The Cockcroft Institute
of Accelerator Science and Technology

Student Handbook

&

Education Programme Syllabus

2016 - 2017

Contents

Welcome to the Cockcroft Institute

The Cockcroft Institute is a collaboration between Lancaster, Manchester, Liverpool Universities and the Accelerator Science and technology Centre at Daresbury (Strathclyde joining soon). It includes both physicists and Engineers.

The Cockcroft Institute is an international centre for Accelerator Science and Technology (AST) in the UK. It was proposed in September 2003 and officially opened in September 2006. It is a joint venture of Lancaster University, the University of Liverpool, the University of Manchester, the Science and Technology Facilities Council, and the Northwest Regional Development Agency. The Institute is located in a purpose-built building on the Sci-Tech Daresbury campus, and in centres in each of the participating universities. In 2016 the institute grew with the addition of Strathclyde University.

The Institute's aim is to provide the intellectual focus, educational infrastructure, and the essential scientific and technological facilities for Accelerator Science and Technology research and development, which will enable UK scientists and engineers to take a major role in accelerator design, construction, and operation for the foreseeable future. The Institute is named after the Nobel prizewinner Sir John Cockcroft FRS.

Director of the Cockcroft Institute:
Prof Peter Ratoff (Lancaster University, Physics)
email: peter.ratoff@cockcroft.ac.uk

Head of education and training:
Dr Louise Willingale (Lancaster University, Physics)
email: louise.willingale@cockcroft.ac.uk

Deputy head of education and training:
Dr Gouxing Xia (Manchester University, Physics)
email: guoxing.xia@manchester.ac.uk

Careers officer:
Dr Amos Dexter (Lancaster University, Engineering)
email: a.dexter@lancaster.ac.uk

Statement of Expectations for Postgraduate Training

The ambitions of the Research Councils' and the other funders[1] who endorse this 'Statement of Expectations for Postgraduate Training' are to continue to develop highly skilled researchers to achieve impact across the whole economy, as well as developing the next generation of researchers to maintain national capability. PhD training is supported through a number of mechanisms; however the principles set out below apply to all students irrespective of mechanism.

Expectations on Research Organisations

- Research Organisations should undertake open, merit-based and transparent recruitment of students, selecting candidate(s) regardless of background or any protected characteristic as defined by the Equality Act (2010).
- Research Organisations should implement a training strategy which is in line with the Organisation's research strategy and in synergy with the funders' strategic objectives.
- The emphasis should be on enhancing the excellence and quality of doctoral training (rather than maximising student numbers).
- A robust process should be in place to attract and recruit outstanding quality applicants.
- Collaboration with Business, Government and Third Sector Organizations should be strongly encouraged, where appropriate.
- Research Organisations should report as required[2]:
  - For Research Council-funded studentships, this will be by providing information on students (including diversity monitoring data) and their training programmes through the Je-S Student Details for inclusion in the Research Council's Management Information Systems.
  - For other endorsing funders studentships, reporting should be carried out as instructed in grant terms and conditions.
- Students should be aware of which funding body that supports them, and be familiar with that organisation's strategic objectives. Funder support should be acknowledged on any publications or any other form of dissemination arising from their PhD.

Expectations of the Training Environment

- Research Organisations are expected to provide excellent standards of supervision, management and mentoring[3]. Supervisors should receive the support and training that they individually need to provide the highest-quality supervisory support to their students, and be aware of their responsibilities

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[1] The Wellcome Trust, Cancer Research UK, British Heart Foundation

[2] Additional reporting may be required for particular schemes; any such bespoke reporting will be described in detail in correspondence between the Research Organisation and the relevant funder.

[3] Research Organisations should adopt the principles, standards and good practice for management of research staff as set out in the Concordat to Support the Career Development of Researchers. The Research Organisation is responsible for implementing the requirements of the QAA Code of Practice for the Assurance of Academic Quality and Standards.

under the Equality Act (2010) to treat all students in a fair, open and non-discriminatory manner.

- Career advice should be provided (both prior to embarking on a PhD and ongoing) to enable students to choose the most appropriate type of PhD and have the confidence and skills to explore the impact they can have in a wide range of relevant sectors and so manage their careers.
- Students enter doctoral programmes with a diverse range of skills and experience. Research Organisations should have mechanisms in place to assess and monitor individual student needs and put in place appropriate development opportunities. The provision of training should be kept as flexible as possible allowing customisation to suit the individual needs of students (and the research area).
- Students should receive in-depth advanced training, as well as developing a broad understanding of their subject area. They should also develop an understanding of how their research fits into the broader "research and innovation system" and of practicable routes to maximising economic, social and/or health impact.
- Funders who endorse this Statement expect the provision of transferable skills to form a fundamental part of doctoral training[4].
- Students should receive training in the principles of good research conduct in their discipline, and understand how to comply with relevant ethical, legal and professional frameworks[5]. Students should be provided with training to identify and challenge unintentional bias as appropriate to their studies.
- Students should receive training in experimental design and statistics appropriate to their disciplines and in the importance of ensuring research results are robust and reproducible.
- Students should, wherever possible, benefit from the advantages of being developed as part of a broader peer group (e.g. through cohort approaches and Graduate schools).
- Students should be encouraged to consider the wider context of their research area, particularly in reference to societal and ethical issues, and the importance of engaging the public with research. Learning and training opportunities should be provided to help develop their public engagement skills[6].
- Research organisations are expected to provide an environment where research students have the opportunity to widen their horizons as part of their training. Experiences outside the "home" Research Organisation, for example with other academic collaborators, in non-academic environments or overseas are encouraged where it fits with the individual and scope of the project. These should be well planned to ensure the student gains maximum benefit.
- Supervisors should recognise doctoral study as a wider training opportunity and encourage and support students in developing their careers.

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[4] Research Organisations should use the Researcher Development Statement to underpin their professional development programmes for students.

[5] For further information regarding the expectations on Research Organisations, see The Concordat to Support Research Integrity (http://www.universitiesuk.ac.uk/Publications/Documents/TheConcordatToSupportResearchIntegrity.pdf) and the RCUK Policy and Code of Conduct on the Governance of Good Research Conduct (http://www.rcuk.ac.uk/Publications/researchers/Pages.grc.aspx)

[6] Further information, guidance and advice on public engagement with research can be found on the following websites: National Coordinating Centre for Public Engagement (https://www.publicengagement.ac.uk/) and RCUK Public Engagement with Research (http://www.rcuk.ac.uk/pe/public-engagement-with-research-strategy/)

Expectations of the Students

- Students should be actively involved in managing and directing their research project and training, taking advice from their supervisor.
- Students will be expected to develop the higher-level capabilities as outlined in the Researcher Development Statement[7].
- Where students get the opportunity to work in a non-academic environment, they should maximise the opportunity by seeking to understand the role of research within the organisation and the wider context.
- Students are expected to participate in training and networking opportunities provided by the funding body.
- Students should complete all information/reporting requests from the funding provider and ensure contact details are maintained.

Expectations of Collaborators

- The collaborating organisation and academic partner should undertake to develop a research project of the same difficulty and challenge to a conventional PhD programme.
- The partners should maximise the quality of the training experience for the student by recognising the broader training and development opportunities which are available through working in academic and non-academic environments.
- Collaborators are encouraged to promote their involvement with both the Research Organisation and funding body, both internally and externally.
- Research Councils expect the Research Organisation and collaborating organisation to have an agreement in place before the project begins, which recognises the student's contribution, to make sure that the IP arising from the research / training can be managed effectively.

Funders will

- Harmonise terms, conditions and guidance around postgraduate training, where practical, whilst recognising there may be valid subject specific or funder-specific reasons for different approaches in some instances.
- Discuss and evaluate recruitment strategy and processes, and postgraduate training approaches at Departmental (or equivalent) and Institutional level on visits and through formal assurance mechanisms, as required.

[7] See www.vitae.ac.uk for more details.

Code of practice for Cockcroft PhD Supervisors

The aim of the PhD is for the student to learn and demonstrate research skills through the intellectual development of a project. The student should deliver an end goal of the project, but must also have made an intellectual contribution to that project and must have a full understanding of all aspects. The end examination is a 200 page thesis and a 2-3 hour viva, but there may be some interim assessments. This means the student must receive training and practice in writing and have sufficient time understanding their subject, as well as involvement in project management. The supervisor should provide guidance to the student, but it is the student's project and they must make the intellectual contribution not the supervisor. The supervisor should advise on project direction and help the student's understanding.

Roles of the supervisor

- The supervisor should normally meet in person with each PhD student once per week for typically one hour. Where students are based overseas the meetings should still be once a week but via phone or video. Students who are based at Daresbury should meet with their supervisors in person once per week, unless their supervisor is from Strathclyde or another institution outside the Northwest of England (in which case phone is ok).
- The supervisor is responsible for ensuring the project is on track, that the student is capable of completing and that the student has sufficient understanding of the project.
- All superiors must have done some diversity & unconscious bias training at their home institution. Additionally, supervisors should have some training in research student supervision and be aware of university progression requirements for their students.
- Staff should not supervise more than 5 full-time PhD students at the same time. Where a student has two or more officially recognised supervisors (registered at the University) such as an ASTeC co-supervisor or a part-time student they can be counted as 0.5 students for this purpose.

Joint ASTeC-University projects

- Where a project is joint with ASTeC there should be an officially recognised (by the University) ASTeC supervisor in addition to the University supervisor. We expect both supervisors to meet with the student, either separately or together, once per week. Neither supervisor should leave the other supervisor to supervise the project alone. ASTeC must retain involvement in ASTeC projects.
- ASTeC also commission projects. In this case ASTeC will have oversight of the project but are not responsible for students. It should be clearly defined at the start of the project if the project is joint or commissioned.
- In these cases the studentship can often be very project driven, but all parties should bear in mind the intellectual requirements for the student. PhD students are not cheap effort and we must ensure that we nurture their learning and lead them to PhD completion. The overall direction of this plan should be set by the supervisors. A project plan should be drawn up by the student in consultation with both supervisors, taking the supervisors? set

direction into account, which should include both project work as well as writing and study time. The University supervisor is responsible for assessing that the research plan provides sufficient intellectual contribution to complete the PhD. Where this is not met the plan should be revised until it is. The students should have responsibility for design and analysis of experiments and their results if possible. The research should be focused such that the student can have a deep understanding of every aspect of the project and both supervisors are responsible for helping the students understand their topic.

- Students should be given at least 20% of their time dedicated to study and writing away from the experimental or laboratory setting. While this can be flexible it is not appropriate to delay this to the end of the PhD.
- The student progression is the sole responsibility of the University supervisor, and the ASTeC supervisor should ensure the student has sufficient time to write any documentation or reports required.

Role of the students

- All students must perform at least 100 hours subject specific training (60 hours from the Cockcroft Institute and 40 hours additional relevant credits, as agreed with the head of E&T) over the course of their PhD. Attendance at the lectures is monitored.
- The Monday morning lectures are compulsory for all 1st and 2nd year students with a Cockcroft supervisor independent of funding. Students based in the North West of England should attend in person; students at Strathclyde should attend at the SUPA grid room (or other) as a group. Other students can view online.
- Students must also complete any stipulated assessments at the Cockcroft Institute, including the introductory assessments between January and March in their 1st year, and from 2nd year onwards present at the annual postgrad conference.
- They must also do two weeks per year of soft skills training; the students may perform this as they wish but must declare how they spent it at the end of each year. Transferable skills (that is, software engineering, communication and presentation skills, outreach training, networking, team working, leadership, time management, entrepreneurship and business skills). Activities undertaken as part of the PhD programme (such as presentations or outreach) do not count, but training on how to give presentations or undertake outreach activities (for example) does.
- The students should attend all research meetings as directed by their supervisor.
- Students are expected to present regularly at internal group meetings, CI wide meetings and external conferences.
- By the end of 1st year students should have a research plan and some technical reports as directed by their supervisor.

Mentoring

Each student should have an independent mentor at the Cockcroft Institute unconnected to the project. Manchester and Lancaster Physics assign these already. Lancaster Engineering and Liverpool students (Physics or Engineering) will be mentored by an appropriate person identified by the Director of Education & Training at the Cockcroft Institute.

The mentor is an independent contact who students can approach for independent advice in confidence. The Head of Education & Training and the Cockcroft Institute Director are also available to assist students with matters that they have been unable to resolve with their supervisor or mentor. Students with welfare issues are able to access counselling from either Daresbury Laboratory welfare services or directly from the welfare services of their home university, as they find appropriate. This provision has been negotiated with STFC and doesn't entitle students to any other STFC employee benefits.

Cockcroft Institute Education Programme

The CI education program is designed as a 2 year course in accelerator science. It is designed to be broad and covers most aspects of accelerator science and technology. The courses have three levels introductory, advanced and options. By the end of your 2nd year, you should have completed 32 hours of introductory lectures, 50 hours of advanced and an additional 40 hours from the options.

Lectures are every Monday starting at 10:30 am and 11:45 am in the Merrison Lecture Theatre (2016 they were in the Walton Seminar Rooms A&B). Occasionally a third lecture may be schedule starting at 2:00 pm. Lectures do not run in July or August for the holiday break. Students are expected to attend the lectures in person and attendance is recorded. For students on travel, lectures can be received on the web at: https://www.cockcroft.ac.uk/webinar. The on demand lectures are normally uploaded a few weeks after the lecture.

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

- 100-level courses are introductory general accelerator physics and are repeated every year. There are a total of 32 hours that all first year student must attend.
- 200-level courses are more advanced and all 1st and 2nd year students should attend.
  - 210 courses run during the academic year 2016-2017.
  - 220 courses run during the academic year 2017-2018.
- 300-level courses are options and all each student must complete at least 40 hours of lectures from these over the 1st and 2nd year.
  - 300 courses run every year through the SUPA program. Note that these lectures are scheduled at different times from the Daresbury CI lectures.
  - 310 courses run during the academic year 2016-2017.
  - 320 courses run during the academic year 2017-2018.
- 400-level courses transferable skills courses.

We have five broad themes that flow through the syllabus and each theme has a convenor to ensure a coherent programme within that theme. The themes are:

- General Particle Accelerators (Acc), overseen by TBC
- Radiofrequency Accelerators (RF), overseen by G Burt
- Beam Dynamics (Beam), overseen by G Xia and A Wolski
- Magnets & insertion devices (Mag), overseen by TBC
- Short wavelength accelerators (SWA), overseen by L Willingale

Assessment

The introductory course is assessed. There is be three pieces of take home coursework released in January which is due to be completed by the end of March 2017. The coursework will cover beam dynamics, magnets and RF and involves calculation, design, theory and conceptual questions. Marks are given to the supervisor.

Transferable skills training
Additionally it is required that all students complete 80 hours per year of transferable skills training. Cockcroft puts on a limited amount of soft skills training under the theme transferable skills (TS). Students are expected to arrange the rest of their training at their university or otherwise (online courses etc). Each October we will require all students in all years to complete a log of their yearly training.

Outreach
The CI has set a goal that all PhD students should assist with two outreach/public events per year. Outreach commitments DO NOT count towards transferable skills training.

Seminars
The CI has an active seminar program and each month we have an external invited seminar speaker and one internal speaker. Students based at Cockcroft are expected to attend all seminars. You will receive notifications about upcoming seminars by email and you can also view the current calendar online at https://www.cockcroft.ac.uk/education-and-training/seminars

PG conference
In October we have a postgraduate conference where all CI PhD students (except the new students) will present their work. Prizes are given to the best presentations. New PhD students are expected to attend to view the presentations. A social event is arranged for the evening.

SCAPA trip
We plan a trip to Glasgow to visit SCAPA the plasma accelerator at Strathclyde university. This is planned as part of an introduction to novel accelerators course The trip will be for all 1st year PhD students and will take place in January.

Course summary tables

The tables below in this .pdf file contain links from the course code to the syallbus page for each course for quick reference.

Introductory courses

The introductory courses run every year and have a 100-level code. All first year students are expected to attend.

Course code	Title	#	Lecturer
CI-Acc-101	Introduction to Accelerators	2	M Poole, H Owen
CI-Acc-102	Relativity & Elements of Electromagnetism	4	J Gratus
CI-RF-103	Introduction to RF	4	G Burt
CI-Beam-104	Introduction to Beam Dynamics	6	R Appleby, I Bailey
CI-Beam-105	Lattice design and computational dynamics	8	R Apsimon, O Mete
CI-Mag-106	Conventional Magnets for Accelerators	4	B Shepherd, A Bainbridge
CI-SWA-107	Introduction to short-wavelength accelerators	4	G Xia

Advanced courses

The 200-level courses are more advanced and all 1st and 2nd year students should attend. 210 courses will run during the academic year 2016-2017 and 220 courses will run during the academic year 2017-2018.

Course code	Title	#	Lecturer
CI-Acc-211	Vacuum Systems & surface science	6	O Malyshev, K Middleman
CI-Acc-212	Beam Diagnostics	6	TBD
CI-Mag-213	Undulators and Synchrotron Radiation	4	J Clarke
CI-SWA-214	Novel electromagnetic materials for high frequency accelerators	6	R Letizia
CI-Acc-221	Electron & Ion Sources	7	B Miltsyn, D Faircloth
CI-RF-222	RF linear accelerators	7	G Burt
CI- Beam-223	Single particle dynamics	8	B Muratori
CI-SWA-224	Particle-beam driven Plasma Wakefield Accelerators (PWFA)	6	B Hidding

Option courses

The 300-level courses are options and all each student must complete at least 40 hours of lectures from these over the 1st and 2nd year. (Note that there are a total of 46 hours of lectures at Daresbury over the two years so unless you select SUPA courses, you will need to attend most of the Daresbury courses!) 300 courses run every year through the SUPA program, 310 courses run during the academic year 2016-2017, 320 courses run during the academic year 2017-2018.

Course code	Title	#	Lecturer
CI-RF-311	Wakefields	6	R Jones
CI-RF-312	Superconducting RF and Cryogenics	6	G Burt, R Valizadeh, S Pattalwar
CI- Beam-313	Collective effects	8	A Wolski
CI-Mag-314	Free electron Lasers	4	B McNeil
CI-SWA-315	Lasers for Accelerators	4	S Jamison
CI- Beam-321	Practical accelerator design	6	H Owen
CI-SWA-322	Particle-in-cell methods	4	A Thomas
CI-SWA-323	Laser-Plasma Particle and Photon Sources	6	L Willingale

SUPA courses

There are a number of courses offered by CI Strathclyde academics that CI student can access. The SUPA classes do not (necessarily) run on Monday and are administered through the SUPA organisation. If you desire, you can opt to take SUPA classes. For example, students with projects on plasma accelerators should take the SUPAPPH course. You should consult your own supervisor to discuss what is most appropriate for you. To participate in the lectures you are signed up for a my.SUPA account. The lectures will be webcast to a location at Daresbury Laboratory. For the up-to-date timetabling for the courses please access the SUPA website at http://my.supa.ac.uk/course/supa_timetable.php.

SUPA courses of particular interest to CI students. Links embedded in the pdf will take you to the SUPA website to display the syllabus for each course.

Course code	Title	#	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

Transferable skills

Every student is required to complete 80 hours of transferable skills training per year. Cockcroft puts on a limited amount of soft skills training under the theme Transferable skills (TS), see the table below (courses are still in development). Students are expected to arrange the rest of their training at their university or otherwise (online courses etc). Each October we will require all students in all years to complete a log of their yearly training.

Course code	Title & link to syllabus	#	Lecturer
CI-TS-401	Applications of Accelerators	8	G Burt, E Seddon and H Owen
CI-TS-402	Project management for accelerator projects	4	A Goulden
CI-TS-403	Computational Physics	?	H Owen
CI-TS-404	Communication and Outreach	?	TBC
CI-TS-405	Intellectual property and business law	?	TBC
CI-TS-406	How to get published	1	O Malyshev

Syllabus: CI-Acc-101 Introduction of Accelerators

Lecturer(s): M Poole and H Owen
Number of lectures and tutorials: 4 lectures and one tutorial
Level: Introductory
Prerequisites: Undergraduate Electromagnetics

Lecture syllabus:

Lecture 1: Early history; basic beam dynamics; synchrotron radiation; DL programmes – NINA and SRS.

Lecture 2: Technology challenges at energy frontier; LEP + LHC; next generation colliders.

Lecture 3: ISIS and new spallation sources; neutrino factory R&D; FFAG and EMMA; generic proton accelerator developments.

Lecture 4: Modern light sources; undulator technology; Diamond; ERLs – ALICE; FEL concepts and examples; recent proposed light sources.

Syllabus: CI-Acc-102 Relativity & Elements of Electromagnetism

Lecturer(s): J Gratus
Number of lectures and tutorials: 4 lectures
Level: Introductory
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.

Course Outline: 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!

Lecture syllabus:

- Relativity (2 lectures)
  Historical overview. Constancy of the speed of light; Lorentz transformations; time dilation, length contraction and the relativistic Doppler effect. Four-vectors; four-velocity and four-momentum; equivalence of mass and energy; particle collisions and four-momentum conservation; four-acceleration and four-force. Examples illustrating the use of four-vectors. Interrelation between relativistic quantities used in accelerator physics. An accelerator problem in relativity. As time permits: Relativistic particle dynamics; Lagrangian and Hamiltonian Formulation; radiation from an accelerating charge. Photons and the wave four-vector. Motion faster than the speed of light

- Electromagnetism (2 lectures)
  Review of Maxwell's equations; interconnection between E and B fields with worked examples. The Lorentz force law; motion of a charged particle under constant electric and magnetic fields. Relativistic transformations of E and B fields. (If time permits: Potentials, E/M four-vectors; worked example.) Electromagnetic energy conservation. Review of waves; phase velocity, group velocity; electromagnetic waves in (i) vacuo, (ii) conducting media. Waves in a uniform conducting guide: a simple example, idea of propagation constant, cut-off frequency, illustrations.

Syllabus: CI-RF-103 Fundamentals of RF

Lecturer(s): G Burt
Number of lectures and tutorials: 4 lectures
Level: Introductory
Prerequisites: Undergraduate Electromagnetics

Course Outline: 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.

Lecture syllabus:

- EM theory for RF, RF Cavity basics, Equivalent circuits
- RF sources, Power and reflections, Low level RF control
- Cavity types, normal and superconducting RF, gradient limits
- Higher order modes, beam-cavity coupling, wakefields, BBU

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.

Assessment: Take home coursework

Syllabus: CI-Beam-104 Introduction to Beam Dynamics

Lecturer(s): R Appleby, I Bailey
Number of lectures and tutorials: 6 lectures
Level: Introductory

Lecture syllabus:

- Multipole fields
- Equations of motion in dipoles and quadrupoles
- Thin lens approximation
- FODO cells
- Hill's equation
- 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)

Assessment: Take home coursework

Syllabus: CI-Beam-105 Lattice design and computational dynamics

Lecturer(s): R Apsimon, O Mete
Number of lectures and tutorials: 8 lectures
Level: Introductory

Course Outline: Introductory course on accelerator lattice design and modelling. This course will cover magnetic guide field and solution of equation of motion under matrix formalism.

Lecture 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)
- 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)

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.

Assessment: None

Syllabus: CI-Mag-106: Conventional Magnets for Accelerators

Lecturer(s): B Shepherd
Number of lectures and tutorials: 4 lectures and one tutorial
Level: Introductory

Course Outline: The course will deal specifically with room temperature (warm) electro magnets – superconductivity and permanent magnets will not be covered.

Lecture syllabus:
This section will establish the fundamentals of magnet theory for non-time varying (ie d.c.) magnetic fields. The basics will be established in the following order:
a) Introduction:

- Dipole magnets;
- Quadrupole magnets;
- Sextupole magnets;
- 'Higher order' magnets.

a) Magneto-statics in free space (no ferromagnetic materials or currents):

- Maxwell's 2 magneto-static equations;
- Solutions in two dimensions with scalar potential (no currents);
- Cylindrical harmonic in two dimensions (trigonometric formulation);
- Field lines and potential for dipole, quadrupole, sextupole;
- Significance of vector potential in 2D.

c) Introduce ferromagnetic poles:

- Ideal pole shapes for dipole, quad and sextupole;
- Field harmonics-symmetry constraints and significance;
- 'Forbidden' harmonics resulting from assembly asymmetries.

d) Cylindrical harmonics in the complex formulation.
e) The introduction of currents and the magnetic circuit:

- Ampere-turns in dipole, quad and sextupole.
- Coil economic optimisation-capital/running costs.
- The magnetic circuit-steel requirements-permeability and coercivity.
- Backleg and coil geometry- 'C', 'H' and 'window frame' designs.

f) Magnet design and f.e.a. software.

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

- Judgement of magnet suitability in design.
- Field computations using conformal transformations in the Z plane.
- Example – the Rogowsky roll-off.
- Magnet ends-computation and design.

A.C. magnets:
As in any synchrotron that "accelerates" particles, the magnetic field must vary with time, the consequences of that variation and the necessary designs for dynamic magnets are introduced as additions or perturbations to the basic theory:

- Variations in design and construction for a.c. magnets; Effects of eddy current in vac vessels and coils; Properties and choice of steel;
- Methods of injecting and extracting beam; Single turn injection/extraction; Multi-turn injection/extraction; Magnet requirements;
- 'Fast' magnets; Kicker magnets-lumped and distributed power supplies; Septum magnets-active and passive septa; Some modern examples.

Measurement of magnets: (A Bainbridge)
The final section of the course deals with measurement techniques for accelerator magnets, including a brief overview of the following:

- Hall effect probes for point-by-point measurements
- NMR probes for high accuracy
- 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

Syllabus: CI-SWA-107: Introduction to short-wavelength accelerators

Lecturer(s): G Xia
Number of lectures and tutorials: 4 lectures and one tutorial
Level: Introductory
Prerequisites: Undergraduate Electromagnetics

Course Outline: 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.

Lecture syllabus:

- Introduction
  - RF-based conventional accelerators (L, S, C, X down to optical)
  - Short wavelength-high frequency acceleration
  - Basics of lasers
  - Basics of plasmas
  - Plasma accelerators
  - Intro to THz sources
- 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

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.

Assessment: Take home coursework

Syllabus: CI-Acc-211: Vacuum Systems & Surface Science

Lecturer(s): O Malyshev, K Middleman
Number of lectures and tutorials: 6 lectures
Level: Advanced

Course Outline: 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.

Lecture 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 measured? 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: Beam Diagnostics

Lecturer(s): TBD
Number of lectures and tutorials: 6 lectures
Level: Advanced

Course Outline: To gain familiarity with a variety of diagnostic techniques and parameters to characterise particle beams.

Lecture syllabus:
The lectures will discuss how to characterise both electron and ions beam properties including (highlighting the differences):

- Profile (transverse/longitudinal)
- Intensity (absolute/relative)
- Position
- Emittance
- Data analysis
- Control system integration

Using the following diagnostics:

- BPM (cavity, stripline and button)
- Faraday cups
- Screens
- Spectrometers
- ICT's
- TDCs
- wire scanners
- pepperpots
- BLMs
- BAMs

Syllabus: CI-Mag-213: Undulators and Synchrotron Radiation

Lecturer(s): J Clarke
Number of lectures and tutorials: 4 lectures
Level: Advanced

Lecture syllabus:

- Synchrotron radiation fundamentals
  - The underlying physical principles and a historical perspective.
  - Derivation of synchrotron radiation wavelength coverage, flux and power levels from first principles for a bending magnet.
- SR from wigglers and undulators
  - The properties of SR from a wiggler based upon knowledge of bending magnets.
  - The interference effects in an undulator. Basics of undulator radiation output.
  - The difference or otherwise between wigglers and undulators.
  - 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.

Syllabus: CI-SWA-214: Novel electromagnetic materials for high frequency accelerators

Lecturer(s): R Letizia
Number of lectures and tutorials: 6 lectures
Level: Advanced
Prerequisites: Undergraduate Electromagnetics, semiconductors

Course Outline: 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.

Lecture syllabus:

- Photonic bandgap structures
- Effective electromagnetic materials
- Intense fields in dielectrics
- Plasmonic waveguides
- Dielectric laser acceleration
- Computational modelling
- THz acceleration
- Beam driven dielectrics

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.

Assessment: None.

Syllabus: CI-Acc-221: Electron & ion sources

Lecturer(s): B Miltsyn and D Faircloth
Number of lectures and tutorials: 4(7?) lectures and 1 tutorial
Level: Advanced
Prerequisites: A-Level Physics and Maths

Lecture syllabus:

Ion Sources (2 x 1 hour)

- Introduction: Ion source basics, History.
- Introduction to Plasma: Basic plasma parameters, Density, Temperature, Charge state, Ionization energy, Temperature distributions, Quasi-neutrality, Percentage ionization
- Electrical Discharges: Overview, Townsend breakdown, Glow discharge, Arc discharge, Importance 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 electrode, 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: Magnetron 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 coefficients, 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 voltage, 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 (SF6), 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, Surface production, Volume production, Negative ion extraction.

- Caesium and surface production: History, Caesium and surfaces, Soviet breakthrough, American 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, Extraction, Caesium trapping, Examples of negative Penning sources around the world, Budker Institute of Nuclear Physics (BINP, Institute for Nuclear Research (INR), Los Alamos National Laboratory (LANL), Rutherford Appleton Laboratory (RAL).

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

Assessment: None

Syllabus: CI-RF-222: RF linear accelerators

Lecturer(s): G Burt
Number of lectures and tutorials: 7 lectures
Level: Advanced
Prerequisites: None

Course Outline: An intermediate course on RF linear accelerators. This course will cover the basics of RF cavities and look at cavity effects, such as beamloading, 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.

Lecture syllabus:

- Lectures 1 & 2: Multicell cavities, equivalent circuits, effect of errors, side-coupled linacs
- Lecture 3: Coupling power to cavities, reflections, transients, beamloading, 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 Widroe, DTL, RFQ, H-mode, Spoke cavities
- Lecture 7: Field limitations, field emission, multipactor, breakdown models, SRF quench, heating, state-of-the art

Learning Outcomes: Understanding of:

- Basic cavity model, power coupling, detuning effects and different cavity types.
- Particle dynamics through accelerating structures and inducedinstabilities.
- Limitations on accelerating gradient, field emissions, multipactor, breakdown etc.

Assessment: Problems as part of the CI assessment

Syllabus: CI-Beam-223: Single particle dynamics

Lecturer(s): B Muratori
Number of lectures and tutorials: 8 lectures
Level: Advanced

Lecture syllabus:

- Hamiltonian formalism
- Transfer maps for linear elements
- Linear optics in periodic, uncoupled beamlines
- Longitudinal dynamics
- Coupling
- Linear imperfections
- Transfer maps for nonlinear elements (Taylor maps, Lie transformations, mixed-variable generating functions)
- Symplectic integrators (splitting methods, Runge-Kutta methods, Wu-Forest-Robin)
- Canonical perturbation theory
- Normal form analysis

Assessment: by homework

Syllabus: CI-SWA-224: Particle-beam driven Plasma Wakefield Accelerators (PWFA)

Lecturer(s): B Hidding
Number of lectures and tutorials: 6 lectures
Level: Advanced
Prerequisites: Undergraduate Electromagnetics

Course Outline: 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.

Lecture syllabus:

- Charged particle beams interacting with plasma
- Generating a wakefield structure
- Scaling
- 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

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.

Assessment: None

Syllabus: CI-RF-311: Wakefields

Lecturer(s): R Jones
Number of lectures and tutorials: 6 lectures and 1 tutorial
Level: Advanced Option

Course Outline: The progress of multiple bunches of electrons through a linear or circular accelerator gives rise to a trailing electromagnetic field. This wakefield can have catastrophic consequences if its progress is left unchecked as the beam can become unstable and develop a BBU (Beam Break Up) instability. This course discusses the beam dynamics issues associated with wakefields and means of damping the fields to acceptable levels. Examples are taken from the recent international next generation linear colliders damping schemes. Wakefield issues in storage rings will also be discussed.

Lecture 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 longrange 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 modeled 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 modeled in detail. This may have particular relevance to CLIC.

- 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.

Assessment: None

Syllabus: CI-RF-312: Superconducting RF and Cryogenics

Lecturer(s): G Burt, R Valizadeh, S Pattalwar
Number of lectures and tutorials: 6 lectures
Level: Advanced Option

Lecture syllabus:

- 2 lectures: Intro to SRF (SRF theory) (G Burt)
  Cooper pairs, energy gap, penetration depth, London theory, Two fluid model, Type I/II materials, BCS, mean free path
- 2 lectures: Cryogenics (S Pattalwar)
  Static and Dynamic heat loads, Approach to Cryostat design, Safety and Economics, Overall system design, Few case studies and tutorials.
- 2 lectures: Thin film coating and measurement (R Valizadeh)
  Thin film synthesis, film characterisation. PVD, CVD/ ALD deposition, thin film characterisation : XPS, AES, XRD, SIMS, RBS

Assessment: None

Syllabus: CI-Beam-313: Collective effects

Lecturer(s): A Wolski
Number of lectures and tutorials: 8 lectures
Level: Advanced Option

Lecture syllabus:

- Space-charge
- Wake fields and impedances
- Potential-well distortion
- Microwave instability; Landau damping
- Transverse mode-coupling instability
- Coupled-bunch instabilities
- Intrabeam scattering
- Touschek effect
- Luminosity and beam-beam

Assessment: by homework

Syllabus: CI-Mag-314: Free Electron Lasers

Lecturer(s): B McNeil
Number of lectures and tutorials: 4 lectures and 1 tutorial
Level: Advanced Option

Lecture syllabus:

Lecture 1: Discuss why FELs are important sources of coherent radiation. Links are given to further sources of information. Basics of the FEL – electron motion in an undulator.

Lecture 2: Radiation emission from an electron in an undulator. Derivation of the fundamental resonant 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.

Assessment: None

Syllabus: CI-SWA-315: Lasers for Accelerators

Lecturer(s): S Jamison
Number of lectures and tutorials: 4 lectures
Level: Advanced Option
Prerequisites: Undergraduate Electromagnetics, Optics

Course Outline: 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.

Lecture syllabus:

- Overview of lasers in accelerators
- Laser cavities and stability
- Mode-locking of lasers
- Optical clocks, timing and optical beam arrival monitors
- Terawatt laser architecture
- General principles for lasers
- Laser-wire scanner for transverse profile
- Coherent radiation spectra for temporal profile
- Electro-optic technique for temporal profile / THz sources
- Optical timing
- Optical beam arrival monitors
- Ultrafast FEL photon diagnostics

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.

Assessment: None

Syllabus: CI-Beam-321: Practical accelerator design

Lecturer(s): H Owen
Number of lectures and tutorials: 6 lectures
Level: Advanced Option

Lecture syllabus:

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

Assessment: by homework

Syllabus: CI-SWA-322: Particle-in-cell methods

Lecturer(s): A Thomas
Number of lectures and tutorials: 4 lectures and 2 tutorials
Level: Advanced Option
Prerequisites: Undergraduate Electromagnetics, basic coding

Course Outline:
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.

Lecture syllabus:

- single particle motion
- different numerical integration schemes
- advection/diffusion
- conservation
- stability analysis
- boundary conditions
- verification and validation
- computational electromagnetics
- run an example PIC code (possibly EPOCH, UPIC or OSIRIS) on a cluster

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.

Assessment: None

Syllabus: CI-SWA-323: Laser-Plasma Particle and Photon Sources

Lecturer(s): L Willingale
Number of lectures and tutorials: 6 lectures
Level: Advanced Option
Prerequisites: UG Electromagnetism

Course Outline: 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.

Lecture syllabus:

- High-power laser pulses (+ future technology such as fiber lasers)
- Laser-plasma interactions
  - Underdense plasma laser propagation, self-focusing, instabilities
  - Overdense plasma absorption mechanisms, relativistic effects, electron transport
- 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

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.

Assessment: None