library/EO1/eo1.html
- http://earthobservatory.nasa.gov/Features/EarthPerspectives/page3.php

Online Data Sources

- NOAA AVHRR: CLASS internet database http://www.class.noaa.gov/nsaa/products/welcome
- Landsat/ASTER: ESDI internet site http://glcfapp.umiacs.umd.edu:8080/esdi/esdi_index.jsp
- Landsat MSS, TM and ETM+: Earth Explorer http://edcsns17.cr.usgs.gov/EarthExplorer/
- Landsat MSS, TM and ETM+: New Earth Explorer http://edcsns17.cr.usgs.gov/NewEarthExplorer/
- Landsat MSS, TM and ETM+ (over USA only): GLOVIS: http://glovis.usgs.gov/
- MODIS level 1b: NASA GSFC http://modis.gsfc.nasa.gov/data/
- ASTER L1B (over USA only): GLOVIS: http://glovis.usgs.gov/
- ASTER L1b (elsewhere): Request access for educational use at https://igskmncnwb001.cr.usgs.gov/aster/afd/index.php

4800 Molecular Biophysics

Aims of the Course

The course will provide the students with insights in the physical concepts of some of the most fascinating processes that have been discovered in the last decades: those underpinning the molecular machinery of the biological cell. These concepts will be introduced and illustrated by a wide range of phenomena and processes in the cell, including biomolecular structure, DNA packing in the genome, molecular motors and neural signalling.

The aim of the course is therefore to provide students with:

- Knowledge and understanding of physical concepts that are relevant for understanding biology at the micro- to nano-scale.
- Knowledge and understanding of how these concepts are applied to describe various processes in the biological cell.

Objectives

- After completing this half-unit course, students should be able to:
- Give a general description of the biological cell and its contents
- Explain the concepts of free energy and Boltzmann distribution and discuss osmotic pressure, protein structure, ligand-receptor binding and ATP hydrolysis in terms of these concepts.
- Explain the statistical-mechanical two-state model, describe ligand-receptor binding and phosphorylation as two-state systems and give examples of “cooperative” binding.
- Describe how polymer structure can be viewed as the result of random walk, using the concept of persistence length, and discuss DNA and single-molecular mechanics in terms of this model
- Explain the worm-like chain model and describe the energetics of DNA bending and packing; explain how such models are relevant for the rigidity of cells
- Explain the low Reynolds-number limit of the Navier-Stoke's equation and discuss its consequences for dynamics in biological systems
- Explain simple solutions of the diffusion equation in biological systems and their consequences for diffusion and transport in cells
- Explain the concept of rate equations and apply it to step-wise molecular reactions
- Give an overview of the physical concepts involved in molecular motors and apply them to obtain a quantitative description of motor driven motion and force generation
- Describe neural signalling in terms of propagating (Nernst) action potentials and ion channel kinetics
- Link the material in the course to at least one specific example of research in the recent scientific literature

Syllabus

(The approximate allocation of lectures to topics is given in brackets below.)

Biological cells [3]

Introduction to the biology of the cell – cell types – cell components – DNA, RNA, proteins, lipids, polysaccharides – overview of functional processes in cells

Statistical mechanics in the cell [4]

Deterministic versus thermal forces – free-energy minimisation and entropy, Boltzmann distribution – free energy of dilute solutions, osmotic pressure/forces – consequences for protein structure and hydrophobicity – equilibrium constants for ligand-receptor binding and ATP hydrolysis

Two-state systems [3]

Biomolecules with multiple states – Gibbs distribution – ligand-receptor binding, phosphorylation – “cooperative” binding

Structure of macromolecules [3]

Random walk models of polymers – entropy, elastic properties and persistence length of polymers – DNA looping, condensation and melting – single-molecule mechanics

Elastic-rod theory for (biological) macromolecules [3]

Beam deformation and persistence length – worm-like chain model – beam theory applied to DNA – cytoskeleton

Motion in biological environment [4]

Navier-Stokes equation – viscosity and Reynold's number in cells – diffusion equation and its solutions – transport and signalling in cells – diffusion limited reactions

Rate equations and dynamics in the cell [3]

Chemical concentrations determine reaction rates – rate equations for step-wise molecular reactions – Michaelis-Menten kinetics

Molecular motors [4]

Molecular motors in the cell – rectified Brownian motion – diffusion equation for a molecular motor – energy states and two-state model for molecular motors – force generation by polymerisation

Action potentials in nerve cells [3]

Nerst potentials for ions – two-state model for ion channels – propagation of action potentials – channel conductance

Prerequisites

It is recommended but not mandatory that students have taken second level Thermal Physics. Second level Statistical Thermodynamics would be useful but is not essential. The required concepts in statistical mechanics will be (re-)introduced during the course.

Methodology and Assessment

This is a half-unit course, with 30 lectures and 3 discussion/problems classes. Basic problem-solving skills will be stimulated by the setting of a weekly problem question. The answers will be collected weekly and more extensively discussed during the discussion/problem classes. The marks on these problem questions account for 10% of the overall course assessment. The remaining 90% is determined via an unseen written examination.

Textbooks

The course will make extensive use of the following book, parts of which will be obligatory reading material:

- Physical Biology of the Cell, 1st Edition, R. Phillips, J. Kondev, and J. Theriot, Garland Science 2009.

Other books which may be useful include the following. They cover more material than is in the syllabus.

- Biological Physics, 1st Edition, Philip Nelson, W.H. Freeman., 2004.
- Mechanics of Motor Proteins and the Cytoskeleton, 1st Edition, J. Howard, Sinauer Associates, 2001.
- Protein Physics, 1st Edition, A.V. Finkelstein and O.B. Ptitsyn, Academic Press, 2002.
- Molecular Driving Forces, 1st Edition, K.A. Dill and S. Bromberg, Garland Science, 2003.

The following books may be useful for biological reference.

- Molecular Biology of the Cell, 4th Edition, B. Alberts et al., Garland Science, 2002.
- Cell Biology, 2nd Edition, T.D. Pollard, W.C. Earnshaw and J. Lippincott-Schwartz, Elsevier, 2007.

4810 Theory of Complex Networks

Aims and objectives:
The purpose of this module is to provide an appropriate level of understanding of the mathematical theory of complex networks. It will be explained how complex network can be quantified and modelled

Syllabus:
This course has four parts

- In part I we focus on the definition and characterization of networks and their topological features. This includes degrees, degree correlations, loops, and spectra.
- In part II we study specific ensembles of random networks, and calculate their properties in the language of part I, such as Erdos-Renyi graphs, small-world networks, `hidden variable' ensembles, and degree-constrained ensembles.
- Part III is devoted to the connection between network topology and collective processes defined on such networks. We discuss the different methods available for studying this link, such equilibrium replica theory, the cavity method, and (very briefly) generating functional analysis.
- In part IV we briefly discuss algorithms for graph generation like preferential attachment, hidden variables, and Steger-Wormald algorithms.

Web page: See http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures per week

Prerequisites:
KCL's 4CCM111A Calculus I or equivalent
KCL's 4CCM141A Probability and Statistics I or equivalent

Assessment:
One two-hour written examination at the end of the academic year. 100%

Books:
S. N. Dorogovtsev and J. F. F. Mendes, *Evolution of Networks: From Biological Nets to the Internet and WWW*, Oxford University Press 2003

4820 Equilibrium Analysis of Complex Systems

Aims and objectives:
The purpose of this module is to provide an appropriate level of understanding of the notions and mathematical tools of statistical mechanics of complex and disordered systems. It will be explained how to use these techniques to investigate complex physical, biological, economic and financial systems.

Syllabus:

- Canonical ensembles and distributions
- Transfer matrices, asymptotic methods (Laplace and saddle point integration) approximation methods (mean-field, variational, perturbative)
- Methods for disordered systems (replica, cavity, restricted annealing)
- Application of statistical mechanics to physical and biological systems, to information processing, optimization, and to models of risk for economic, financial, and general process-networks.

Web page: See http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures per week

Prerequisites:
KCL' s 4CCM111A Calculus I or equivalent
KCL' s 4CCM112A Calculus II or equivalent
KCL' s 4CCM141A Probability and Statistics I or equivalent

Assessment:
One two-hour written examination at the end of the academic year. 100%

Books:
L E Reichl, *A Modern Course in Statistical Physics*, 3rd edition, Wiley VCH (2009)
D J C MacKay, *Information Theory, Inference, and Learning Algorithms*, Cambridge Univ Press (2003)
J Voit, *The Statistical Mechanics of Financial Markets*, Springer Berlin (2001)

4830 Dynamical Analysis of Complex Systems

Aims and objectives:
The purpose of this module is to provide an appropriate level of understanding of the notions and mathematical tools of dynamics of complex systems. It will be explained how to use these techniques to deeply comprehend dynamical properties of complex biological and physical systems.

Syllabus:

- Stochastic processes, Markov chains (Chapman-Kolmogorov equation, irreducibility and aperiodicity, stationary distribution).
- Deterministic processes and Liouville's equation; Jump processes and Master equation; Diffusion processes and Fokker-Planck equation.
- Stochastic differential equation, stochastic integration, Langevin equation
- Generating functional analysis formalism
- Application to complex and disordered systems, physical, biological, financial.

Web page: See http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures per week

Prerequisites:
KCK's 4CCM111A Calculus I
KCK's 4CCM112A Calculus II
KCK's 4CCM141A Probability and Statistics
KCK's 4CCM131A Introduction to Dynamical Systems
KCK's 5CCM211A Partial Differential Equations and Complex Variables

Assessment:
One two-hour written examination at the end of the academic year. 100%

Books:
N.G.Van Kampen, *Stochastic processes in Physics and Chemistry*, Elsevier 3rd edition 2007
Crispin Gardiner, *Stochastic Methods, A handbook for the Natural and Social Science,* Springer 4th edition 2008
Jean Zinn-Justin, *Quantum field theory and critical phenomena*, Oxford University Press 4th edition 2002

4840 Mathematical Biology

Aims and objectives:
The purpose of this module is to provide an appropriate level of understanding of the Mathematical Biology. With the advent of computational biology and gene sequencing projects, mathematical modelling in biology is becoming increasingly important. The module will introduce mathematical concepts such as a nonlinear dynamical systems and reaction-diffusion partial differential equations, which will be applied to biological structures and processes.

Syllabus:
- Continuous and discrete population models for single species
- Models for Interacting Populations - Predator–Prey Models: Lotka–Volterra Systems, Competition Models.
- Reaction Kinetics – Enzyme Kinetics, the Michaelis–Menten system, Autocatalysis, Activation and Inhibition.
- Biological Oscillators and Switches – Feedback Control Mechanisms, Hodgkin–Huxley Theory of Nerve Membranes.
- Belousov–Zhabotinskii Reactions.
- Dynamics of Infectious Diseases – Simple Epidemic Models, Multi-Group Models.
- Reaction Diffusion, Chemotaxis, and Nonlocal Mechanisms.
- Biological Waves in Single-Species Models

Web page: See http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures per week

Prerequisites:
KCL’s 4CCM111A Calculus I
KCL’s 4CCM112A Calculus II
KCL’s 4CCM113A Linear Methods
KCL’s 4CCM131A Introduction to Dynamical Systems
KCL’s 5CCM211A Partial Differential Equations and Complex Variables
----or equivalent courses

Assessment:
One two-hour written examination at the end of the academic year. 100%

Books:
J.D. Murray, *Mathematical Biology*, 3rd Edition Springer 2002

4850 Elements of Statistical Learning

Aims and objectives:
The purpose of this module is to provide an appropriate level of understanding of Statistical Learning presented in the framework of Bayesian Decision theory. It will be explained how to use linear models for regression and classification as well as Kernel Methods, graphical models and approximate inference.

Syllabus:

- Introduction
- Probability distributions
- Linear models for regression and classification
- Kernel methods
- Graphical Models
- Approximate Inference

Web page: See http://www.mth.kcl.ac.uk/courses-10-11/

Teaching arrangements:
Two hours of lectures per week

Prerequisites:
KCL's 4CCM141A Probability and Statistics I or equivalent

Assessment:
One two-hour written examination at the end of the academic year. 100%

Books:
C. Bishop, *Pattern Recognition and Machine Learning*, Springer 2006
D. Barber, *Bayesian Reasoning and Machine Learning*, 2009