# Cockcroft Institute

## Postgraduate Handbook and Education Programme Syllabus

2020/21

*Version 1.0*

(page left blank)

# Contents

# Welcome

The Cockcroft Institute is a collaboration between the Universities of Lancaster, Liverpool, Manchester and Strathclyde, and with the Accelerator Science and Technology Centre of the Science and Technology Facilities Council at Daresbury Laboratory, Cheshire. Including the efforts of mainly physicists and engineers but also of other disciplines, the Institute carries out world-leading research and technology development in the field of particle accelerators at a number of centres both within the UK and around the world; its main site is on the world-renowned Daresbury Science and Innovation Campus, co-located with many staff that work for the Science and Technology Facilities Council.

Named after the Nobel Prize winner Sir John Cockcroft FRS who pioneered early methods to utilise particle accelerators for scientific research, the Institute's aim is to provide the intellectual focus, educational infrastructure, and the scientific and technological facilities, for particle accelerator research and development. It thus enables UK scientists and engineers to take a major role in accelerator development, operation and application, both now and for the future.

This handbook gives information about the educational programme of the Institute, primarily directed at postgraduate researchers and those who work with them.

**Director of the Cockcroft Institute:**

Prof. Peter Ratoff (Lancaster University, Department of Physics)

*email: peter.ratoff@cockcroft.ac.uk*

**Directors of education and training:**

Prof. Andy Wolski (University of Liverpool, Department of Physics)

*email: a.wolski@liverpool.ac.uk*

Dr Laura Corner (University of Liverpool, Department of Engineering)

*email: laura.corner@liverpool.ac.uk*

Throughout this handbook, ‘Institute’ should be understood as referring to ‘The Cockcroft Institute’.

# Code of Practice for PhD Researchers and Supervisors at the Cockcroft Institute

The aim of a PhD is for the postgraduate researcher to learn and demonstrate research skills through the development of a suitable research project. By the time of their examination the PhD candidate should have delivered an end goal of their project, and most importantly they should have provided an intellectual leadership of the work that led to that goal.

The supervisor's role is to provide the intellectual guidance and support required for the postgraduate researcher to achieve their goals, within the context of the wider work of that field. In many cases a particular postgraduate researcher may have more than one nominated supervisor; for example, the postgraduate may be working at an overseas laboratory with a local collaborating supervisor plus they also have an academic supervisor. It is important to note that it is the primary *academic* supervisor at the postgraduate's registered university that is ultimately responsible for the postgraduate's ability to successfully submit a thesis.

Postgraduates working towards a PhD will typically have a limit of four years by which time they must submit a thesis for examination. This limit will be different for other intended qualifications (e.g. MSc) and for part-time students (e.g. those also working full-time for a national laboratory or in industry). Also, there may be different restrictions on *how soon* a thesis may be submitted, and the funding duration the postgraduate has received may differ from the other time limits. It is the academic supervisor's responsibility to understand and advise the postgraduate researcher on these matters.

At the end of their studies the postgraduate researcher will submit a thesis for examination that is typically around 200 pages in length; each university has its own rubric on the required format and content of the thesis, how it is to be submitted, and how it is to be examined. The examination that follows submission will assess the research quality evidenced by the thesis, the understanding of the candidate not only of their own work but of the wider subject, and thereby the suitability of the candidate to have the title 'PhD' conferred upon them. In the UK a PhD examination is typically of several hours' duration, and is most typically conducted with the aid of a single external examiner who is an acknowledged expert in the research topic discussed in the submitted thesis.

To help the postgraduate researcher to successfully complete a PhD, the supervisor must not only support their day-to-day work to obtain results suitable for a thesis, but also to enable them to have their own intellectual leadership of that work. In addition, the postgraduate researcher may also need to undertake various other training, for example in writing, presenting and so forth; the supervisor must facilitate this.

## Specific Guidance for Supervisors

Please note that individual universities within the Institute have their own supervision procedures, which should be read and followed in conjunction with the specific guidance for Cockcroft Institute researchers given here. This may, for example, include certain administrative, reporting and examination activities; a notable point is the requirement of some universities to submit intermediate reports part-way through the PhD study period that may also be examinable. The guidance here is not intended to supplant or replace individual university guidance, but is meant to support and augment it.

- All postgraduate researchers and their supervisor(s) must together develop a project plan for the postgraduate's work; this is often also a requirement of the university at which the postgraduate is registered. It is to be expected that this project plan will be updated numerous times during the course of the PhD study period, and that a schedule for writing up and submitting be part of the plan. The academic supervisor, in discussion with other supervisor(s) and with the postgraduate, is responsible for ensuring that the project plan provides a clear, timely route toward a successful thesis submission.

- The postgraduate researcher and their supervisor(s) will typically meet in person at least once per week for perhaps an hour or more; however, some universities will have a supervision schedule that may be different from that. A significant fraction of the Institute's PhD researchers are based outside of the UK but with UK-based academic supervisors; in this case it is understood that some of the regular meetings may need to take place via telephone or video, but efforts should still be made by all supervisors to be in regular contact with their researcher.
- The supervisor (or supervisors) are responsible for ensuring their postgraduate researchers are making suitable progress towards submitting a thesis within the time limits set out for them; the academic supervisor has ultimate responsibility for this. Whilst it is normal for postgraduate researchers to undertake work which contributes to the wider research efforts of their research group, university and Institute, supervisors must give their researchers adequate opportunity and time to develop the work required for a successful thesis.
- To assist in successful supervision, the Cockcroft Institute has a policy that supervisors undertake suitable training in supervision skills, diversity awareness and unconscious bias as offered by their individual employers. This is in addition to understanding the progression and administrative requirements of the university at which their postgraduate researcher is registered.
- It is the policy of the Cockcroft Institute that no supervisor should be supervising more than five PhD students at any given time. However, joint supervision and part-time students may be counted as pro-rata load based on the rate set at the supervisor's university, and with agreement by the Cockcroft Management Committee.

## Joint ASTeC-University Projects

The Institute has a significant number of projects where the postgraduate researcher works primarily within the Accelerator Science and Technology Centre (ASTeC) of STFC, with day-to-day supervision by a staff researcher within ASTeC but with a primary academic supervisor at one of the Cockcroft partner universities. It is therefore worth highlighting some specific guidance for those postgraduate researchers.

- ASTeC may either commission projects to be carried out separate to them, or may by joint supervisors on a project they are actively involved in. It must be clearly defined prior to the start of any project what sort it is.
- Joint projects within ASTeC should have a named ASTeC member of staff as a recognised supervisor in addition to the required academic (university) supervisor. As with any other project, both supervisors should meet with their postgraduate researcher at least once per week, and neither supervisor should leave the other to solely carry out the supervision of the postgraduate.
- Joint projects within ASTeC will often involve day-to-day work on the wider goals of the particular research group the postgraduate is working in; however – similar to any other PhD study topic - it is mandatory that postgraduate researchers have sufficient time to develop their topic and to have intellectual leadership of it such that they can eventually submit a successful thesis.
- Whilst joint postgraduate researchers are primarily based within ASTeC for their day-to-day research work, they are still registered with their home universities and required to undertake

the training, administrative and examination duties specified by that university. Supervisors must allow their students to undertake those activities.

## Specific Guidance for Postgraduate Researchers

Each partner university sets its own assessment and progression requirements, and postgraduate researchers at the Cockcroft Institute must satisfy those requirements. Also, the Cockcroft Institute has specific sub-programmes and funding grants (for example, European Union Training Grants) that have their own training requirements; postgraduate members of those programmes or grants must likewise satisfy the requirements of those programmes. However, there is a common set of requirements for all postgraduate researchers, which are listed below. In cases where there are conflicts about satisfying the various training requirements, postgraduate researchers should contact the Director of Education for advice.

The list of general requirements are as follows:

- Postgraduates should attend all supervision and research meetings (such as group and project meetings) as directed by their supervisor(s).
- Postgraduates are expected to present appropriate work at subject-specific workshops and conferences during their PhD studies.
- By the end of their 1st year of studies, postgraduates should have carried out a literature review, obtained preliminary results and completed a research plan for the remainder of their PhD studies; usually this activity will be done as a matter of course because of university-specific requirements.
- All postgraduates must complete at least 100 hours of subject-specific training over the course of their PhD studies. This comprises 60 hours from the Cockcroft Institute education programme and 40 hours of additional relevant credits (as agree with the director of education). The Cockcroft lecture series will satisfy the first 60-hour requirement, and in most cases the other 40 hours will be satisfied by their courses available from their home university.
- Postgraduate researchers should attend the Cockcroft Institute lecture courses appropriate to their programme (typically held on Mondays in term time). Postgraduates based at Daresbury, Liverpool, Manchester or Lancaster should attend in person; postgraduates based at Strathclyde should attend via the SUPA grid room (or other equivalent) connection. Other postgraduates may view the lectures online.
- Postgraduates should complete any assessments which are set as part of their coursework. For 1st-year postgraduates there are assessments between January and March 2020 for the introductory courses; there is a pass mark of 50% for these assessments, which all postgraduates taking the module should attain.
- Postgraduate researchers should arrange to attend in person the Institute postgraduate conference held each year (around Oct 2019). 2nd year postgraduate researchers are required to make a poster presentation or talk at this conference.
- Postgraduates must complete, each year, 2 weeks (80 hours) of transferable skills (‘soft skills’) training. This training may include transferable skills such as programming, software engineering, communication and presentation, outreach training, networking, team-working, leadership training, time management training, and business and entrepreneurship training. Activities that do not count include such things as giving presentations at conferences. Postgraduates should keep a personal record of their training and submit it to the Institute office at the end of each semester.

- Postgraduates are expected to attend a reasonable number of seminars given by external speakers that visit the Institute.
- Postgraduates are required to comply with the CI policy on social media use, which is available from the Institute Directorate.
- Postgraduates are reminded of their registered university's policy on plagiarism, which is considered a serious matter both by the university and by the Institute. A summary of specific guidance is given below.

## Mentoring Arrangements

Each postgraduate researcher should have an assigned mentor not connected to the postgraduate's project. The purpose of the mentor is to be an independent contact within the Institute from which advice and support may be obtained in confidence, and the mentor should be contacted in the first instance if a postgraduate has issues with their studies which they do not feel they can discuss with their supervisor. As a second line of support, the Director of Education and the Cockcroft Institute Director may also be contacted for advice.

In most cases this mentor will be assigned as a matter of course by their home university. Postgraduates who do not have an assigned mentor should contact the Director of Education, who will arrange for one to be assigned.

## Welfare Arrangements

Postgraduates with personal issues not connected with their studies may make use of the counselling, welfare and other support services available from their home universities. Postgraduates who are also STFC members of staff (for example, part-time students) may also use the STFC welfare services. Whilst STFC offers welfare services to its own staff, postgraduates who are not STFC staff are not eligible to use those services, and they should use the services available from their home university.

It is recognised that many postgraduates at the Institute will be geographically remote from their home universities, and the Institute support staff will assist in accessing welfare services.

## Student Office Accommodation and Resources

Postgraduates based at the main Cockcroft Institute site at Daresbury Laboratory will normally be provided with a dedicated desk for a maximum period of four years; other postgraduates will have accommodation provided via their registered university or host laboratory. During their funding period all postgraduates may make use of the local resources at the main CI site, such as the Library. Postgraduates requiring access after this period should make arrangements via their supervisor to access a 'hot desk' and other facilities.

At the completion of their studies, it is the student's responsibility to dispose of or re-allocate any office items, to clear their desks and office storage, and to ensure that any IT equipment is returned to their supervisor / host institution.

## Academic Malpractice and Plagiarism

Academic malpractice is any activity – intentional or otherwise – that is likely to undermine the integrity essential to scholarship or research. It includes plagiarism, collusion, fabrication or falsification of results, and anything else that could result in unearned or undeserved credit for those committing it. Academic malpractice can result from a deliberate act of cheating or may be committed unintentionally.

As a postgraduate you are expected to cooperate in the learning and research process throughout your programme of study by completing assignments of various kinds that are the product of your own study or research. You must ensure that you are familiar with, and comply with, your University's regulations and conventions: ignorance of the University regulations and conventions cannot be used as a defence for plagiarism or some other form of academic malpractice. Please refer to your University's policy on academic malpractice for further information.

## UKRI Policy on Postgraduate Research

UK Research and Innovation (UKRI) has published a "Statement of Expectations for Doctoral Training", which sets out common principles for all Research Council-funded students, including students funded by STFC (the main funder of the Cockcroft Institute). Further information is available from the STFC and UKRI web sites:

https://stfc.ukri.org/funding/studentships/

https://www.ukri.org/skills/policy-and-frameworks/

# The Cockcroft Institute Education Programme

The Cockcroft Institute education programme is designed as a 2-year course in accelerator science, and is intended to be broad enough that each postgraduate student may cover a wide range of accelerator science and technology.

There are 3 levels of courses: Introductory; Advanced; Options.

By the end of the 2nd year of study, postgraduates should have completed

- 32 hours of Introductory modules
- 50 hours of Advanced modules
- 40 hours of Options modules

Cockcroft Institute lecture courses are generally given on Mondays (with some exceptions), and will typically be at 10:30, 11:45 and 14:00. Lectures run year-round except during July and August, and postgraduates should plan to attend sufficient courses to make up their full attendance requirement.

Lectures may be viewed online at www.cockcroft.ac.uk/webinar.

Each course has a course code of the form CI-Type-XXX:

- 100-level (Introductory); 34 hours, repeats every year
- 200-level (Advanced)
  - 210 courses run 2020/2021 (22 hours) – **THIS YEAR**
  - 220 courses run 2021/2022 (28 hours)
- 300-level (Options); PhD students should complete at least 40 hours of these
  - 300 courses (SUPA programme) run every year (note: scheduled at different times to main Daresbury course lectures)
  - 310 courses run 2020/2021 (16 hours) – **THIS YEAR**
  - 320 courses run 2021/2022 (28 hours)
- 400-level (Transferable); these are transferable skills courses run by Cockcroft

The Institute has five broad themes that run through the syllabus, which are reflected in the course codes. The themes are:

- General particle accelerators (ACC)
- Radiofrequency accelerators (RF)
- Beam dynamics (BEAM)
- Magnets and insertion devices (MAG)
- Short-wavelength accelerators (SWA)

The Institute maintains a calendar of educational and other events, which is available at:

http://tiny.cc/cicalendar

## Module Assessments

Some course modules are assessed; this is indicated in the module description. Participants of assessed modules must complete the assessments to the satisfaction of the course module leader.

There are 3 compulsory modules for which assessments must be completed by all postgraduates during their 1st year of studies:

- CI-RF-103
- CI-BEAM-104
- CI-MAG-106

These assessments use a common format – 'take-home' assessment paper – and consist of a set of questions with a total module mark of 50. The pass mark for each modules is 50%, i.e. 25 marks out of 50, and postgraduates that obtain a mark below 50% on any module may be asked to re-take an assessment until a passing grade is obtained.

The normal university rules on plagiarism apply for any assessments carried out within the Institute. Whilst it is understood that collaborative working will occur and is encouraged to further postgraduate understanding, submitted work should be substantively the efforts of that individual with proper attribution given if the results of someone else are used or quoted. Penalties may apply if there is evidence of plagiarism or other academic malpractice.

## Transferable Skills Training

It is required that all postgraduate researchers complete 2 weeks (80 hours) of transferable skills training. Cockcroft makes available some of this training under 400-level course codes, and postgraduates are expected to complete the remainder of their requirement using training available at their home universities or elsewhere. Postgraduates should maintain a *personal record* of their transferable skills training, which will be audited by the Director of Education at each academic year end (September).

## Outreach and Communication

The Cockcroft Institute has set a goal that all postgraduate researchers should participate in at least two outreach/public events per year (during PhD study years 1 and 2); these are intended to satisfy two Institute goals:

- providing postgraduate students with experience in communicating their ideas to specialist and general audiences;
- ensuring postgraduates' work is effectively disseminated to the public and stakeholders, so that we justify our work and its funding.

These may include such things as giving outreach talks, assisting on open days and other events, or collaborating on one of our outreach projects. Postgraduates should maintain a *personal record* of their outreach activities. Note that outreach activities *do not* count towards the requirement for 80 hours of transferable skills training.

## Seminars

The Institute has an active programme of seminars at which prominent external speakers are invited to discuss topical research. Students based at the Daresbury site are expected to regularly attend seminars.

The Institute maintains a calendar of seminars, which is available at:

http://tiny.cc/cicalendar

## Postgraduate Conference

Each year (usually in October or November) the Institute holds a postgraduate conference at which all Cockcroft postgraduate researchers present their work; prizes are given to the best presentations. New postgraduate researchers are expected to attend to see the presentations as part of their overall training. A social event is arranged for the evening.

## Networking Trips

Each year the Institute arranges networking trips to foster closer collaboration between the partners, particularly a trip for Daresbury researchers to visit the Strathclyde SCAPA site. The SCAPA visit usually takes place in January.

## Summary of Training Requirements

To assist postgraduate researchers with attaining their educational requirements within the Cockcroft Institute, the following is a brief summary of the training requirements that should be completed by each PhD researcher in the Institute. This set of training requirements is for those PhD researchers in the main Institute programme. Researchers carrying out PhDs within sub-programmes such as EU networks, industrial programmes and so forth; these researchers should confirm with their programme manager that they are undertaking sufficient modules for their programme.

Table 1: Summary of general PhD training requirements within the Cockcroft Institute. The numbers given are for the *total* requirements over the course of the PhD studies.

| **Training requirement** | **Number of hours that should be completed** |
|---|---|
| 100-level Introductory Modules | 32 hours |
| 210/220 Advanced Modules | 50 hours |
| 310/320 Options Modules | 40 hours |
| Transferable Skills (TS) Training | 80 hours |
| Outreach Activities | 4 events |
| Seminar Attendance | (no specific requirement, but please record) |
| Postgraduate Conference | At least 1 |
| Networking Trip (Strathclyde) | At least 1 |

## PhD Researcher Personal Training Record

To help postgraduate researchers complete the educational requirements within the Cockcroft Institute, the following example of a personal training record is provided. This may be used as a template, to help postgraduate researchers and their supervisors monitor progress towards achieving the education and training goals.

Table 2: Example personal training record. Please fill in your own training record here.

| *Name: Ms. Joanne Bloggs* | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Training Event* | *Date Completed* | *Number of Hours* | | | | *Number of Events* | |
| | | 100 | 200 | 300 | TS | Outreach | Other |
| CI Lectures: CI-ACC-101 | Oct 2018 | 2 | | | | | |
| CI Lectures: CI-BEAM-105 | Dec 2018 | 10 | | | | | |
| CI Lectures: CI-ACC-221 | Feb 2019 | | 7 | | | | |
| CI Lectures: CI-BEAM-223 | Mar 2019 | | 8 | | | | |
| CI Seminars | July 2019 | | | | | | 3 |
| Blue Dot Festival | June 2019 | | | | | 1 | |
| Daresbury Open Day | July 2019 | | | | | 1 | |
| | | | | | | | |
| **Totals** | | **12** | **15** | | | **2** | |
| **Required Totals** | | **32** | **50** | **40** | **80** | **4** | |

# Cockcroft Institute Postgraduate Course Modules

The tables below summarise the course modules delivered by the Institute. Syllabus descriptions and assessment requirements are given afterwards for each module. Please note that details are subject to change.

## 100-Level Introductory Modules (Semester 1, October-January)

Introductory modules run every year. All 1$^{st}$-year postgraduates are expected to attend.

| Module Code | Title | Number of Lectures | Lecturer |
|---|---|---|---|
| CI-ACC-101 | Introduction to Accelerators | 2 | Hywel Owen |
| CI-ACC-102 | Relativity and Elements of Electromagnetism | 4 | Jonathan Gratus |
| CI-RF-103 | Introduction to Radio Frequency Systems | 4 | Louise Cowie |
| CI-BEAM-104 | Introduction to Beam Dynamics | 6 | Ian Bailey |
| CI-BEAM-105 | Lattice Design and Computational Dynamics | 10 | Rob Apsimon and Oznur Mete |
| CI-MAG-106 | Conventional Magnets for Accelerators | 4 | Alex Bainbridge |
| CI-SWA-107 | Introduction to Short-Wavelength Accelerators | 4 | Guoxing Xia |

## 200-Level Advanced Modules (Semester 2, February-September)

Advanced modules run in alternate years. 1$^{st}$- and 2$^{nd}$-year postgraduates are expected to attend.

### 210 Courses (Semester 2, 2020/2021 Session)

| Module Code | Title | Number of Lectures | Lecturer |
|---|---|---|---|
| CI-ACC-211 | Vacuum Systems and Surface Science | 6 | Oleg Malyshev |
| CI-ACC-212 | Beam Diagnostics | 6 | Stewart Boogert |
| CI-MAG-213 | Synchrotron Radiation and Undulators | 4 | Jim Clarke |
| CI-SWA-214 | Novel EM Materials for High-Frequency Accelerators | 6 | Rosa Letizia |

### 220 Courses (Semester 2, 2021/2022 Session)

| Module Code | Title | Number of Lectures | Lecturer |
|---|---|---|---|
| CI-ACC-221 | Particle Sources and Secondary Beams | 6 | Dan Faircloth |
| CI-RF-222 | RF Linear Accelerators | 7 | Graeme Burt |
| CI-BEAM-223 | Single Particle Dynamics | 8 | Bruno Muratori |
| CI-SWA-224 | Particle-Beam-Driven Plasma Wakefield Accelerators (PWFA) | 6 | Bernhard Hidding, Guoxing Xia |
| CI-ACC-225 | Electron Sources | 6 | Boris Militsyn |

## 300-Level Option Modules

Option modules run in alternate years. Postgraduate students must complete at least 40 hours of Options modules over the 1st and 2nd years.

- 300 courses (SUPA programme) run every year (note: scheduled at different times to main Daresbury course lectures)
- 310 courses run 2020/2021
- 320 courses run 2021/2022

### 300 Courses (Semester 2, each year)

There are a number of courses offered at CI Strathclyde as part of the SUPA programme; participants must register for a my.SUPA account. Please consult your PhD supervisor to discuss attendance on these modules. The most relevant modules have explicit CI codes as follows:

| Module Code | Title | Number of Lectures | Lecturer |
|---|---|---|---|
| CI-SUPA-301 | (SUPAACC) Accelerators | 9 | D Jaroszynski, M Wiggins, B Ersfeld |
| CI-SUPA-302 | (SUPAPPH) Plasma Physics | 12 | A Cross, K Ronald, B Eliasson, D Diver |
| CI-SUPA-303 | (SUPALDP) Laser Driven Plasma Acceleration | 16 | D Jaroszynski, P McKenna |
| CI-SUPA-304 | (SUPABAL) Biomedical Applications of Lasers, Beams and Radiation | 12 | B Hidding, G Manahan |

### 310 Courses (Semester 2, 2020/2021 Session)

| Module Code | Title | Number of Lectures | Lecturer |
|---|---|---|---|
| CI-RF-311 | Wakefields | 6<br>+ 1 Tutorial | Roger Jones |
| CI-RF-312 | Superconducting RF and Cryogenics | 6<br>+ 2 Guest Lectures | Graeme Burt/<br>Shrikant Pattalwar/<br>Reza Valizadeh/<br>John G. Weisend II |
| CI-BEAM-313 | Collective Effects | 6 | Andrzej Wolski/<br>Bruno Muratori |
| CI-MAG-314 | Free-Electron Lasers | 6 | Brian McNeil |
| CI-SWA-315 | Lasers for Accelerators | 4 | Steve Jamison |

### 320 Courses (Semester 2, 2021/2022 Session)

| Module Code | Title | Number of Lectures | Lecturer |
|---|---|---|---|
| CI-BEAM-321 | Practical Accelerator Design | 6 | Hywel Owen |
| CI-SWA-322 | Particle-In-Cell Methods | 4 | Elisabetta Boella |
| CI-SWA-323 | Laser-Plasma Particle and Photon Sources | 6 | t.b.d. |

## 400-Level Transferable Skills Modules

It is required that all postgraduate researchers complete 2 weeks (80 hours) of transferable skills training. Cockcroft makes available some of this training under 400-level course codes, and postgraduates are expected to complete the remainder of their requirement using training available at their home universities or elsewhere. Postgraduates should maintain a *personal record* of their transferable skills training, which will be audited by the Director of Education at each academic year end (September).

Please note that 400-level courses are still in development.

| **Module Code** | **Title** | **Number of Lectures** | **Lecturer** |
|---|---|---|---|
| CI-TS-401 | Applications of Accelerators | 8 | Graeme Burt/ Elaine Seddon/ Hywel Owen |
| CI-TS-402 | Project Management for Accelerator Projects | 4 | Andy Goulden/ Lisa Howard |
| CI-TS-403 | Computational Physics | 6 | t.b.d. |
| CI-TS-404 | Communication and Outreach | 4 | Chris Edmonds |
| CI-TS-405 | Intellectual Property and Business Law | 4 | Liz Bain |
| CI-TS-406 | How to Get Published | 1 | Oleg Malyshev |

| | |
|---|---|
| **CI-Acc-101** | **Introduction to Accelerators** |
| **Lecturer(s)** | Hywel Owen |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 2 Lectures in Semester 1 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | Accelerator Physics (3rd Edition), S. Y. Lee, World Scientific (2011) |
| **Supplementary Texts** | Handbook of Accelerator Physics and Engineering (ed. A. Chao and M. Tigner), 2nd edition, World Scientific (2013) |
| **Aims** | This module introduces some key concepts and ideas in the field. |
| **Learning Outcomes** | Participants will be able to identify the major types of accelerator, their primary uses, and appreciate some of the techniques utilised in their design and operation. |
| **Syllabus** | Lecture 1: Particle accelerators – history and principles<br>- Early history<br>- DC accelerators<br>- Linacs, Cyclotrons, Betatrons and Synchrotrons<br>- Phase stability and strong focusing<br>- Storage rings and colliders<br>- Beam cooling<br>- Synchrotron radiation<br>- Beam optical systems<br><br>Lecture 2: Particle accelerators – types and uses<br>- Types of accelerator |

- Challenges
- Technologies
- Radiotherapy
- High-intensity proton accelerators
- Synchrotron radiation
- Free-electron lasers
- Accelerators for particle physics

| | |
|---|---|
| **CI-Acc-102** | **Relativity and Elements of Electromagnetism** |
| **Lecturer(s)** | Jonathan Gratus |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Previous exposure to simple ideas of relativity and a knowledge of Maxwell's equations of Electromagnetism. Familiarity with basic vector calculus including the use of div, grad and curl and standard theorems such as Gauss, Stokes and Green |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 4 Lectures in Semester 1 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | Handbook of Accelerator Physics and Engineering (ed. A. Chao and M. Tigner), 2nd edition, World Scientific (2013) |
| **Supplementary Texts** | Relativity (W. Rindler), 2nd edition, OUP (2006)<br>Classical Electrodynamics (J. D. Jackson), Wiley (1998)<br>Electromagnetism (G. Pollack, D. Stump), Pearson (2002) |
| **Aims** | The course comprises four lectures covering the main ideas of Special Relativity and Electromagnetism that will be needed for work in accelerator physics. The lectures review material that should already have been studied in most undergraduate physics degrees, so some familiarity with the subject will be assumed. Historically, Maxwell's electromagnetic theory revealed light to be an electromagnetic phenomenon whose speed of propagation proved to be observer-independent. This discovery led to the overthrow of classical Newtonian mechanics, in which space and time were absolute, and its replacement by Special Relativity and space-time. The theories together with quantum theory are essential for an understanding of modern physics; in particular, without these discoveries, accelerators would not work! |

| | |
|---|---|
| **Learning Outcomes** | Students will develop an understanding of the relationship between special relativity and electromagnetism. They will gain the ability to do relevant calculations involving Maxwell’s equations, Lorentz transformations, 4-vectors, and the Lorentz force. |
| **Syllabus** | Relativity (2 lectures)<br><br>Constancy of the speed of light, Spacetime diagrams, Lorentz transformations. Four-vectors: four-velocity and four-momentum; Use of invariants: particle collisions and photon emission. Index notation.<br><br>Electromagnetism (2 lectures)<br><br>Review of Maxwell's equations and the Lorentz force law, Constitutive Relations. EM waves. Charge in Magnetic field. Potentials. Relativistic transformations of E and B field. Waves in a uniform conducting guide: a simple example, idea of propagation constant, cut-off frequency, illustrations. Radiation from a moving point source. |

| | |
|---|---|
| **CI-RF-103** | **Introduction to Radiofrequency Systems** |
| **Lecturer(s)** | Graeme Burt |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 4 Lectures in Semester 1 |
| **Assessment** | Take-home coursework in S2 |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course covers a brief introduction to RF starting with a pillbox cavity to define the key parameters. The course will move on to the RF Power, Higher order modes and technology options |
| **Learning Outcomes** | Students will at the end of this course be familiar with RF system outlines used in accelerators. The students will know about gradient limits and technology choices and will understand how to specify an outline RF system |
| **Syllabus** | EM theory for RF, RF Cavity basics, Equivalent circuits<br><br>RF sources, Power and reflections, Low level RF control<br><br>Cavity types, normal and superconducting RF, gradient limits<br><br>Higher order modes, beam-cavity coupling, wakefields, BBU |

| | |
|---|---|
| **CI-Beam-104** | **Introduction to Beam Dynamics** |
| **Lecturer(s)** | Ian Bailey |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 6 Lectures in Semester 1 |
| **Assessment** | Take-home coursework in S2 |
| **Recommended Text** | K. Wille, "The physics of particle accelerators", Oxford (2001) |
| **Supplementary Texts** | Handbook of Accelerator Physics and Engineering (ed. A. Chao and M. Tigner), 2nd edition, World Scientific (2013)<br>Accelerator Physics (3rd Edition), S. Y. Lee, World Scientific (2011)<br>A. Wolski, "Beam dynamics in high energy particle accelerators", Imperial College Press (2014)<br>A. Larkoski, “Elementary particle physics”, Cambridge University Press (2019) |
| **Aims** | Introductory course on transverse and longitudinal beam dynamics. The course introduces the common concepts and notations used to describe the motion of a particle beam under the assumption that the transverse and longitudinal motions can be considered separately and that the magnetic fields can be represented by a linear approximation. |
| **Learning Outcomes** | Students will understand the origin and limitations of Hill's equations applied to linear transverse beam dynamics. They will be familiar with piecewise solutions of the equations in dipole and quadrupole magnets and be able to carry out simple calculations using the solutions. |

Students will be familiar with the Courant-Snyder formalism and the role of the Courant-Snyder parameters and the emittance. They will be able to calculate the parameters at different locations in simple lattices.

Students will understand the origin of resonances in transverse beam dynamics and the importance of optimising the tune of a lattice to avoid resonances, including the role of dispersion and chromaticity.

Students will be familiar with the basics of longitudinal beam dynamics and understand the concept of phase stability and its dependence on the momentum compaction factor, leading to the idea of a transition energy.

Students will understand the origin of synchorotron radiation and how it can lead to both damping and heating of a beam.

**Syllabus**

- Multipole fields
- Equations of motion in dipoles and quadrupoles
- Thin lens approximation
- FODO cells
- Hill's equation
- Twiss (Courant-Snyder) parameters
- Betatron action (amplitude) and phase
- Tunes; resonances
- Transverse emittance; Liouville's theorem
- Dispersion
- Phase slip and momentum compaction factor; transition
- Synchrotron motion
- Chromaticity
- Synchrotron radiation (damping and quantum excitation)

**Syllabus** 

# CI-Beam-105

| | |
|---|---|
| **CI-Beam-105** | **Lattice Design and Computational Dynamics** |
| **Lecturer(s)** | Rob Apsimon and Oznur Mete |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 10 Lectures in Semester 1 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | Introductory course on accelerator lattice design and modelling. This course will cover magnetic guide field and solution of equation of motion under matrix formalism. |
| **Learning Outcomes** | Students will be familiar with basic lattice functions, cells and optics, realistic modelling of a periodic lattice considering errors and implementation of insertions into a periodic lattice as well as advanced implementation of MADX. |
| **Syllabus** | Session 1: Taylor expansion of magnetic guide field, various multipole magnets, solution of equation of motion and transfer matrices, FODO lattice, parametric representation of emittance, Twiss parameters, transfer matrix for Twiss parameters and periodic lattices, stability condition for FODO lattice, maximum and minimum beta functions, transfer matrix in terms of beta function. (O. Mete)<br>Session 2: Introduction to MADX code, implementation of a periodic FODO lattice, matching, lattice errors and corrections. (O. Mete) |

Session 3: Dispersion suppression and straight sections. (O. Mete)

Session 4: Design of a full ring structure consisting of FODO arc cells, dispersion suppressors and straight sections. (O. Mete)

Session 5: Different cell designs (Chasman-Green, triple-bend achromats, matching and injection/extraction cells), matching with a macro. (R. Apsimon)

Session 6: Create a ring with CG and TBA cells and matching sections, compare parameters. Insert injection and extraction regions. (R. Apsimon)

Session 7: Advanced matching in MADX (global vs local optimisation, isochronicity, nonlinear optics, user defined figures of merit). (R. Apsimon)

Session 8: Insert sextupoles and correct chromaticity. Perform global optimisation to correct other second order terms. (R. Apsimon)

| | |
|---|---|
| **CI-Mag-106** | **Conventional Magnets for Accelerators** |
| **Lecturer(s)** | Alex Bainbridge |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 4 Lectures in Semester 1 |
| **Assessment** | Take-home coursework in S2 |
| **Recommended Text** | "Iron Dominated Electromagnets" by Jack Tanabe. Legally available online for free at https://www.slac.stanford.edu/pubs/slacreports/reports16/slac-r-754.pdf |
| **Supplementary Texts** | |
| **Aims** | The course will deal primarily with room temperature (warm) electro magnets for beam control. Superconducting magnets and insertion devices will not be covered, although permanent magnets are briefly addressed. |
| **Learning Outcomes** | To have a thorough understanding of the types of magnets found in accelerator systems, their effect on beams, and the key decisions employed in their design and construction. |
| **Syllabus** | **Lecture 1:**<br>a) Introduction to:<br>• Dipole magnets;<br>• Quadrupole magnets;<br>• Sextupole magnets;<br>• 'Higher order' magnets.<br>b) Magneto-static theory (no ferromagnetic materials or currents): |

• The Maxwell equations and their solutions in 2 dimensions.

• The significance of scalar and vector magnetic potentials.

• Field lines and ideal pole shapes calculated from potentials for dipole, quadrupole, sextupole.

• Treatment of the field as a series of cylindrical harmonics and complex functions.

• Symmetry constraints and significance of field harmonics.

• ’Forbidden’ harmonics resulting from assembly asymmetries.

**Lecture 2:**

c) Electromagnetic excitation and the magnetic circuit:

• Calculation of field vs Ampere-turns in dipole, quad and sextupole.

• Coil design and economic optimisation.

• The magnetic circuit, steel properties (permeability and coercivity.)

• Realistic magnet geometries.

d) Practicalities of magnet design:

• FEA techniques - Modern codes- OPERA 2D; TOSCA.

• Optimisation of magnetic circuit.

• Advantages and disadvantages of different geometries.

• Field quality assessment and optimisation.

• Magnet ends-computation and design (roll-offs and shimming).

**Lecture 3:**

e) Introduction to time-varying fields:

• Key differences to DC magnets including electrical circuit inductance, solutions to Maxwell’s equations and material properties.

• Calculation of eddy currents arising from rapidly changing fields, and considerations on the vacuum chamber design.

• Field perturbations and the introduction of skin depth.

• Additional challenges in yoke design for fast-switching magnets.

f) Types of time-varying magnets:

• Correctors and kickers.

• Different types of “septum” magnets, their purpose, design and construction.

• Methods of injecting and extracting beam; Single turn injection/extraction; Multi-turn injec- tion/extraction; Magnet requirements;

• Exciting time-varying fields through different types of power supply – distributed and lumped circuits.

**Lecture 4:**

g) Measurement of magnetic fields:

• The Hall effect, Hall effect probes for point-by-point measurements, sources of inaccuracy.

• NMR probes and fluxgate magnetometry for high accuracy and calibration.

• Stretched wire and flipping coil methods for integral measurements

• Rotating coil method for measurements of harmonics.

• Pulsed wire and vibrating wire for narrow-gap devices and magnetic centre measurements.

h) Less obvious practical considerations:

• Magnet bussing, laminations and core stacking, varying BH properties.

| | |
|---|---|
| **CI-SWA-107** | **Introduction to Short-Wavelength Accelerators** |
| **Lecturer(s)** | Guoxing Xia |
| **Level** | Introductory (Postgraduate Year 1) |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 10 Lectures in Semester 1 |
| **Assessment** | Take-home coursework in S2 |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course covers a brief introduction plasma and dielectric based accelerating structures. The course will move on to the RF Power, Higher order modes and technology options. |
| **Learning Outcomes** | Students will at the end of this course be familiar with plasma and dielectric accelerating structures and the basics of the driving mechanisms. The students will understand the limitations of current RF conventional accelerators and how short-wavelength structures are miniaturising accelerators. |
| **Syllabus** | • Introduction<br>– RF-based conventional accelerators (L, S, C, X down to optical) – Short wavelength-high frequency acceleration<br>– Basics of lasers<br>– Basics of plasmas<br>– Plasma accelerators – Intro to THz sources<br>• Laser-driven plasma particle accelerators |

– Laser driven electron acceleration – Radiation sources based on LWFA – Laser driven ion acceleration

• Beam driven plasma wakefield acceleration PWFA

– Electron-driven plasma wakefield acceleration – Positron-driven plasma wakefield acceleration – Proton-driven plasma wakefield acceleration

• Dielectrics in accelerators

– Laser driven dielectric acceleration – THz driven dielectric acceleration – Beam driven dielectric acceleration

## Syllabus **CI-Acc-211**

| | |
|---|---|
| **CI-Acc-211** | **Vacuum Systems and Surface Science** |
| **Lecturer(s)** | Oleg Malyshev (and colleagues) |
| **Level** | Advanced |
| **Prerequisites** | |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course will provide the basic background to enable an accelerator scientist to understand why vacuum is required in most accelerators and how to obtain it. It will cover some basic vacuum science, the production and measurement of low pressures, materials properties which affect vacuum and some of the peculiarities of designing vacuum systems for accelerators. The basic approach will be descriptive although there will be some equations where necessary. The course will be given by the scientists from the ASTeC Vacuum Science Group. |
| **Learning Outcomes** | |
| **Syllabus** | Session 1 (Dr. Oleg Malyshev) |

The vacuum requirements of accelerators. Brief review of different classes of accelerators and why vacuum levels differ. Beam-gas interactions. Introduction to vacuum design of accelerators.

Basic principles of vacuum Kinetic theory; gas laws. Basic concepts ? mean free path, pressure, impingement rate. Gas flow regimes. Conductances. Pumping speeds. Pressure ranges.

Session 2 (Dr. Keith Middleman)

The measurement of vacuum Direct and indirect gauges for total pressure. What is actually mea- sured? Gauge effects. Calibration. Partial pressure measurement (residual gas analysis).

The production of low pressures Pumping mechanisms. Displacement pumps: Rotary pumps, dry roughing pumps, turbo-molecular pumps. Capture pumps: Getter Ion pumps, sublimation pumps, non evaporable getter pumps. Cryogenic pumps.

Session 3 (Dr. Keith Middleman)

Material properties related to vacuum Relevant mechanical properties. Outgassing and desorption phenomena. Selection of materials for vacuum.

Processing techniques for vacuum components and systems Cleaning; degassing; bakeout. Quality control techniques for vacuum.

Session 4 (Joe Herbert)

Components and construction techniques Flanges and joints. Welding and brazing. Valves, bellows, windows, feedthroughs. Moving devices in vacuum.

Session 5 (Dr. Reza Valizadeh)

Surface science in accelerator R&D What is surface. Surface analysis techniques. Surface coating. NEG coating. Photocathodes. Superconducting coating.

Session 6 (Dr. Oleg Malyshev)

Basic vacuum design of accelerators. Calculations to support the design. Examples and Revie.

Specifications. Putting it all together. Some common pitfalls. Pumping speeds. Pressure distributions. Software packages Discussion of some current and future accelerator projects. Review of course.

## Syllabus

# CI-Acc-212

| | |
|---|---|
| **CI-Acc-212** | **Beam Diagnostics** |
| **Lecturer(s)** | Stewart Boogert |
| **Level** | Advanced |
| **Prerequisites** | |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | To gain familiarity with a variety of diagnostic techniques and parameters to characterise particle beams. |
| **Learning Outcomes** | |
| **Syllabus** | The lectures will discuss how to characterise both electron and ions beam properties including (highlighting the differences):<br>• Profile (transverse/longitudinal) • Intensity (absolute/relative)<br>• Position<br>• Emittance<br>• Data analysis<br>• Control system integration Using the following diagnostics: |

• BPM (cavity, stripline and button) • Faraday cups

• Screens

• Spectrometers

• ICT’s

• TDCs

• wire scanners
• pepperpots

• BLMs

• BAMs

| | |
|---|---|
| **CI-Mag-213** | **Synchrotron Radiation and Undulators** |
| **Lecturer(s)** | James Clarke |
| **Level** | Advanced |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | |
| **Classes** | 4 Lectures in Semester 2 (alternate years) |
| **Assessment** | |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | • Synchrotron radiation fundamentals<br>– The underlying physical principles and a historical perspective.<br>– Derivation of synchrotron radiation wavelength coverage, flux and power levels from first principles for a bending magnet.<br><br>• SR from wigglers and undulators<br>– The properties of SR from a wiggler based upon knowledge of bending magnets.<br>– The interference effects in an undulator. Basics of undulator radiation output.<br>– The difference or otherwise between wigglers and undulators.<br>– Undulator flux and brightness. |

• Undulators in more detail

– The effect of real electron beams on undulator output.

– Polarized light from undulators.

– How to practically build an undulator using permanent magnets.

• Undulator magnet design

– Including iron in permanent magnet designs.

– Realizing elliptical undulators in practice.

– The engineering challenges of undulators.

– Advanced undulator schemes; cryogenics, electromagnets, superconducting.

| | |
|---|---|
| **CI-SWA-214** | **Novel EM Materials for High-Frequency Accelerators** |
| **Lecturer(s)** | Rosa Letizia |
| **Level** | Advanced |
| **Prerequisites** | |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course covers aspects of using dielectric structures to generate accelerating structures. The design and modelling of the waveguides as well as the different driving techniques will be discussed. |
| **Learning Outcomes** | Students will at the end of this course be familiar with the ways in which dielectric materials can be used to create short-wavelength accelerating structures. They should be able to design a basic waveguide and understand the differences between laser driven, THz driven and beam driven accelerators. |
| **Syllabus** | • Photonic bandgap structures<br>• Effective electromagnetic materials • Intense fields in dielectrics<br>• Plasmonic waveguides<br>• Dielectric laser acceleration<br>• Computational modelling<br>• THz acceleration<br>• Beam driven dielectrics |

| | |
|---|---|
| **CI-Acc-221** | **Particle Sources and Secondary Beams** |
| **Lecturer(s)** | Dan Faircloth |
| **Level** | Advanced |
| **Prerequisites** | Undergraduate General Physics and Electromagnetism |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | **Ion Sources (2 Hours)** |

• Introduction: Ion source basics, History.

• Introduction to Plasma: Basic plasma parameters, Density, Temperature, Charge state, Ion- ization energy, Temperature distributions, Quasi-neutrality, Percentage ionization

• Electrical Discharges: Overview, Townsend breakdown, Glow discharge, Arc discharge, Im- portance of the power supply, Paschen curve, Collisions, Work function, Thermionic emission, Magnetic confinement, Debye length, Plasma sheath.

• Extraction: Meniscus emitting surface, Solid emitting surface, Emittance, Energy spread, Brightness, Space charge, Child-Langmuir law, Perveance, Pierce extraction, Suppressor elec- trode, Negative ion extraction, Low-energy beam transport.

• Positive ion sources: Electron bombardment sources, Plasmatrons, Duoplasmatron, Microwave ion sources, Electron beam ion sources, Laser ion sources, Vacuum arc ion sources.

• Negative ion sources: The negative ion, Uses, Physics of negative ion production, Charge exchange, Caesium and surface production, Surface physics processes, Maintaining caesium coverage, Volume production, H? destruction, Surface plasma cold cathode ion sources: Mag- netron and Penning, Multicusp ion sources, Hot-cathode-driven plasma production, multicusp surface converter sources, Filament cathode multicusp volume sources, Internal and external RF antenna multicusp volume sources.

• Running and developing sources: Which source?Power supplies, Control systems, Developing sources.

**Introduction to High Voltage (1 Hour)**

• Introduction: Uses, Challenges, Aims, Factors affecting HV breakdown.

• Calculating electric fields: Maxwell’s equations, Poisson and Laplace equations, Derivation, Solving Laplace?s equation, Infinite parallel-plate capacitor, Infinite coaxial line, Electric fields measured in experimental analogues, Numerical techniques.

• Electrical discharges: Background ionization, Electron impact ionization, Photo-ionization, Discharge current/voltage landscape, Avalanche breakdown, Townsend?s ionization coeffi- cients, Streamers, Leaders, Paschen curve, Vacuum breakdown, Mechanisms, High-voltage conditioning, Insulator breakdown, Surface breakdown, Tracking, Bulk breakdown, Partial discharges, Corona discharges, Importance of polarity, Corona inception and extinction volt- age, Importance of the power supply, Glow discharge, Debye length, Cathode plasma sheath, Towards arc transition, Arc discharge, Glow to arc transition, Thermal arcs, Factors affecting properties of discharges, Statistical variability, Environmental conditions, Type of applied voltage, Magnetic fields, Contamination and lost beams.

• High-voltage design and technology: Electrodes, Electrode design, Corona shields, Sputtering, Electrode materials, Insulators, System design, Triple junction effect, Triple junction shielding, Insulator material, Insulator surface profile, Insulator protection, Insulation coordination, Gaseous and liquid insulation, Air, Sulphur hexafluoride ($SF_6$), Oil, Commercially available HV components, Bushings, Connectors, Cables, Insulators, Voltage dividers, High-voltage platforms, System design, Isolated power supplies, Isolated control signals, Other isolated systems, High-voltage power supplies, Power supply technologies, High-voltage power supply manufacturers, Insulation test equipment.

• Safety: Electric shocks, Earthing systems, Interlock systems, Other hazards related to high voltage, HV safety design rules, Reasonably practicable.

**High Current Negative Ion Sources: Magnetron and Penning (1 Hour)**

• Introduction: Basic electrode topology, Early history, Variations.

• Plasma generation by electrical discharge: Electrical discharges, Townsend breakdown, Glow discharge, Arc discharge, Plasma properties, Work function, Thermionic emission, Debye length, Plasma sheath, Magnetic field and electron trajectories.

• Negative ions: The negative ion, Production mechanisms, Overview, Charge exchange, Sur- face production, Volume production, Negative ion extraction.

• Caesium and surface production: History, Caesium and surfaces, Soviet breakthrough, Amer- ican developments, Surface production of negative ions, Surface physics processes, Low-work- function surface production, Maintaining caesium coverage, H? destruction, The additional benefits of caesium.

• Magnetron surface plasma source: Construction, H? production, Extraction, Temperature control, Caesium trapping, Duty cycle and noise limitations, Examples of negative ion source magnetrons around the world: Budker Institute of Nuclear Physics (BINP), Fermi National Accelerator Laboratory (FNAL), Deutsches Elektronen-Synchrotron (DESY), Brookhaven National Laboratory (BNL).

• Penning surface plasma source: Construction, H? production, Temperature control, Extrac- tion, Caesium trapping, Examples of negative Penning sources around the world, Budker Institute of Nuclear Physics (BINP, Institute for Nuclear Research (INR), Los Alamos Na- tional Laboratory (LANL), Rutherford Appleton Laboratory (RAL).

• Discussion: Operating and tuning, Sputtering, Other failure modes, Lifetime comparison

**Secondary Beams (1 Hour)**

• Neutron production; neutron control; spallation; nuclear reactions and monochromatic sources; applications of muons

• Muon production; muon and neutrino facilities; muon colliders

• Antiproton production and uses

• Radioactive ion beams

## Syllabus

# CI-RF-222

| | |
|---|---|
| **CI-RF-222** | **RF Linear Accelerators** |
| **Lecturer(s)** | Graeme Burt |
| **Level** | Advanced |
| **Prerequisites** | Undergraduate Electromagnetism, CI-RF-103 |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 7 Lectures + 1 Tutorial in Semester 2 (alternate years) |
| **Assessment** | Problem sheets given as part of the CI assessment (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |

**Aims**

An intermediate course on RF linear accelerators. This course will cover the basics of RF cavities and look at cavity effects, such as beam loading, microphonics and detuning. This course will look at the dynamics of beams travelling through RF structures as well as instabilities such as wakefields, impedance and head tail instability. We will then investigate the limitations on accelerating gradient due to field emission, multipactor, breakdown SRF quenching and pulsed heating.

**Learning Outcomes**

Understanding of:

• Basic cavity model, power coupling, detuning effects and different cavity types.

• Particle dynamics through accelerating structures and induced instabilities.

• Limitations on accelerating gradient, field emissions, multipactor, breakdown etc.

**Syllabus**

• Lectures 1 & 2: Multicell cavities, equivalent circuits, effect of errors, side-coupled linacs

• Lecture 3: Coupling power to cavities, reflections, transients, beam loading, microphonics,

detuning

• Lecture 4: Travelling wave structures, power flow, matching couplers, constant impedance/gradient, Floquet theorem, CLARA linac

• Lecture 5: Longitudinal & transverse dynamics, longitudinal motion, phase damping, linac acceptance, capture, RF defocussing, coupler kicks, focussing in linacs

• Lecture 6: Low beta structures, Alvarez and Wideroe, DTL, RFQ, H-mode, Spoke cavities

• Lecture 7: Field limitations, field emission, multipactor, breakdown models, SRF quench,

heating, state-of-the art

## Syllabus

# CI-Beam-223

| | |
|---|---|
| **CI-Beam-223** | **Single Particle Dynamics** |
| **Lecturer(s)** | Bruno Muratori |
| **Level** | Advanced |
| **Prerequisites** | Undergraduate Electromagnetism, CI-ACC-101, CI-ACC-102, CI-BEAM-104, CI-BEAM-105 |
| **Follow-up Units** | |
| **Classes** | 8 Lectures in Semester 2 (alternate years) |
| **Assessment** | Problem sheets (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | • Hamiltonian formalism<br>• Transfer maps for linear elements<br>• Linear optics in periodic, uncoupled beamlines<br>• Longitudinal dynamics<br>• Coupling<br>• Linear imperfections<br>• Transfer maps for nonlinear elements (Taylor maps, Lie transformations, mixed-variable gen- erating functions)<br>• Symplectic integrators (splitting methods, Runge-Kutta methods, Wu-Forest-Robin)<br>• Canonical perturbation theory<br>• Normal form analysis |

| | |
|---|---|
| **CI-SWA-224** | **Particle-Beam Driven Plasma Wakefield Accelerators (PWFA)** |
| **Lecturer(s)** | Bernhard Hidding, Guoxing Xia |
| **Level** | Advanced |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | |
| **Classes** | 7 Lectures in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course covers particle-beam driven plasma wakefield accelerators (rather than laser-driven). The generation of a plasma wakefield accelerating structure for particle acceleration will be presented. The course will describe state-of-the-art demonstration experiments and the next steps for boasting particle energies. |
| **Learning Outcomes** | Students will at the end of this course be familiar with the generation of a plasma wakefield by a charged particle beam. The students will understand the scaling and limitations of the schemes as well as having a knowledge of the proof-of-principle experiments. |
| **Syllabus** | • Charged particle beams interacting with plasma • Generating a wakefield structure<br>• Scaling<br>• Limitations |

• Electron-beam driven PWFA – Motivation

– Current status

• Positron-beam driven PWFA

• Proton-beam driven PWFA (AWAKE)

– Motivation: Why protons?

– Current proton machines worldwide

– Basic mechanism of proton-driven PWFA

– Short proton bunch generation

– Self-modulation instability of long proton beam – Proof-of-principle experiment-AWAKE

• Positron acceleration in a plasma wakefield

| | |
|---|---|
| **CI-Acc-225** | **Electron Sources** |
| **Lecturer(s)** | Boris Militsyn |
| **Level** | Advanced |
| **Prerequisites** | Undergraduate General Physics and Electromagnetism |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | |

## Syllabus

# CI-RF-311

| | |
|---|---|
| **CI-RF-311** | **Wakefields** |
| **Lecturer(s)** | Roger Jones |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | |
| **Classes** | 6 Lectures + 1 Tutorial in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | "RF Linear Accelerators", Wiley & Sons Publishers (1998), by Thomas Wangler<br>"RF Superconductivity for Accelerators", Wiley Publishers (1998), by Hasan Padamsee, Jens Knobloch and Tom Hays<br>"Physics of Collective Beam Instabilities in High Energy Accelerators" (free pdf download : http://www.slac.stanford.edu/%7Eachao/wileybook.html) , Wiley & Sons Publishers (1993) by Alexander Chao<br>"The Physics of Particle Accelerators: An Introduction", Oxford University Press (2000) by Klaus Wille<br>"Impedances and Wakes in High Energy Particle Accelerators", World Scientific Publishers (1998), by Bruno W Zotter and Semyon Kheifets |
| **Supplementary Texts** | "Fundamentals of Beam Physics" Oxford University Press (2003) by James Rosenzweig<br>"Particle Accelerator Physics I & II", (study edition) Springer-Verlag (2003) by Helmut Wiedemann |
| **Aims** | This course will address the fundamentals of wakefields and their relation to the beam impedance. The features of both long-range and short-range wakefields will be discussed. Circuit models of relativistic electron beams coupled to multiple accelerator cavities will be |

developed to calculate the coupled modal frequencies and wakefields. In addition to the general theoretical formalism of wakefields, practical methods to damp and measure the wakefields will be described with techniques taken from ongoing research on high-energy linacs (L-band and X-band linacs in particular). Throughout the course, basic physical principles such as superposition, energy conservation and causality will be emphasized.

**Learning Outcomes**

1. Be able to understand the meaning of a wakefield in the context of em fields.
2. Be able to distinguish between the short-range and long-range regime of wakefields –and apply the appropriate formulae to analyse their behaviour.
3. Appreciate the significance of synchronous modes in the context of wakefield excitation.
4. Ability to calculate the geometric and resistive wall wakefield and to assess their relative importance.
5. Become familiar with the terms used in the literature in the context of wakefields –such as loss factor, kick factor etc.
6. Ability to understand fundamental mechanisms which limit the operation of a linear accelerator –beam break up (BBU) in particular –and means to ameliorate these effects.
7. Understand experimental and simulation methods to measure wakefields –both beam-based and benchtop wire measurement.
8. Be aware of the limitations of various codes and which to apply according to the physics of the situation under consideration
9. Be able to construct circuit models which facilitate rapid wakefield computation.

**Syllabus**

Part I of Fundamentals of wakefields and impedance: Basic concepts and definitions are introduced. A field function analysis of wakefields is discussed and practical simplifications are introduced. The features of short-range and long-range wakefields are sketched out.

Part II of Fundamentals of wakefields and impedance and applications to linear colliders. Further general features of wakefields are described. The wakes in both L-band (superconducting) and X-band (normal conducting) linacs are investigated. Mode coupling issues that are likely to arise in the ILC main superconducting linacs are described. A circuit model of the dipole wakefield is developed for moderate to heavily damped accelerator structures. Interleaving the cell frequencies of adjacent structures is introduced as a means to combat insufficient fall-off in wakefields. Manifold damped structures are modelled with a transmission-line combined with an L-C circuit model and the additional features (built-in BPM and structure alignment thorough monitoring of manifold radiation) of DDS (Damped Detuned Structures) are modelled in detail. This may have particular relevance to CLIC.

Part III of Fundamentals of wakefields and impedance and applications to linear colliders. Special topics: Detailed study of resistive wall wake. BBU (Beam Break Up). Impedance and wakefield via a bench measurement. Higher modes of the TESLA accelerator and measurements made at the TTF (TESLA Test Facility). A coaxial wire method, for determining the modes likely to be excited by a particle beam, is described, from its original concept though to the latest research.

| | |
|---|---|
| **CI-RF-312** | **Superconducting RF and Cryogenics** |
| **Lecturer(s)** | Graeme Burt, Shrikant Pattalwar, John Weisend II, Reza Valizadeh |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Physics or equivalent |
| **Follow-up Units** | |
| **Classes** | 8 Lectures in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | RF Superconductivity, H. Padamsee (Wiley, 2009) |
| **Supplementary Texts** | Handbook of Cryogenic Engineering. J. G. Weisend (CRC Press, 1998)<br>Experimental Techniques in Low-Temperature Physics, G. White (Oxford University Press, 2002) |
| **Aims** | To provide students with an understanding of the basic theory of superconductivity for DC and RF, and SRF in practice. This includes bulk SRF, thin-film SRF and cryogenics. |
| **Learning Outcomes** | For students to understand basic superconductivity theory including penetration depth, coherence length and Type I/II materials. To give students an understanding of the effects on SRF from different impurities and contamination. To introduce students to the concept of cryogenics, and the basics of cryostat design and operations. To introduce students into how thin film coatings are produced and the pros and cons of each method. |
| **Syllabus** | • Lectures 1 & 2: Introduction to SRF (SRF theory) (Graeme Burt) |

Cooper pairs, energy gap, penetration depth, London theory, Two fluid model, Type I/II materials, BCS, mean free path. Impurities and contamination.

- Lecture 3: Cryogenics for Accelerators (John Weisend II)

  Cryogenics is an important technology for modern particle accelerators. Cryogenic cooling is used in superconducting magnets that bend and focus the beam and in superconducting radiofrequency cavities that accelerate the beam. Cryogenics is used in particle detectors in both large superconducting magnets that provide background fields and in liquid argon calorimeters. Liquid hydrogen moderators and targets are additional examples of cryogenics in accelerators.

  This lecture surveys the applications of cryogenics in accelerators and describes the technology used in cryogenic refrigeration plants, distribution systems and end users. Cooling schemes, fluid transport, controls and reliability are discussed. A systems approach is emphasized. Examples are drawn from ESS, ISIS, CERN and the LCLS-II projects.

- Lecture 4: Introduction to Cryostat design (John Weisend II)

  Cryostats are the fundamental building blocks of a cryogenic system. The design of cryogenic refrigerators, liquid storage tanks, transfer lines and superconducting magnets all involve cryostats. This talk reviews cryostat requirements, use of proper materials, thermal insulation approaches, safety, transfer lines and structures. Examples are taken from particle accelerators, fusion energy and space cryogenics systems.

- Lectures 5 & 6: Case Studies of Cryogenic system design (Shrikant Pattalwar)

  Development of cryogenic systems with illustration of the vertical test cryostat for ESS – SRF cavities and cryomodules for PIP-II. This will also include a guided visit to SuRF lab.

- Lectures 7 & 8: Coatings (Reza Valizadeh)

  Coating thin films, coating methods, coating analysis

## Syllabus

# CI-Beam-313

| | |
|---|---|
| **CI-Beam-313** | **Collective Effects** |
| **Lecturer(s)** | Andrzej Wolski and Bruno Muratori |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate electromagnetism<br>Single-particle linear beam dynamics |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | Problem sheets (100%) |
| **Recommended Text** | A. Wolski, "Beam Dynamics in High Energy Particle Accelerators", Imperial College Press (2014). |
| **Supplementary Texts** | H. Wiedemann, "Particle Accelerator Physics", Springer (4th Edition, 2015).<br>A.W. Chao, "Physics of Collective Beam Instabilities in High Energy Accelerators", Wiley (1993). |

**Aims**

- To introduce students to a range of phenomena associated with collective effects in high energy accelerators.
- To introduce students to some of the techniques used to describe and analyse collective effects, and to estimate their impact.

**Learning Outcomes**

By the end of the course, students should be able to:

- describe a range of effects from collective interactions on beam behaviour in high-energy particle accelerators, including space charge, scattering and wake field effects;
- explain how wake fields and impedances can be used to characterise the forces on particles arising from the presence of other particles in an accelerator;

- describe some simple models for single-bunch and coupled-bunch instabilities, and use simple formulae to estimate instability thresholds and growth rates;
- describe the impact of beam-beam interactions in colliders;
- explain how various countermeasures (such as damping mechanisms and feedback systems) can be used to suppress the impact of collective effects.

**Syllabus**

- Space charge
- Scattering effects: intrabeam scattering and Touschek effect
- Wake fields and impedances
- Potential-well distortion
- Microwave instability; Landau damping
- Head-tail instability
- Coupled-bunch instabilities
- Luminosity and beam-beam

| | |
|---|---|
| **CI-Mag-314** | **Free-Electron Lasers** |
| **Lecturer(s)** | Brian McNeil |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Electromagnetism |
| **Follow-up Units** | |
| **Classes** | 5 Lectures + 1 Tutorial in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | Brian WJ McNeil and Neil R Thompson, X-ray free-electron lasers, Nature Photonics, 4, 814, 2010 (doi:10.1038/nphoton.2010.239) |
| **Supplementary Texts** | E A Seddon et al., Short-wavelength free-electron laser sources and science: a review, Rep. Prog. Phys. 80, 115901, 2017 (https://doi.org/10.1088/1361-6633/aa7cca) |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | Lecture 1: Discuss why FELs are important sources of coherent radiation. Links are given to fur- ther sources of information. Basics of the FEL – electron motion in an undulator.<br>Lecture 2: Radiation emission from an electron in an undulator. Derivation of the fundamental res- onant wavelength and harmonics. Interaction of many electrons in a fixed resonant electromagnetic field – electron bunching and coherent emission. The self-consistent interaction between electrons and radiation in an undulator – the FEL interaction. Introduction to basic FEL linear theory. |

Lecture 3: Different gain regimes of the FEL – low & high gain. The high gain regime and the exponential instability. Pulse effects and Self Amplified Spontaneous Emission (SASE)

Lecture 4: Effects of electron beam energy spread, emittance, radiation diffraction etc. The basic design process of an FEL facility – where to start. Some examples of how FELs are developing into more advanced schemes.

| | |
|---|---|
| **CI-SWA-315** | **Lasers for Accelerators** |
| **Lecturer(s)** | Steve Jamison |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Electromagnetism and OPtics |
| **Follow-up Units** | This course is a prerequisite for all subsequent units |
| **Classes** | 4 Lectures + 1 Tutorial in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course covers laser architecture and systems used for accelerator sciences, both as a beam diagnostic and as a driver for accelerators. Beam diagnostic techniques will be discussed. |
| **Learning Outcomes** | Students will at the end of this course be familiar with the design of high- power laser systems and how ultrafast laser pulses can be used to measure particle beam properties. |
| **Syllabus** | • Overview of lasers in accelerators<br>• Laser cavities and stability<br>• Mode-locking of lasers<br>• Optical clocks, timing and optical beam arrival monitors<br>• Terawatt laser architecture<br>• General principles for lasers<br>• Laser-wire scanner for transverse profile<br>• Coherent radiation spectra for temporal profile<br>• Electro-optic technique for temporal profile / THz sources<br>• Optical timing<br>• Optical beam arrival monitors<br>• Ultrafast FEL photon diagnostics |

## Syllabus

# CI-Beam-321

| | |
|---|---|
| **CI-Beam-321** | **Practical Accelerator Design** |
| **Lecturer(s)** | Hywel Owen |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Electromagnetism, CI-BEAM-104, CI-BEAM-105 |
| **Follow-up Units** | |
| **Classes** | 6 Lectures + 1 Tutorial in Semester 2 (alternate years) |
| **Assessment** | Problem sheets (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |

**Syllabus**

- Synchrotrons and discovery colliders (circular accelerators)
- FELs and precision colliders (linear accelerators)
- Beam delivery systems
- Medical accelerators
- FFAGs
- Cyclotrons

| | |
|---|---|
| **CI-SWA-322** | **Particle-in-cell Methods** |
| **Lecturer(s)** | t.b.d. |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Electromagnetism, CI-SWA-107 |
| **Follow-up Units** | |
| **Classes** | 4 Lectures + 2 Tutorials in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | This course covers a specific method of numerical modelling, particle-in-cell (PIC), that is used as the workhorse code for plasma accelerators as well as for beam dynamics. The architecture of a PIC code, with emphasis on stability and validity of the outputted data will be examined. |
| **Learning Outcomes** | Students will at the end of this course be familiar with the particle-in-cell method and should have an understanding of the limitations and validity of results from a PIC code. |
| **Syllabus** | • single particle motion<br>• different numerical integration schemes<br>• advection/diffusion<br>• conservation<br>• stability analysis<br>• boundary conditions<br>• verification and validation<br>• computational electromagnetics<br>• run an example PIC code (possibly EPOCH, UPIC or OSIRIS) on a cluster |

| | |
|---|---|
| **CI-SWA-323** | **Laser-Plasma Particle and Photon Sources** |
| **Lecturer(s)** | Charlotte Palmer |
| **Level** | Advanced Options |
| **Prerequisites** | Undergraduate Electromagnetism, CI-SWA-107 |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 (alternate years) |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | Short Pulse Laser Interactions with Matter – An Introduction, P. Gibbon (Imperial College Press, 2005). |
| **Supplementary Texts** | The physics of laser plasma interactions, Kruer, William L., (Westview, 2003).<br>A Superintense Laser-Plasma Interaction Theory Primer, Macchi, Andrea (Springer, 2013). |
| **Aims** | This course begins with an overview of high-power laser pulses that can be used to drive plasma accelerators and laser-plasma interaction regimes. Then the mechanisms to produce compact electron, x-ray, ion, neutron and positron beams will be discussed. |
| **Learning Outcomes** | Students will at the end of this course be familiar with the state-of-the-art compact accelerator sources of particles and photons produced from a high-intensity laser plasma interaction. |
| **Syllabus** | • High-power laser pulses (+ future technology such as fiber lasers) • Laser-plasma interactions<br>– Underdense plasma laser propagation, self-focusing, instabilities<br>– Overdense plasma absorption mechanisms, relativistic effects, electron transport<br>• Laser Wakefield Acceleration (LWFA) |

– Optimization: Plasma density, dephasing length, injection mechanisms

– Electron beam properties and control; energy bandwidth, temporal duration, emittance, pointing stability

• Betatron x-ray generation

– Spectra, brightness, source size, temporal duration, stability

• Inverse-Compton scattering

• Laser-driven ion acceleration mechanisms

– Target normal sheath acceleration, beam properties and applications

– Ultrathin foil targets: Radiation Pressure Acceleration (RPA), Light Sail, Breakout

Afterburner (BOA)

– Shock-ion acceleration

– Magnetic vortex acceleration

• Neutron beam generation

– Pitcher-catcher configuration, neutron measurement, neutron properties

• Positron production

– Solid target interaction, LWFA-converter, ultrahigh intensities

| | |
|---|---|
| **CI-TS-401** | **Applications of Accelerators** |
| **Lecturer(s)** | Graeme Burt, Elaine Seddon and Hywel Owen |
| **Level** | Transferable Skills Options |
| **Prerequisites** | Undergraduate Electromagnetism,<br>CI-BEAM-104, CI-BEAM-105 |
| **Follow-up Units** | |
| **Classes** | 8 Lectures in Semester 2 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | Applications of Particle Accelerators in Europe, EuCARD2 Report (2017) (also https://edms.cern.ch/ui/file/1325147/2/EuCARD2-Del-D-4-5-Final.pdf) |
| **Supplementary Texts** | H. Owen et al., 'Hadron Accelerators for Radiotherapy;, Contemp. Phys. 55(2), 55-74 (2014) |
| **Aims** | To introduce students to the variety of applications of accelerators outside of HEP. Understand how accelerators are used in medical, security and industrial environments. Understand the generation of X-rays and neutrons from electron and proton beams and the interaction of these particles with matter. |
| **Learning Outcomes** | Students will understand the breadth of applications of accelerators, students will understand how particles can be used in a variety of applications, students will understand requirements of accelerators for non HEP applications |
| **Syllabus** | X-ray production from brem., X-ray attenuation in matter, cargo scanning systems, material separation, linacs for cargo screening, neutron scanning<br>Industry/ Cross-linking, Curing, Sterilisation, Gem-stone colouring, flue gas and water treatment, industrial accelerators (linacs, DC, Rhodotrons) |

| | |
|---|---|
| **CI-TS-402** | **Project Management for Accelerator Projects** |
| **Lecturer(s)** | Andy Goulden, Lisa Howard |
| **Level** | Transferable Skills Options |
| **Prerequisites** | None |
| **Follow-up Units** | |
| **Classes** | 4 Lectures in Semester 2 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | |

| | |
|---|---|
| **CI-TS-402** | **Computational Physics** |
| **Lecturer(s)** | t.b.d. |
| **Level** | Transferable Skills Options |
| **Prerequisites** | Undergraduate Physics or Engineering |
| **Follow-up Units** | |
| **Classes** | 6 Lectures in Semester 2 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | |

## Syllabus

# CI-TS-404

| | |
|---|---|
| **CI-TS-404** | **Communication and Outreach** |
| **Lecturer(s)** | Chris Edmonds |
| **Level** | Transferable Skills Options |
| **Prerequisites** | Undergraduate Physics or Engineering |
| **Follow-up Units** | |
| **Classes** | 4 Lectures in Semester 2 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | |

| | |
|---|---|
| **CI-TS-405** | **Intellectual Property and Business Law** |
| **Lecturer(s)** | Liz Bain |
| **Level** | Transferable Skills Options |
| **Prerequisites** | Undergraduate Physics or Engineering |
| **Follow-up Units** | |
| **Classes** | 4 Lectures in Semester 2 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | |

## Syllabus

# CI-TS-406

| | |
|---|---|
| **CI-TS-406** | **How to Get Published** |
| **Lecturer(s)** | Oleg Malyshev |
| **Level** | Transferable Skills Options |
| **Prerequisites** | Undergraduate Physics or Engineering |
| **Follow-up Units** | |
| **Classes** | 1 Lecture in Semester 2 |
| **Assessment** | Attendance only (100%) |
| **Recommended Text** | |
| **Supplementary Texts** | |
| **Aims** | |
| **Learning Outcomes** | |
| **Syllabus** | |