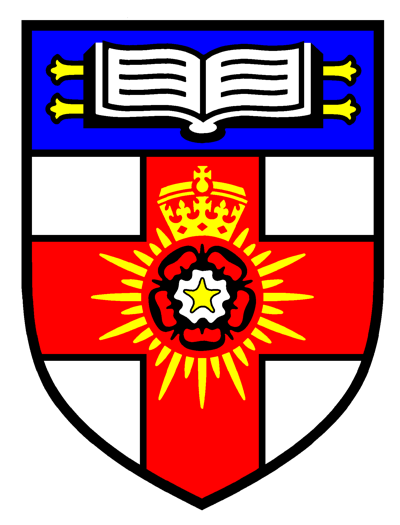
**University of London**

**Intercollegiate Programme**

****

**Physics**

**STUDENT HANDBOOK**

Intercollegiate taught modules for 2024-25

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Courses and Teachers

Each module has a numerical code used by the Intercollegiate MSci board shown on the left-hand side. Each college use their own local module codes for the modules they offer. These codes may differ from the intercollegiate code number therefore please ensure you check all the module information for the relevant college.

All modules are worth 15 credits which may equate to a half or full course unit at your home institution. Please check with your local administrator for clarity on how this pertains to your programme of study.

The module list in this handbook will display the following information:

* Intercollegiate module code
* Module title
* Teaching Term
* Examination period
* Module Lead (ML)
* Institution
* Local module code
* Contact details for the Module Organiser and any links to any supporting materials required for the module

**Module Symbols**

~ Course unavailable/potentially unavailable to RHUL students for syllabus reasons

+ Course taught by the Mathematics department at KCL

€ Course content is mathematically demanding

**Please note: in the interest of balance and/or for syllabus reasons, the MSci Intercollegiate board has set up the following rules:**

* Students should take no more than three KCL Maths modules

**Modules new for this year (2024/25):**

* 7CCP3000 Quantum Information and Computing
* 7CCP5000 Statistical Field Theory
* 7XA4240 Quantum Field Theory
* 7XA4321 Research Topics in Astrophysics

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Host Module Code** | **Module Title** | **Semester/ Term** | **Exam Period** | **Module Lead** | **Taught by** | **Module Lead email address** | **Webpage** |
| PH4320 | Advanced Astrophysics | 2 | April - June | Professor Stephen Gibson | RHUL | [stephen.gibson@rhul.ac.uk](mailto:stephen.gibson@rhul.ac.uk) | <https://moodle.royalholloway.ac.uk/course/view.php?id=22909> |
| 7CCP4931 | Advanced Condensed Matter | 2 | May/June | Dr Ivana Savic & Dr Jan Tomczak | KCL | pgt-physics@kcl.ac.uk | [Course: 7CCP4931 Advanced Condensed Matter(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119916) |
| 7CCP4650 | Gravitational Wave Physics | 2 | May / June | Prof Mairi Sakellariadou | KCL | pgt-physics@kcl.ac.uk | [Course: 7CCP4650 Gravitational Wave Physics(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=120032) |
| 7CCP4473 | Theoretical Treatments of Nanosystems | 2 | May / June | Prof Lev Kantorovich | KCL | pgt-physics@kcl.ac.uk | [Course: 7CCP4473 Theoretical Treatments of Nano-Systems(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119799) |
| 7CCP4600 | Cosmology | 2 | May / June | Prof Malcolm Fairbairn and Dr Furqaan Yusaf | KCL | pgt-physics@kcl.ac.uk | [Course: 7CCP4600 Cosmology(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119933) |
| PH4442 | Advanced Particle Physics | 1 | April - June | Prof. Glen Cowan | RHUL | [g.cowan@rhul.ac.uk](mailto:g.cowan@rhul.ac.uk) | <https://moodle.royalholloway.ac.uk/course/view.php?id=22908> |
| PH4226 | Advanced Quantum Theory | 1 | April - June | Dr Giovanni Sordi | RHUL | [giovanni.sordi@rhul.ac.uk](mailto:giovanni.sordi@rhul.ac.uk) | <https://moodle.royalholloway.ac.uk/course/view.php?id=23044> |
| PH4610 | Analysing Gravitational Waves | 1 | April - June | Dr Greg Ashton | RHUL | [gregory.ashton@rhul.ac.uk](mailto:gregory.ashton@rhul.ac.uk) | <https://moodle.royalholloway.ac.uk/course/view.php?id=16141> |
| 7CCP4935 | Dark Matter and Dark Energy | 1 | Coursework - Semester 1 | David Marsh | KCL | david.j.marsh@kcl.ac.uk | [Course: 7CCP4935 Dark Matter and Dark Energy(24~25 SEM1 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119917) |
| PH4240 | Quantum Field Theory | 1 | May | TBC | RHUL | TBC |  |
| 7CCMMS01 | Lie Groups and Lie Algebras € | 1 | May/June | Dr Petr Kravchuk | KCL+ | petr.kravchuk@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=3314851&chapterid=284174> |
| 7CCPNE05 | Modelling Quantum Many-Body Systems | 1 | January | Dr Joe Bhaseen | KCL | joe.bhaseen@kcl.ac.uk | [Course: 7CCPNE05 Modelling Quantum Many-body Systems(24~25 SEM1 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119904) |
| PH4472 | Order and Excitations in Quantum Materials | 2 | April - June | Dr Andrew Seel | RHUL | [andrew.seel@rhul.ac.uk](mailto:andrew.seel@rhul.ac.uk) | <https://moodle.royalholloway.ac.uk/course/view.php?id=22910> |
| PH4450 | Particle Accelerator Physics | 1 | April - June | Dr P Karataev | RHUL | pavel.karataev@rhul.ac.uk | <http://moodle.rhul.ac.uk/course/view.php?id=250> |
| 7CCP4126 | Photonics & Metamaterials | 2 | May/June | Dr Francisco Rodriguez-Fortuno | KCL | francisco.rodriguez\_fortuno@kcl.ac.uk | [Course: 7CCP4126 Photonics and Metamaterials(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119882) |
| 7CCP3000 | Quantum Information and Computing | 1 | May/June | TBC | KCL | TBC | [Course: 7CCP3000 Quantum information and computing(24~25 SEM1 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=120081) |
| 7CCP5000 | Statistical Field Theory | 2 | May/June | TBC | KCL | TBC | [Course: 7CCP5000 Statistical Field Theory(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=120082) |
| PH4475 | Nano-Electronics and Quantum Technology (previously named Physics at the Nanoscale) | 1 | April - June | Dr V Antonov | RHUL | v.antonov@rhul.ac.uk | <http://moodle.rhul.ac.uk/course/view.php?id=249> |
| 7CCP4501 | Standard Model Physics and Beyond | 2 | April - June | Chris McCabe | KCL | christopher.mccabe@kcl.ac.uk | [Course: 7CCP4501 Standard Model Physics and Beyond(24~25 SEM2 000001) | KEATS (kcl.ac.uk)](https://keats.kcl.ac.uk/course/view.php?id=119870) |
| PH4515 | Statistical Data Analysis | 1 | April - June | Prof G D Cowan | RHUL | g.cowan@rhul.ac.uk | <http://www.pp.rhul.ac.uk/~cowan/stat_course.html> |
| PH4211 | Statistical Mechanics | 2 | April - June | Prof B P Cowan | RHUL | b.cowan@rhul.ac.uk | <http://personal.rhul.ac.uk/UHAP/027/PHPH4211/> |
| 7CCMMS34 | Strings, Branes and Quantum Gravity € | 2 | May | Dr Mario Martone | KCL+ | mario.martone@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=3314851&chapterid=284209> |
| 7CCMMS40 | Supersymmetry and Conformal Field Theory €€ | 2 | May | Prof C Herzog | KCL+ | christopher.herzog@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=3314851&chapterid=28PH4211> |
| 7CCMCS02 | Theory Of Complex Networks | 1 | May | Dr Izaak Neri | KCL+ | izaak.neri@kcl.ac.uk | [Level 7 modules: 7CCMCS02 Theory of Complex Networks (kcl.ac.uk)](https://keats.kcl.ac.uk/mod/book/view.php?id=7028020&chapterid=662156) |
| 7CCMCS03 | Equilibrium Analysis of Complex Systems | 2 | May | Dr Francois Huveneers | KCL+ | francois.huveneers@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=7028020&chapterid=662157> |
| 7CCMCS04 | Dynamical Analysis of Complex Systems | 2 | May | TBC | KCL+ | TBC |  |
| 7CCMCS05 | Mathematical Biology | 2 | May | Dr Alessia Annibale | KCL+ | alessia.annibale@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=7028020&chapterid=662159> |
| 7CCMCS06 | Elements of Statistical Learning | 1 | May | Dr Davide Pigoli | KCL+ | davide.pigoli@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=7028020&chapterid=662160> |
| 7CCMMS32 | Quantum Field Theory | 1 | May | Prof George Papadopoulos | KCL+ | george.papadopoulos@kcl.ac.uk | <https://keats.kcl.ac.uk/mod/book/view.php?id=7028020&chapterid=662182> |
| 7CCMMS35 | Ads/CFT and Related Topics | 2 | May | TBC | KCL+ | TBC |  |

# Programme Strands

The table below gives a coherent base of modules for your registered programme and specialisation interests. It is strongly recommended that you choose one of these programme strands, and then select other modules to make up your full complement. You should consult your local programme structures to find out what intercollegiate modules are available for your programme of study.

***Please note: - some modules, particularly the mathematical based ones, may require a high level of mathematical ability. Students may find the mathematical level of these modules higher than what is included in a standard single-honours Physics programme. Such modules would be appropriate for some joint degrees. Should you need academic advice about your module selections, please contact your home institution.***

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Recommended Courses** | | |
| **Strand** | **Autumn Term** | | **Spring Term** |
| **Particle Physics** | 7CCMMS01: Lie Groups and Lie Algebras  PH4450: Particle Accelerator Physics  7CCPNE05: Modelling Quantum Many-Body Systems  PH4515: Statistical Data Analysis  7CCP4935: Dark Matter & Dark Energy | | PH4211: Statistical Mechanics  7CCP4501: Standard Model Physics and Beyond  7CCMMS34: String Theory and Branes  7CCMMS40: Supersymmetry and Conformal Field Theory |
| **Condensed Matter** | 7CCPNE05: Modelling Quantum Many-Body Systems  PH4475: Nano-Electronics and Quantum Technology  PH4515: Statistical Data Analysis | | PH4211: Statistical Mechanics  7CCP4931: Advanced Condensed Matter  7CCP4473: Theoretical Treatments of Nano-systems |
| **Astrophysics** | | PH4515: Statistical Data Analysis  7CCP4935: Dark Matter and Dark Energy |  |
| **General / Applied Physics** | | PH4475: Nano-Electronics and Quantum Technology  PH4515: Statistical Data Analysis | PH4211: Statistical Mechanics  7CCP4126: Photonics & Metamaterials |
| **Theoretical Physics** | | 7CCMMS01: Lie Groups and Lie Algebras  7CCPNE05: Modelling Quantum Many-Body Systems | PH4211: Statistical Mechanics  7CCMMS34: Strings, Branes and Quantum Gravity  7CCMMS40: Supersymmetry and Conformal Field Theory |

# Teaching and Examination Arrangements

***Please note: - not all colleges have reading weeks, please ensure you are aware of all teaching dates for each college.***

### **Teaching Term Dates**:

Modules are typically taught over eleven weeks. For the 2024/25 academic year, the teaching dates are:

**Semester 1 Teaching – Autumn 2024**

* KCL Physics and KCL Maths: Monday 23rd September – Friday 6th December 2024
* RHUL: Monday 25th September 2023 – Friday 8th December 2023

**Autumn Reading Week 2024**

* KCL Physics: w/c Monday 28th October 2024
* KCL Maths: w/c Monday 28th October 2024
* RHUL: No reading week

**Semester 2 Teaching – Spring 2024**

* KCL Physics & KCL Maths: Monday 13th January – Thursday 28th March 2025
* RHUL: Monday 15th January - Thursday 28th March 2024

**Spring Reading Week 2024**

* KCL Physics: w/c Monday 17th February 2025
* KCL Maths: No reading week
* RHUL: No reading week

### MSci Administrative contact points at each College

|  |  |  |  |
| --- | --- | --- | --- |
| KCL Physics | Shania Craig | [pgt-physics@kcl.ac.uk](mailto:pgt-physics@kcl.ac.uk) | 0207 848 1207 |
| KCL Mathematics | Amelia Groves | mathematics-pgt@kcl.ac.uk | 0207 848 2828 |
| RHUL | Tim Wilson-Soppitt | [epms-school@rhul.ac.uk](mailto:epms-school@rhul.ac.uk) | 01784 276881 |

### Module Registration

*It is essential that you complete a module registration form for the relevant college for any Intercollegiate modules you request to take* ***i.e., you must fill out a RHUL form for RHUL taught courses, a KCL form for KCL taught modules etc.*** Failure to complete and submit an approved form may result in you not being correctly registered for the assessment associated with the module. This can affect your progression or final award for your programme of study. Forms must be approved and signed by the appropriate member of staff at your home institution and, submitted to the relevant person as per your college regulations. If you have any questions, please contact your home administrator for further information. You can find registration forms on the [Intercollegiate website.](https://nms.kcl.ac.uk/intercollegiate/)

**Registration Deadlines**

Please ensure you submit your completed and approved forms to your local administrators within the deadlines listed below. You are advised to submit your registration at your earliest convenience in order to gain your college credentials and access to module materials as soon as possible.

Once registered onto a course at the selected college, you should receive a confirmation email with information including your user ID, password, and email address from the relevant college. Whilst you are waiting for your college credentials, you may contact the relevant college administrator for information about how to access classes and course materials for your chosen modules.

**Module Registration Deadlines**

* KCL Physics – Friday 4th October 2024
* KCL Maths - Friday 4th October 2024
* RHUL – Friday 6th October 2023

**Autumn Module Amendments**

Amendments to Autumn term modules can be requested up until **4pm Friday 4th October 2024**.

**Spring Module Amendments**

Amendments to Spring term modules can be requested up until **4pm Friday 17thJanuary 2025**.

***Please Note: - If you request to be withdrawn from a module at another College, you should inform both your own College and the administrator at the relevant College. Please ensure you submit the request in keeping with the College deadlines as you will not be able to be removed from modules past this date and will be expected to attend and complete all assessment.***

### Class locations

The MSci timetable found on the [Intercollegiate Webpage](https://nms.kcl.ac.uk/intercollegiate/) includes the following details of colleges and room locations:

* KCL modules are taught at the Strand, Kings College London,
* RHUL modules are either taught at Senate House or at the RHUL Egham campus.

### Attendance

Your attendance might be monitored in the form of a register at lectures as some colleges have an attendance requirement for certain modules.

### Coursework policy

Some modules have a coursework element as part of the assessment pattern. Details of all module assessment elements will be provided the relevant college.

### Extenuating/Mitigating Circumstances Policy

In the event you have extenuating/mitigating circumstances and are unable to complete an assessment by the deadline, you should follow your home institutions policy and submit a claim via your home school. Any affected host schools will be notified of the outcome and a suitable extension/alternate sitting will be arranged where requests have been approved.

### College Email(s)

You should ensure you link your email addresses, so you do not miss any communications from each college. Detailed instructions on [how to forward and re-direct mail](http://help.outlook.com/)can be accessed by visiting <http://help.outlook.com/> which will utilise the **Options** and **Connected Accounts Tab** on outlook. This process is user friendly easy, but you must frequently check and maintain your college account. When you delete a forwarded message e.g., from Hotmail, it will not be deleted from your home institution account.

***Please note: - you may need to use an Internet Explorer (Edge) browser to access this as the link may not work on some browsers***

***It is your responsibility to log on to your college account frequently and conduct account maintenance or your account may become full and therefore will not forward messages*.**

### Examination arrangements

You must ensure you are correctly registered for your modules at your home institution **AND** the college(s) that you will be studying Intercollegiate modules with by the registration deadline. Remember these dates may vary from college to college. Once registered, you are expected to attend classes and complete all assessment elements for each of your modules.

The examination periods may vary across the colleges and may not take place at the same time as your home institution.

Exams **can** take place across 3 examination periods including in January, April/May/June and August/September. To date, the current exam periods for each college are: -

**KCL Physics**

* Semester 1 modules will be examined between Monday 6th January – Friday 10th January 2025
* Semester 2 modules will be examined between Monday 28th April – Friday 30th May 2025
* Summer resits/replacement exams be examined between Monday 4th August – Friday 15th August 2025

**KCL Maths**

* Semester 1 modules will be examined between Monday 6th January – Friday 10th January 2025
* Semester 2 modules will be examined between Monday 28th April – Friday 30th May 2025
* Summer resits/replacement exams be examined between Monday 4th August – Friday 15th August 2025

**RHUL**

* Semester A and B Modules will be examined between Tuesday 30th April – Friday 31st May 2024
* Summer resits/replacement exams: TBC

Assessment policies concerning resit examinations may vary across the Colleges, please ensure you are aware of all assessment policies across the colleges and how it pertains to your programme of study.

**Exam Locations**

The arrangements are as follows:

**KCL students**:

* KCL and RHUL examinations take place at KCL

**RHUL students**:

* All exams take place at RHUL

***Please note: Changes to the format of the exams will be communicated to students from the relevant colleges. Students with Personalised/Exam Assessment Arrangements (PAAs/EAAs) special examination arrangements or inclusion plans will sit all examinations at their home college. If this is applicable to you, please contact your home administrator for further information.***

# College and Class Locations

### King’s College, Strand, London, WC2R 2LS

**Travel by tube:** Temple (District and Circle lines): 2-minute walk. Charing Cross (Bakerloo and Northern lines): 10-minute walk, Embankment (District, Circle and Bakerloo lines): 10 minute walk, Waterloo (Jubilee, Northern, Bakerloo, Waterloo & City lines): 12 minute walk, Holborn (Central and Piccadilly lines): 12 minute walk, Chancery Lane (Central line): use exit 4 - 15 minute walk.

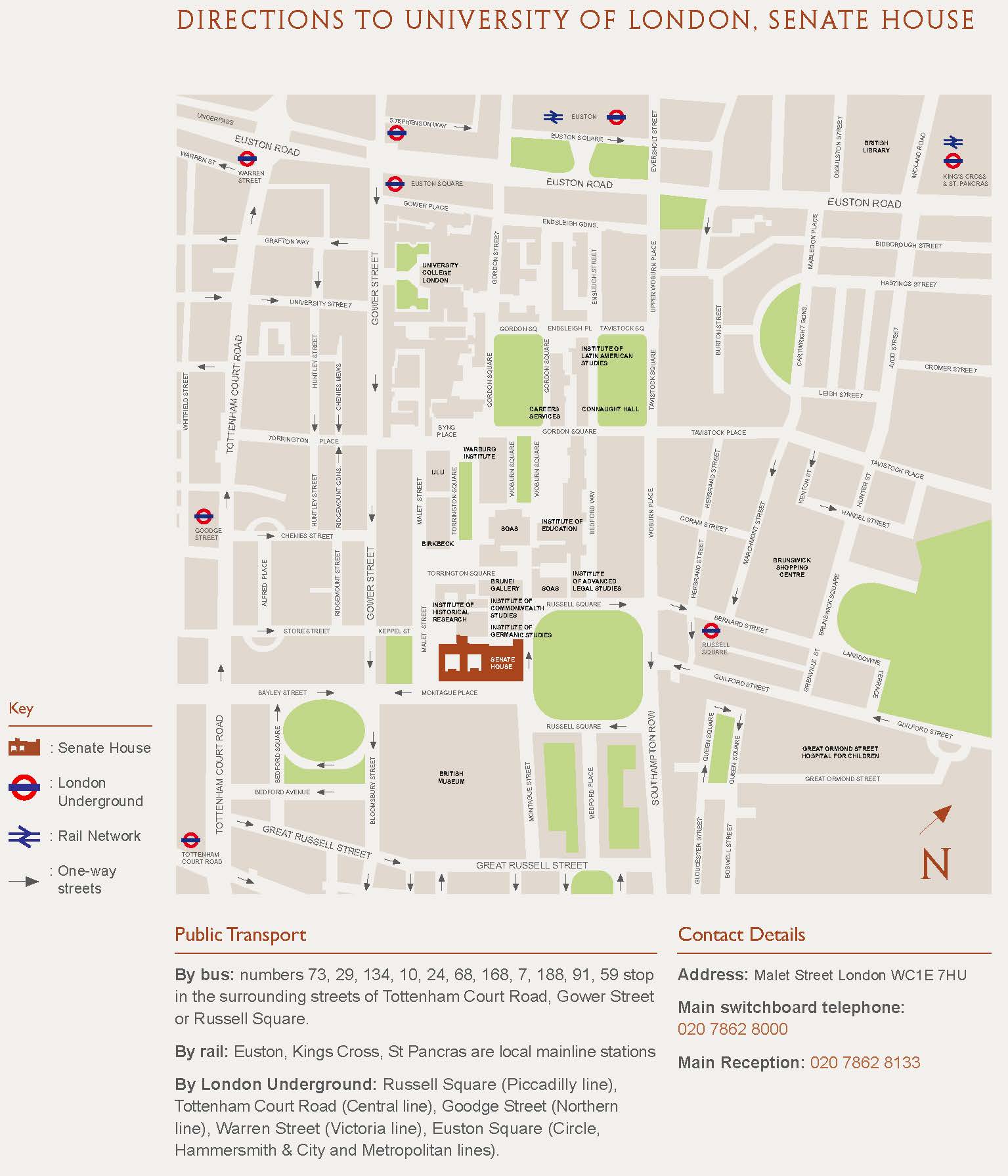
**Travel by train:** Charing Cross: 9-minute walk. Waterloo: 12-minute walk. Waterloo East: 10-minute walk. Blackfriars: 12-minute walk.

**Travel by bus:** Buses stopping minutes from the university: 1, 4, 26, 59, 68, 76, X68, 168, 171, 172, 176 (24 hour), 188, 243 (24 hour), 341 (24 hour), 521, RV1.

Directions to classrooms from the main Strand reception can be found here:

<https://internal.kcl.ac.uk/timetabling/room-info/strand/index.aspx>

### Royal Holloway, University of London, central London base Senate House



### Royal Holloway, University of London, Egham Campus, TW20 0EX

### N:\Physics\Admin\Handbooks\Handbooks 18-19\MSci Handbook\Campus Plan Aug 2018.jpg

T125 – located in the Department of Physics on the ground floor of the Tolansky Laboratory

**By Rail**: There are frequent services from London Waterloo to Egham station (40 mins).

**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.

**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 Department of Physics – Tolansky and Wilson Laboratories.

**By Road**: The College is on the A30, 19 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. After leaving the motorway follow the A30 west (signposted Bagshot and Camberley)-this is the Egham by-pass. At the end of the by-pass, continue on the A30 up Egham Hill. The entrance to the College is on the left immediately after the second footbridge.

Car parking on campus is restricted to permit holders.

Further details can be found at <https://intranet.royalholloway.ac.uk/students/campus-life/travel/home.aspx>

# Course Details

### **KCL Physics - Advanced Condensed Matter (**7CCP4931)

**Aims of the course**

The purpose of this module is to provide an introduction to modern topics of condensed matter physics. This module will introduce the formalism required to understand complex quantum phenomena in condensed matter, such as the Kondo effect or the Wigner crystal. It will also discuss how quantum effects in materials can be probed by experiments, and how the experimental measurements can be analysed with the help of theoretical tools and simple model Hamiltonians.

**Objectives**

On completion of this course, students should understand:

* The theoretical framework related to electronic properties of materials, the general concepts required to understand quantum phenomena in condensed matter
* The derivation of effective theories and model Hamiltonians used to describe the phenomenology
* The mathematical tools and numerical techniques used to make theoretical predictions
* The connection between the theoretical approaches and state-of-the-art experimental techniques used to probe quantum phenomena

**Syllabus:**

**Introduction** (week 1)

This lecture will cover introductory topics of condensed matter: band structure, Brillouin zone, Fermi surface, Nesting, density of states, Van Hove singularities

**Second quantization** (week 2)

This lecture will introduce the second quantization and the representation of one- and two-body operators. Extensions will be discussed: the Bloch theorem, the Mott insulator, Wannier orbitals, hopping matrix elements, the atomic limit

**Tight binding theory** (week 3)

This lecture will introduce the tight binding model. We will discuss the real space and reciprocal space representation of the theory, its diagonalization and the matrix notations. Applications to modern condensed matter topics will be discussed:

* + - i) External magnetic field, Hofstadter butterfly, orbital currents
    - ii) Low dimensionality: graphene and semi-metallicity
    - iii) Disorder: the Anderson Impurity Model
    - iv) Correlation: The limit of the Wigner Crystal

**Single electron Green’s function** (week 4)

This lecture will discuss the single particle Green’s function. The concepts of advanced and retarded Green’s function will be introduced. We will introduce the equation of motion and spectral functions.

**Linear response** (week 5)

In this lecture we will introduce the linear response. We will introduce the notation of magnetic susceptibility and polarization. In this lecture, we will also make connections with experimental probes (ARPES, STM, X-ray) and how the theory can model these experiments. We will also introduce the concept of screening via the discussion of the Friedel oscillations.

**Quantum magnetism** (week 6)

We will in this lecture discuss the theory of quantum magnetism, and the origin of the magnetic moment in transition metal ions. We will discuss the eg-t2g orbitals, the Hund’s rule, the crystal field effect, the super-exchange. We will introduce the Stoner criteria and extend further the discussion to modern topics:

* + - i) Magnetic frustration and Mermin-Wagner theorem
    - ii) Jahn Teller, ferro-electricity
    - iii) Dzyaloshinskii-Moriya interactions
    - iv) The Kondo effect

**Strong correlations** (week 7)

In this lecture we will extend the tight binding model to include the effect of electronic correlations. We will discuss the Hubbard model and the derivation of the low energy effective t-J model. We will derive the Anderson ‘Resonating Valence Bond’ theory of superconductivity from the t-J model. We will finally discuss the concept of quasi-particles and excitations.

**Mean field theory** (week 8)

In this lecture we will give tools to the student to treat the electronic correlations via the mean-field approach. We will discuss the Bogoliubov - DeGennes theory.

**Density functional theory** (week 9)

In this lecture we will introduce how electronic correlations can be included at the level of density functional theory (DFT) and provide an introduction to DFT+U

**Effective low energy theories** (week 10)

In this lecture we will discuss how advanced DFT calculations (week 9) can be projected onto a low energy effective subspace spanned by Wannier functions (week 2). This allows deriving simple model Hamiltonians, which can be in turn solved with the techniques introduced in the lecture (tight binding, mean field theory). A short introduction to Quantum Espresso, an open source DFT package, and to Wannier90, an open source down-folding method, will be given via a hands-on session.

**Prerequisites**

Normally we expect students taking this module to have background knowledge equivalent to the content of the following modules available at King's: 5CCP2240 Modern Physics, 6CCP3221 Spectroscopy and Quantum Mechanics

**Text books**

[1] J. M. Ziman, *Elements of Advanced Quantum Theory*, ISBN-10: 0521099498, ISBN-13: 978-0521099493

[2] A. L. Fetter and J. D. Walecka, *Quantum Theory of Many-Particle Systems*, ISBN-10: 0486428273, ISBN-13: 978-0486428277

[3] Michael P. Marder, *Condensed Matter Physics*, ISBN-10: 0470617985, ISBN-13: 978-0470617984

[4] P. Taylor, *A Quantum Approach to Condensed Matter Physics*, ISBN-10: 0521778271, ISBN-13: 978-0521778275

**Methodology and assessment**

10 lectures 2 hours each followed by a 1-hour problem class.

Assessment is based quizzes -10%, presentation - 15%, mini project – 15% and written 3-hour exam – 60%

**KCL Physics - Dark Matter and Dark Energy (7CCP4935)**

**Introduction**

Lighting Review of Friedman-Robertson-Walker Equations (not derivation)

* Expansion history for different equations of state (matter, radiation, cosmological constant)
* Thermal History of Universe

Brief review of Standard Model Particles and their Quantum Numbers

Nucleosynthesis prediction for baryon density and its incompatibility with Hubble expansion rate

**Dark Matter**

Independent Astrophysical Evidence for Dark Matter in clusters and Galaxies

• Rotation Curves

• Virial Theorem

• Dwarf Spheroidal galaxies and Low Surface Brightness Galaxies

• Milky Way Timing argument

• CDM model, halo density profiles (NFW), simulations and the concentration parameter

Astrophysical probes of particle nature of dark matter

• Cold/warm/hot dark matter – free streaming length and structure formation

• Constraints on dark matter self interaction (Bullet Cluster, NGC 720)

Thermal Relics (including WIMPs)

• Calculation of the self-annihilation cross section of fermions

• Thermal freeze-out and relic abundance

• Quantum numbers of dark matter and particle physics beyond the standard model

• Direct detection of WIMP dark matter (event rate, existing detectors and limits)

• Indirect detection of WIMP dark matter (gamma rays, anti-matter, diffusion loss equation in the galaxy)

• Collider production of WIMP dark matter (monojet searches, calculate rate in simplified model, LHC searches)

Sterile Neutrinos

• Right Handed Neutrinos and see-saw mechanism

• Light Sterile neutrinos

• Relic abundance and velocity – effect on power spectrum

• Calculation of decay into photons and subsequent detection

Axions

• Strong CP problem and theta parameter

• Theta as phase of Peccei-Quinn field, axions

• Axions as dark matter and relic abundance

• Coupling of axions to other particles, detection and mixing.

Other Dark Matter candidates

• Primordial black holes

• Millicharged particles

• Asymmetric Dark Matter

• Exotics

Modified Newtonian Dynamics as an alternative to dark matter

**Dark Energy**

Age of the Universe if history of cosmology 1990 to present day

Type 1a Supernovae as standard candles, luminosity distance and angular distance

Measures of expansion and geometry history.

Cosmological Constant – Original Motivation and CDM

Old Cosmological constant problem (why **)

New Cosmological constant problem (why ****)

Possible solutions, Anthropic Principle, Landscape, Bousso-Polshinski mechanism

Weinberg’s Anthropic Argument – derivation and understanding

Modified Gravity and Quintessence

Structure formation in alternatives to CDM (qualitative)

**Prerequisites**

Students should have taken third year level particle physics courses and some cosmology and/or astrophysics course where they have studied the Friedman equations, although their derivation is not necessary for this course. Students should be familiar with four vector notation in special relativity.

**Assessment**

100% Coursework

### KCL Maths - Lie Groups and Lie Algebras (7CCMMS01)

**Aims and objectives**

This course gives an introduction to the theory of Lie groups, Lie algebras and their representations, structures which arise frequently in mathematics and physics.

Lie groups are, roughly speaking, groups with continuous parameters, the rotation group being a typical example. Lie algebras can be introduced as vector spaces (with extra structure) generated by group elements that are infinitesimally close to the identity. The properties of Lie algebras, which determine those of the Lie group to a large extent, can be studied with methods from linear algebra, and one can even address the question of a complete classification.

**Syllabus**

Basic definitions and examples of Lie groups and Lie algebras. Matrix Lie groups, their Lie algebras; the exponential map, Baker-Campbell-Hausdorff formula. Representations of Lie algebras, sub-representations, Schur's Lemma, tensor products. Root systems, Cartan-Weyl basis, classification of simple Lie algebras (perhaps with some of the proofs being left out.)

**Teaching arrangements**

Usually two hours of lectures per week**.** Lectures are supported by small group tutorials.

**Prerequisites**

Basic ideas about Groups and Symmetries as taught in a second year UG course; a good knowledge of vector spaces and linear maps; elements of real analysis.

**Note – A relatively high level of mathematical ability is required for this course.**

**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
* A. Kirillov Jr., *Introduction to Lie Groups and Lie Algebras*, CUP, 2008

**Assessment**

One 2 hour written examination at the end of the academic year.

Assignments: Weekly problem sheets. Solutions will be provided.

### KCL Physics - Modelling Quantum Many-Body Systems (7CCPNE05)

**Aims of the Module**

This module aims to provide an introduction to the theory and applications of quantum many-body systems. Topics include harmonic oscillators, second quantization for bosons and fermions, model Hamiltonians, collective excitations, correlation functions, path integrals and links to statistical mechanics. The module will focus primarily on systems at or close to equilibrium, with a view towards non-equilibrium quantum systems.

**Objectives**

On completion of this module, students should understand:

* The experimental motivation for studying quantum many-body systems
* The use of model Hamiltonians for describing collective phenomena
* The computation of physical observables, using operator methods and path integral techniques

**Syllabus**

The approximate allocation of lectures to topics is shown in brackets below. The lectures are supplemented by homework problem sets and problem classes.

***Experimental Motivation (2)***

Illustrative examples of the novel behaviour displayed by quantum many-body systems in condensed matter and cold atomic gases.

***Second Quantization (2)***

Simple harmonic oscillators; creation and annihilation operators; coupled oscillators; Fourier transforms; phonons; second quantization for bosons and fermions.

***Quantum Magnetism (4)***

Spin operators; quantum ferromagnets and antiferromagnets; spin wave theory, magnons and the Holstein-Primakoff transformation; low-dimensional systems, fermionization and the Jordan-Wigner transformation.

***Path Integrals (6)***

Principle of least action; calculus of variations; classical fields; Noether’s theorem; path integrals for a single particle including the simple harmonic oscillator; canonical quantization; path integrals for fields; generating function; propagators; statistical field theory; coherent states; Grassmann numbers; path integrals for fermions.

***Interacting Bosons (2)***

Superfluidity; Bogoliubov theory of the weakly interacting Bose gas; broken symmetry; Goldstone bosons.

***Interacting Fermions (2)***

Metals; BCS theory of superconductivity.

***Relativistic Fermions*** (2)

The Dirac equation; representations of the gamma matrices; applications of the Dirac Hamiltonian in low-dimensions, including one-dimensional electrons and graphene.

**Prerequisites**

There are no formal prerequisites. Normally we expect students taking this module to have knowledge equivalent to the following modules available at King’s: 5CCP2240 Modern Physics, 6CCP3221 Spectroscopy and Quantum Mechanics.

**Textbooks**

* T. Lancaster and S. J. Blundell, *Quantum Field Theory for the Gifted Amateur,*

Oxford University Press, 1st Edition (2014).

* A. Altland and B. D. Simons, *Condensed Matter Field Theory,*

Cambridge University Press, 2nd Edition (2010).

* J. M. Ziman, *Elements of Advanced Quantum Theory,*

Cambridge University Press, (1969).

* A. L. Fetter and J. D. Walecka, *Quantum Theory of Many-Particle Systems,*

Dover (2003).

* A. M. Zagoskin, *Quantum Theory of Many-Body Systems: Techniques and Applications,* Springer, 2nd Edition (2014).
* R. P. Feynman and A. R. Hibbs, *Quantum Mechanics and Path Integrals,*

Dover (2010).

* J. W. Negele and H. Orland, *Quantum Many-Particle Systems,*

Advanced Book Classics, Westview Press (1998).

* G. D. Mahan, *Many-Particle Physics,* Kluwer Academic/Plenum Publishers, 3rd Edition (2000).

**Methodology and Assessment**

20 lectures and 10 problem classes. The lectures are supplemented by homework problem sets for discussion in the problem classes.

Written examination of 3 hours contributing 100%

### RHUL - Particle Accelerator Physics (PH4450)

**Aims of the course**

This course aims to:

* Introduce students to the key concepts of modern particle accelerators
* Apply previously learned concepts to the acceleration and focusing of charged particle beams
* Appreciate the use of particle accelerators in a variety of applications including particle physics, solid state physics, and medicine

**Objectives**

On completion of the course the students should be able to:

* Understand the principles and methods of particle acceleration and focusing
* Describe the key elements of particle accelerators and important applications
* Understand the key principles of RF systems and judge their applicability to specific accelerators
* Understand the key diagnostic tools and related measurements that are crucial to accelerator operation and evaluate their expected performance in key sub- systems

**Syllabus**

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

**Introduction** (2)

History of accelerators; Development of accelerator technology; Basic principles including centre of mass energy, luminosity, accelerating gradient

**Characteristics of modern accelerators** (2)

Colliders; 3rd and 4th generation light sources; compact facilities

**Transverse beam dynamics** (8)

Transverse motion, principles of beam cooling; Strong focusing and simple lattices; Circulating beams

**Longitudinal dynamics** (4)

Separatrix, Phase stability; Dispersion

**Imperfections** (2)

Multipoles, non-linearities and resonances

**Accelerating structures** (1)

Radio Frequency cavities, superconductivity in accelerators

**Electrons** (3)

Synchrotron radiation, electron beam cooling, light sources

**Applications of accelerators** (2)

Light sources; Medical and industry uses; Particle physics

**Future** (2)

ILC, neutrino factories, muon collider, laser plasma acceleration, FFAG

**Prerequisites**

Mathematics and Electromagnetism

**Text Books**

*Recommended*

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

*Optional*

* Sessler and E. Wilson, *Engines of DISCOVERY: A Century of Particle Accelerators*, World Scientific, 2007
* M.G. Minty and F. Zimmermann, *Measurement and Control of Charged Particle Beams,* Springer, 2003
* H. Wiedemann, *Particle Accelerator Physics, Parts I and II*, Second Edition, Springer, 2003

**Website**

<http://moodle.rhul.ac.uk/>

Formal registration to the course to obtain password is required

The following material will be available

* Course outline
* Lecture notes/summaries
* Additional notes
* Links to material of interest
* Problem assignments
* Links to past examination papers

**Methodology and Assessment**

26 lectures and 4 seminars/tutorials; 120 hours private study time, including problem solving and other coursework, and examination preparation.

Exam: (90%) (2½ hour) Three questions to be answered out of five.

Coursework: (10%) 5 sets of assessed problems.

Deadlines: Coursework deadlines are within 2 weeks from the issues of the problem set, unless otherwise advised by the lecturer.

### KCL Physics - Photonics and Metamaterials (7CCP4126)

**Aims of the Course**

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 nano photonics.

Students will be exposed to modern concepts in photonics and understand the main physical principles behind modern photonic technologies, such as optical communications, nano photonics, plasmonics, metamaterials, biosensing and bio-imaging and their applications in everyday life.

**Objectives**

The successful student should be able to:

* Demonstrate comprehension of the concepts of photonics. Link and apply these concepts to a range of physical situations, solving simplified model problems
* Demonstrate problem formulation and solving (both numerical and symbolic), written and verbal communication skills

**Syllabus**

* The course will cover aspects of optics and materials science as applied in photonics. (throughout the course)
* The course will survey the main types of photonic applications and concepts. (throughout the course)

The course will address these aspects by covering the following specific topics:

* Light manipulation at the micro and nano scale:
* **optical waveguides** (4.5 lectures). This section of the course will introduce and develop the formalism necessary to describe the emergence of modes in planar dielectric geometries.
* **surface plasmons polaritons (SPPs) and their devices** (7.5 lectures). Building on the previous section, this part of the course will develop the concepts necessary to understand a keystone building block of nano photonics: SPPs. The field distribution of those modes will be derived in simple planar systems along with their dispersion and general properties, including optical coupling, hybridization in complex multilayers, etc. The manipulation of these waves will be discussed thoroughly for various structures, such as dielectric-loaded wavequides, metal-insulator-metal structures, amongst other geometries relevant for the design of integrated devices.
* **photonic and plasmonic crystals** (4.5 lectures). Periodic structures often demonstrate unique physical properties. This is true for electronic properties in atomic crystals and is equally true for both photonic and plasmonic crystals. This part of the course will use the fundamental concepts presented in the previous section and apply them to periodic nanostructured metallo-dielectric interfaces. Simple models will be presented to understand the formation of plasmonic bands (Bloch modes) and their properties, including dispersion, reflection, refraction, localization, coupling to localized modes, interaction with light, etc.
* **localized surface plasmons (LSPs)** (3 lectures). This part of the course will touch on another important keystone building block in nano photonics: LSPs. Here again, the formalism necessary to understand the optical response of these nanoscopic metallic resonators will be presented. Selected geometries will be discussed to give an understanding of their strong potential for sensing applications, optical cloaking, as well as their use as building blocks in metamaterials.
* **metamaterials** (7.5 lectures). This part of the course will introduce the conceptual ideas behind metamaterials and introduce their major historical development. Moving on, the course will introduce electric and magnetic metamaterials. The former, which can exhibit hyperbolic dispersion, open up the possibility tailor the effective plasma frequency for differently polarized waves in the media, while the former further combine magnetic resonances to produce so-called double negative (DNG) metamaterials (negative magnetic permeability) leading to exotic effects such as negative refraction, optical cloaking, and both super- and hyper-lenses.
* Modern applications of photonics
* **biophotonics, sensing, and energy** (1.5 lectures). This part of the course will focus on the implementation of modern photonics and plasmonic approaches to tackle inter-disciplinary problems where optical techniques have distinct advantages over conventional techniques. These advantages will be illustrated and discussed.
* **advanced optical characterization techniques** (1.5 lectures): As the drive toward the miniaturisation of photonics devices gathers pace, researchers and industrial players require instrumentation that can characterize nanoscale functional media and devices with resolution, both temporal and spatial, that surpass conventional microscopic techniques. Here, the course will centre on state-of-the-art techniques such as Scanning Near-Field Optical Microscopy and Cathodoluminesence. This part of the course will include a tour of the facilities at KCL.

**Prerequisites**

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

**Textbooks**

1. *Fundamentals of Photonics*, H. Saleh

2. *Principles of Nano-Optics*, L. Novotny and B. Hecht

3. *Introduction to Nanophotonics*, S. V. Gaponenko

4. *Optical Metamaterials: Fundamentals and Applications*, W. Cai, V. Shalaev

**Methodology and Assessment**

The course comprises 10 lectures of 2 hours over a 10-week period.

KEATS assignments 20% – presentation – 15% and 3 hour written examination – 65%

### RHUL - Nano-Electronics and Quantum Technology (previously named Physics at the Nanoscale) (PH4475)

**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*/2*e* 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.***

**Prerequisites**

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.

**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 contributing 90%, coursework 10%

### KCL Physics - Standard Model Physics and Beyond (7CCP4501)

**Aims of the course:**

To introduce the student to the physics of the Standard Model of Particle Physics. 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 some applications by computing, via appropriate tree-level Feynman graphs, cross sections or decay rates (to leading order in the respective couplings) of several physical processes, such as quantum electrodynamics processes, nucleus beta decays and other processes that occur within the Standard Model of electroweak interactions.

**Objectives of the Course:**

On completing the course, the students should have understood the basic features of the Standard model that unifies the electromagnetic and weak interactions of particle physics, in particular the students should be able to comprehend **(i)** The detailed gauge group structure and the associated symmetry breaking patterns underlying the electroweak model, **(ii)** the short range of the weak interactions, as being due to the massiveness of the associated gauge bosons that carry such interactions, **(iii)** the long-range of electromagnetism, as being due to the masslessness of the associated carrier, that is the photon, **(iv)** the detailed mechanism (Higgs) by means of which the weak interactions gauge bosons acquire their mass, as a consequence of the spontaneous breaking of gauge invariance. The students should also be capable of: **(v)** Computing fundamental processes within the standard model, at tree-level, such as the decays of the weak interaction gauge bosons, the nuclear beta decay and its inverse, or scattering processes within electrodynamics, such as electron-muon or electron-proton scattering. The students should be conversant in computing decay widths and cross sections (both differential and total).

**Syllabus (33 hours)**

(The **approximate** allocation of lectures/tutorial to topics is shown in brackets – by ‘tutorials’ it is meant an hour of lectures in which applications/problems of the material covered in the previous hours or homework exercises are analysed/solved in detail.)

1. Review of Lie Algebras, Lie Groups and their representations and their connection to Particle Physics – examples of Lie groups with physical significance **(3 hours)**

2. Free Relativistic Fields of spin 0 (scalar), spin ½ (fermions) and Spin 1 (massless (photons) and massive vector mesons: Lagrange formalism and Symmetries (space-time and continuous internal (gauge) symmetries- a first glimpse at gauge invariance) **(4 hours, 2 tutorials)**

3. Interacting Fields and Continuous Internal Symmetries in Particle Physics (global and local (gauge)) and methods of computing the associated Noether currents (e.g. the Gell-Mann-Levy method **(2 hours, 1 tutorial)**

4. Spontaneous Breaking of Global Continuous Symmetries – the Fabri-Picasso and Goldstone Theorems – Massless Goldstone modes **(2 hours, 1 tutorial)**

5. Spontaneous Breaking of local (gauge) Abelian (U(1)) and Non-Abelian symmetries – absence of massless Goldstone modes from the physical spectrum – mechanism for mass generation of gauge bosons, the Higgs particle **(4 hours, 2 tutorials)**

6. The Standard Model Lagrangian: SU(2) x UY(1) gauge group as the physical group unifying weak and electromagnetic interactions and its spontaneous breaking patterns to Uem (1) of electromagnetism; chiral spinors, lepton sectors, quark sectors, quark-lepton symmetry as far as weak interactions are concerned – Brief discussion on incorporating colour SU(3) group in the Standard Model, gauge-invariant fermion mass. **(4 hours, 2 tutorials)**

7. Applications of the Standard Model: Feynman Rules, Computing physical processes such as Nuclear Beta Decay Quantum Electrodynamics processes, such as electron-muon or electron-proton scattering (**3 hours, 3 tutorials)**

**8. TWO Extra hours of Lectures on BEYOND THE STANDARD MODEL**, such as the role of supersymmetry in view of the Higgs Discovery and Stability of the Electroweak Vacuum have been provided in the past years by John Ellis, Maxwell Professor of Physics at King’s College London and this tradition is foreseen for several years to come. The material is not examinable but serves the purpose of broadening the students horizons

**Prerequisites**

Essential knowledge of Relativistic Quantum Fields (course offered in the MSci programme as prerequisite), including relativistic kinematics of fields of various spins. Excellent Knowledge of tensor calculus. Very Good knowledge of Particle Physics and a basic knowledge of Lie Groups, provided either through a specialized course on the subject or an equivalent one in the physics syllabus, such as symmetry in Physics. Knowledge of Lagrange equations are essential prerequisites for the course.

**Study Material - Textbooks**

Lecture Notes (N.E. Mavromatos) (Latex) provided

**Textbooks:**

Robert Mann, *An Introduction to Particle Physics the Physics of the Standard Model* (CRS Press, Taylor & Francis Book, 2010), ISBN 978-1-4200-8298-2 (hard cover).

The book provides a comprehensive and up-to-date description of the most important concepts and techniques that are used in the study of Particle Physics and the Physics of the Standard Model in particular.

I.J.R. Aitchison and A.G.J. Hey, two volumes: *Vol. 1: Gauge Theories in Particle Physics: From Relativistic Quantum Mechanics to QED* (Taylor & Francis Group, 2003), ISBN: 0-7503-0864-8, 978-0-7503-0864-9) and *Vol. 2: Gauge Theories in Particle Physics: QCD and the Electroweak Theory* (Graduate Student Series in Physics) (Paperback) (IOP Publishing, 2004), ISBN: 0-7503-950-4.

Other more advanced textbooks on related topics (mostly gauge field theories), for students planning to continue into higher academic degrees in theoretical particle physics are

M.E. Peskin and H.D. Schroeder, *An Introduction to Quantum Field Theory* (Addison- Wesley, 1995).

T.P. Cheng and L.F. Li, *Gauge Theory of Elementary Particle Physics* (Oxford, 1984, last reprint 2000)

S. Weinberg, *The Quantum Theory of Fields, Vols. I, II and III* (they cover several advanced topics, including supersymmetry) (Cambridge U.P. 1995, 1996, 2000).

**The web page of the course can be found in this link (accessible upon proper registration):**

<http://keats.kcl.ac.uk/course/view.php?id=22727>

**Methodology and Assessment**

33 hours of lectures and tutorials (three hours each week: either three hours of lectures or two hours of lectures, followed by one hour of tutorials, depending on the week). Weekly sets of exercises are provided to the students, who are then asked to solve them, usually within a week, and then the problems are solved in the tutorial hour, with written solutions provided through the course web page (see above).

Mini project – 20% and written examination of 3 hours contributing 80%

### RHUL - Statistical Data Analysis (PH4515)

On completion of the course, students should be able to:

• Understand and be able to use effectively the statistical tools needed for research in physics through familiarity with the concepts of probability and statistics and their application to the analysis of experimental data.

**Course content**

• 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, Markov Chain Monte Carlo

• Statistical tests: formalism of frequentist test, choice of critical region using multivariate methods, significance tests and p-values, treatment of nuisance parameters

• Parameter estimation: properties of estimators, methods of maximum likelihood and least squares, Bayesian parameter estimation, interval estimation from inversion of a test

• Overview of Bayesian methods, marginalisation of nuisance parameters, Bayes factors

**Prerequisites**

Familiarity with programming in a high-level language such as C++ (or PH3170 as co-requisite)

**Books**

Lecture notes provided online.

<http://www.pp.rhul.ac.uk/~cowan/stat_course.html>

G D Cowan, *Statistical Data Analysis*, Clarendon Press, 1998. (530.0285.COW)

R J Barlow, *Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences*, John Wiley, 1989. (530.13.BAR)

**Assessment**

Written examination of 2½ hours contributing 80%, coursework contributing 20%

### RHUL - Statistical Mechanics (PH4211)

**Aims of the course**

Consolidation of previous knowledge and understanding of Statistical and Thermal Physics within the context of a more mature framework. Introduction to the ideas and concepts of interacting systems. Introduction to the ideas and concepts of phase transitions including some specific examples. Introduction to the ideas and concepts of irreversibility: non-equilibrium statistical mechanics and irreversible thermodynamics.

**Objectives**

On completion of the course, students should be able to:

* explain the difference between the macroscopic and the microscopic descriptions macroscopic phenomena;
* explain the essential concepts in the laws of thermodynamics from both macroscopic and microscopic perspectives;
* apply the methods of statistical mechanics to simple non-interacting systems;
* demonstrate how weakly-interacting systems may be studied through approximation schemes;
* describe the phenomena and classification of phase transitions;  
  explain and demonstrate some of the approximate methods of treating phase transitions, including the van der Waals method, mean-field approaches;
* describe and demonstrate how the Landau theory provides a general framework for the understanding of phase transitions;
* explain how irreversibility and the transition to equilibrium may be understood in terms of fluctuations;
* show how the Langevin equation provides a link between transport coefficients and equilibrium fluctuations.

**Syllabus**

**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)

**Prerequisites**

Classical and Statistical Thermodynamics course at 2nd year level.

**Text 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/>

**Methodology and Assessment**

30 lectures and 3 problem class/discussion periods. Lecturing supplemented by homework problem sets. Written solutions provided for the homework after assessment. Links to information sources on the web provided on the course web page.

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

### RHUL – Order and Excitations in Quantum Materials (PH4472)

**Course Content**

Atomic Scale Structure of Material: The rich spectrum of condensed matter; Energy and time scales in condensed matter systems; Crystalline materials; Formal introduction to reciprocal space.

Scattering Theory: Scattering from a crystal lattice, Laue Condition and unit cell structure factors; Ewald construction; Dispersion corrections; QM derivation of cross-section; X-ray form factors and Neutron scattering lengths; Coherent and incoherent scattering.

Excitations of Crystalline Materials: Dispersion curves of 1D monoatomic chain (revision); Understanding of dispersion curves in 3D materials; Examples of force constants in FCC and BCC lattices; Dispersion in 1D and 3D. Phonons and second quantization; Anharmonic interactions.

Modern Spectroscopic Techniques: Neutron scattering: Spectroscopy across different time- and length-scales, time-of-flight and monochromation, polarized neutrons, X-ray scattering: X-ray magnetic circular dichroism.

Sources of X-rays and Neutrons: Full day visit to RAL. Neutron Sources and Instrumentation. Synchrotron Radiation.

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

Order and Magnetic Structure: Overview of magnetic order in crystalline materials; Weiss model; Spin glasses; Magnetism in metals; Spin-density waves; Kondo effect.

Magnetic Excitations: Excitations in ferromagnets and antiferromagnets; Magnons; Bloch T3/2 law; Excitations in 1, 2 and 3 dimensions; Quantum phase transitions.

Phase transitions and Critical Phenomena: Broken symmetry and order parameters in condensed matter. Landau theory; Ising and Heisenberg models. Critical exponents. Universality and scaling.

Local Order in Liquids and Amorphous Solids: Structure of simple liquids; Radial distribution function; Dynamics in simple and molecular liquids; Glass formation; Simple and complex glasses. Overview of small-angle scattering.

**Prerequisites**

PH2710 Solid State Physics (or equivalent from another department)

**Learning Outcomes**

1. Understand structures and excitations in crystalline materials and reciprocal space and answer associated problems.

2. Understand condensed matter magnetism – single-ion and cooperative magnetism, magnetic order and excitations - and answer associated problems.

3. Understand phase transitions and critical phenomena and answer associated problems.

4. Understand local order in crystalline materials, amorphous solids and liquids and answer associated problems.

5. Describe sources of neutrons and x-rays, modern spectroscopic techniques and scattering theory.

**Assessment**

The total number of notional learning hours associated with this module are 150.

These will normally be broken down as follows:

33 hours of Lectures across 11 weeks

117 hours of Guided Independent Study

Formative Assessment:

Coursework assignments - Written and verbal comments

Summative Assessment:

Progress/ Engagement (20%) 20 hours

Exam (80%) 2.5 hours

### KCL Maths - Strings, Branes and Quantum Gravity (7CCMMS34)

**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.

**Teaching Arrangements**

Usually two hours of lectures each week. Lectures are supported by small group tutorials.

**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.

7CCMMS01 Lie Groups and Lie Algebras would be helpful

**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.

**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.

**Assessment**

Written examination of 2 hours contributing 100%

### KCL Maths - Supersymmetry and Conformal Field Theory (7CCMMS40)

**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 supersymmetry and BPS monopoles.

**Teaching arrangements**

Usually two hours of lectures each week. Lectures are supported by small group tutorials.

**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.

**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

**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.

**Assessment**

Written examination of 2 hours contributing 100%

### KCL Physics - Theoretical Treatments of Nano-systems (7CCP4473)

**Aims of the Course:**

This course provides an introduction to the rapidly growing area of atomistic-based theoretical modelling in nano-science, based on fundamental quantum theory. It introduces the physics of many electron systems as well as the theoretical background of some state of the art techniques needed to successfully model the structure and dynamical evolution of functional nano-sized systems and materials in general. The role of symmetry in describing the systems electronic structure and vibrations and the role of statistical averaging in dealing with rare events and bridging to higher length scales are also highlighted throughout the course.

Concrete examples of research applications are also provided, involving modern concepts on the nano-scale behaviour of functional materials.

**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 problems can be attacked by mean-field techniques at different levels of complexity.
* Appreciate how theories underpinning the current research on nano-systems such as Density Functional Theory, Statistical methods (molecular dynamics, Monte Carlo, free energy) and Orbital Representation can be rationalised at a more fundamental level in terms of modern mathematical tools such as, e.g., Stochastic Processes and Group Theory.
* Understand how these theories and tools can be used to generate accurate quantitative predictions on the behaviour of materials at the nanometre/picosecond size- and time- scales and above, enabled by QM-accurate potential energy surfaces and inter-atomic forces used in simulations techniques.

**Topics in lectures 1-3:**

**Many-body problem and quantum mechanics of identical particles**

Schroedinger equation for a many-body system. Approximate casting as an effective one-body problem. The particle exchange operator, symmetry of a two-body wave function with spin. Wavefunction classes constructed from spin orbitals. Reminder of perturbation theory: perturbative approach of the ground state and the first excited state of the Helium atom.

**Variational method**

Calculus of variations: definition of a functional and functional derivative. Many-body Schrodinger equation cast as a variational principle. Examples: i) virial theorem for Coulombic systems, ii) ground state energy of the Helium atom through trial wavefunction with one variational parameter, and iii) Self-consistent field applied to Hartree equation for the ground state of the Helium atom.

**The Hartree-Fock method**

Pauli principle and Slater determinants. Derivation of the Hartree-Fock equations. Direct and exchange interactions, and consequences for materials. Hartree Fock in the homogeneous electron gas. Koopman’s theorem. Success and shortcomings of the HF method, and the importance of electronic screening.

**Density Functional Theory**

Hohenberg-Kohn and Kohn-Sham theorems, and connection to Slater’s X-alpha method. V- and N- representability of densities. Kohn-Sham ansatz. Brief discussion of DFT in terms of a Legendre transformation. Making DFT practical: Local Density Approximation and beyond. Brief discussion of extension of DFT. Success and shortcomings of DFT.

**Topics in lectures 4-8:**

**Separation of electronic and nuclear degrees of freedom**

The full Hamiltonian operator, the Born-Oppenheimer approximation, diabatic expansion, introduction to non-adiabaticity. the Hellman-Feynman theorem. Classical force fields. Fitting forces. Elements of machine learning. Vibrations. Stability. QM-based forces on atoms. Examples: vibrations of finite and extended systems; elimination of translations and rotations. Quantum vibrations. Free energy. Quasiharmonic approximation. Configurational entropy. Examples of material modelling with Helmholtz and Gibbs free energies.

The Verlet Algorithm and First-Principles Molecular Dynamics. Classical potentials, the problem of accuracy and transferability. A coarse graining technique example from supramolecular assembly. The problem of validation: fitting force fields from QM data. Bayes Theorem, and elements of Machine Learning techniques for atomistic modelling.

**Statistical methods in material modelling**

Statistical ensembles. Important thermodynamic averages. Correlation functions. Molecular dynamics. Ergodicity. Verlet and velocity Verlet algorithms. NVT molecular dynamics (MD) methods: Andersen, Nose and Langevin (stochastic) methods. Static and dynamic properties via MD: radial distribution function, diffusion, diffusion coefficient and velocity autocorrelation function. The main idea of Monte Carlo (MC) methods. Random numbers. Sampling discrete and continuous distributions. Integration using MC. Convergence of an MC generated Markov chain. Detailed balance. Reducibility. Metropolis method. Applications to NVT, NPT and Grand Canonical ensembles MC simulations. Practical issues. Rare events. Kinetic MC. Calculation of rates (classical transition state theory). Calculation of energy barriers.

**LCAO method in quantum chemistry and DFT**

Formulation of Hartee-Fock and Kohn-Sham methods using localised basis set. Slater and Gaussian type atomic orbitals. Generalised eigenproblem in non-orthogonal basis set. Cholesky factorisation. Problems related to localised basis set (completeness, BSSE, Pulay). Example: two level system. Change of the basis. Naphthalene molecule.

**Topics in lectures 9-10:**

**Group theory**

Symmetry operations of molecules: rotations, reflections, inversion. Abstract group theory (definition, properties, subgroup, direct product, cosets, shift, class, generators). Point groups. Action of an operation on a function. Action on atomic orbitals. Theory of group representations. Unitary representation, reducible and irreducible representations, Schur’s lemmas, orthogonality relations, characters, decomposition of a reducible representation, regular representation, projection operator method. Quantum mechanics and symmetry. Wigner’s theorem. Example: quasidiagonalisation for a square molecule. Periodic systems. Translational group and its irreducible representations. Brillouin zone. Symmetry adapted functions and Bloch theorem. Main ideas for implementation of HF and KS equations for periodic systems. Space groups. Bravais lattices. Crystal classes. Space group operations. Fedorov’s theorem. International Tables of Crystallography.

**Bibliography:**

Richard Martin, “Electronic Structure”, Cambridge University Press.

B.H.Bransden and C.J.Joachain, “Physics of Atoms and *Molecules*”, Longman.

M.Finnis, “*Interatomic Forces in Condensed Matter*”, Oxford University Press.

M.P.Allen and D.J.Tildesley, “*Computer Simulations of Liquids*”, Oxford University Press.

D.Frenkel and B.Smit, “*Understanding Molecular Simulations*”, Academic Press.

C. Bradley and A. Cracknell, “*The Mathematical Theory of Symmetry in Solids: Representation Theory for Point Groups and Space Groups*“ (Oxford Classic Texts in the Physical Sciences), 2009.

M. Hamermesh, “*Group Theory and Its Application to Physical Problems*” Dover Books on Physics, 2003,

L. Kantorovich, *Quantum theory of the solid state: a introduction*:, Dover, 2004.

J. P. Elliott and P. G. Dawber, “*Symmetry in Physics: Principles and Simple Applications*”, Oxford, 1985

R. Knox, A. Gold1. “*Symmetry in the solid state*”, Benjamin, 1964.

**Assessment:**

Written examination contributing 100% of the total marks.

**Pre-requisites:**

Spectroscopy and Quantum Mechanics or equivalent

### KCL Physics - Cosmology (7CCP4600)

**Aims of the Course:**

The module will focus on cosmology and gravitational and high energy physics in the context of early universe. The standard cosmological model will be developed, the need for inflation and the various inflationary models will be studied in depth, Baryogenesis, leptogenesis and nucleosynthesis will be discussed. Spontaneously broken symmetries and the formation of topological defects will be covered. The physics of topological defects with emphasis on cosmic strings will be deeply discussed.

The hot topics of dark matter and dark energy will be explored. The origin of large scale structure and cosmic microwave background temperature anisotropies will be covered in detail.

**Syllabus**

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.

**Weekly teaching arrangements**

3 hours of lectures

**Pre-requisites**

Beyond the Standard Model

General Relativity and Gravitation

Particle Physics

Astrophysics

**Summative assessment**  
**Details of the module's summative assessment/s**  
Written Exam (3 hours) May/June

**Formative assessment**

None

**Required reading/resources**

S. Weinberg: "Cosmology" Oxford University Press

V. Mukhanov: "Physical foundations of Cosmology" Cambridge University Press

E. Kolb and M. Turner: " The early universe" Frontiers in Physics

### KCL Maths - Quantum Field Theory (7CCMMS32)

**Aims**

To provide basic foundational material in quantum field theory.

**Syllabus**

Classical field theory: Lagrangian; Hamiltonian; symmetries; Noether's theorem. Relativistic wave equations: Klein-Gordon equation; Dirac equation; Maxwell equations. Non-Abelian gauge fields. Free field theory: quantisation of scalar, Fermion, and Maxwell fields; Fock spaces; normal ordering; time ordering; Feynman propagators. Interactions: perturbation theory; Wick’s theorem; Feynman diagrams; regularization.Cross-sections.

**Teaching Arrangements**

Usually three hours of lectures and a one hour tutorial per week.

**Assessment**

2 hr written examination weighted at 100%

**Formative Assessment**

Exercise sheets circulated during tutorials

### KCL Maths - Theory Of Complex Networks (7CCMCS02)

**Aims and objectives**

Present the basic concepts of the theory of complex networks. Introduce various techniques which should enable the student to partake in active research in the field.

**Syllabus**

Microscopic properties of networks: adjacency matrix, vertex degree, clustering coefficient, measures of node centrality and node similarity. Macroscopic properties of networks: degree distributions, graph modularity, and assortativity. Processes on networks: voter model, diffusion process, random walk on a graph, PageRank, and spectral distribution. Random graphs: Erdos-Renyi ensemble, graphs with a prescribed degree distribution, giant components and percolation transition.

**Teaching arrangements**

Usually two hours of lectures per week. Lectures are supported by small group tutorials.

**Prerequisites**

Good knowledge of multivariate calculus, linear algebra and probability concepts.

**Books**

**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.

**Assessment**

Written examination of 2 hours contributing 100%

### KCL Maths - Equilibrium Analysis of Complex Systems (7CCMCS03)

**Aims and objectives**

The course aims to give an introduction to the concepts and tools of statistical mechanics of complex and disordered systems. It will be explained how to use these tools and concepts to investigate complex biological, physical, 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.

**Teaching arrangements**

Usually two hours of lectures per week. Lectures are supported by small group tutorials.

**Prerequisites**

Good knowledge of multivariate calculus, linear algebra and probability concepts.

**Books**

**Assignments**

Problem sheets will be made available via the module KEATS page.

**Assessment**

Written examination of 2 hours contributing 100%

### KCL Maths - Dynamical Analysis of Complex Systems (7CCMCS04)

**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 supersymmetry and BPS monopoles.

**Teaching arrangements**

Usually two hours of lectures each week. For 20/21 there will be one hour of live lectures each week with further pre-recorded lectures. Lectures are supported by small group tutorials.

**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.

**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

**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.

**Assessment**

Written examination of 2 hours contributing 100%

### KCL Maths - Mathematical Biology (7CCMCS05)

**Aims and objectives**

Mathematical biology is a very active and fast growing interdisciplinary area in which mathematical concepts, techniques, and models are applied to a variety of problems in developmental biology and biomedical sciences. Many biological processes can be quantitatively characterised by differential equations. This course introduces you to a variety of models mainly based on ordinary differential equations and techniques for analysing these models. Mathematical concepts on nonlinear dynamics and chaos will be introduced. Population models (predator-prey, competition), epidemic models and reaction enzyme kinetics will be discussed. Some probabilistic modelling of population dynamics and molecular evolution will also be introduced.

**Syllabus**

Continuous population models for single species

Discrete population models for single species

Galton Watson processes for population dynamics

Continuous population models for interacting species

Modelling infectious disease transmission/spread using ODEs

Reaction kinetics

Introduction to DNA and modelling of molecular evolution

**Teaching arrangements**

Usually three hours of lectures per week. Lectures are supported by small group tutorials.

**Prerequisites**

**Books**

**Assignments**

Exercise sheets will be given out.

**Assessment**

Written examination of 2 hours contributing 100%

### KCL Maths - Elements of Statistical Learning (7CCMCS06)

**Aims and objectives**

The aim of the module is to introduce key statistical techniques for learning from data, mostly within the framework of Bayesian statistics. The module will cover linear models for regression and classification as well as more advanced approaches including kernel methods, graphical models and approximate inference.

**Syllabus**

Review of basic notions of probability.

Learning of probability distributions: maximum likelihood and Bayesian learning of Gaussian distributions, conjugate priors, Gaussian mixtures, expectation-maximization approach.

Learning of input-output relations: linear regression, evidence approximation for optimizing hyperparameters, Gaussian processes.

Linear classification, Gaussian process classification, Laplace approximation, link to Support Vector Machines, sparsity.

Graphical models.

Approximate inference: variational methods, expectation-propagation, sampling methods.

**Teaching arrangements**

Usually two hours of lectures per week. Lectures are supported by small group tutorials.

**Prerequisites**

**Books**

**Assignments**

The module book, which has a number of exercises and additional exercise sheets, will be provided. Any problems encountered will be discussed in tutorial sessions as needed. You are strongly encouraged to hand in your solution attempts to the tutor regularly for feedback.

**Assessment**

Written examination of 2 hours contributing 100%

**KCL Physics – Quantum Information and Computing (7CCP3000) NEW 2024/5**

**Aims and objectives**

At the end of the module, students will be able to:

1. Select and apply principles and concepts of quantum information processing appropriate to describe operations ranging from single qubit manipulation on the Bloch sphere to entangled multi-qubit setups, the underpinning state space, Pauli operators and the gates necessary for universal quantum computers.

2. Evaluate the limitations of quantum computation, projective/POVM measurements, using fundamental theorems such as no-cloning theorem, as well as the potential of quantum devices, synthesizing information from a diversity of sources in this rapidly expanding field.

3. Design circuit diagrams, their translation to/from matrix operations, and perform simple operations

4. Demonstrate advanced understanding of the core aspects of key quantum algorithms, including Deutsch-Jozsa, quantum Fourier Transform and Hamiltonian simulation.

5. Demonstrate the ability to embed understanding of these principles into a practical framework, with hands-on programming in a quantum emulation environment to mimic and test the application of quantum algorithms.

**Teaching arrangements**

2 hour weekly lecture, 2 hour weekly examples/ programming class

**Assessment**

Written exam contributing 70%

Coursework contributing 30%

**KCL Physics – Statistical Field Theory (7CCP5000) NEW 2024/5**

**Aims and objectives**

1. Understand and apply Green’s function techniques to interacting many-body systems at finite temperatures using second quantization

2. Formulate many-body statistical mechanics in terms of functional integrals

3. Apply a systematic understanding of mean-field theory, upper-and lower-critical dimension to relevant systems

4. Identify and demonstrate the idea of universality i.e., why the same mathematical theories describe a wide range of physical systems

5. Perform the simplest Wilsonian renormalisation group calculations (e.g., block-spin transformation or phi-4)

6. Identify and apply the most relevant tools introduced in the module to unfamiliar systems, analysing the potential and limitations of such tools

**Assessment**

Written exam contributing 80%

KEATS quizzes contributing 20%