Cockcroft Institute

Postgraduate Handbook

Education Programme Information and Syllabus

2022/23

Version 1.0

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Contents

1. The Cockcroft Institute Education Programme

The Cockcroft Institute education programme is designed as a two-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. The course consists of a number of short modules on different topics.

There are 3 levels of module: Introductory; Advanced; Specialised.

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 Specialised modules

Cockcroft Institute lectures 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 modules to make up their full attendance requirement.

Details of the lecture schedule, together with other information and useful resources, can be found on the Cockcroft Lectures Indico page:

https://indico.stfc.ac.uk/category/88/

Lectures may be viewed online at:

https://www.cockcroft.ac.uk/lectures

Each module has a code of the form CI-THEME-XXX.

There are five themes that run through the course:

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

The final part of the module code indicates the level and specific topic:

- 1XX: Introductory.
  - The Introductory modules are repeated every year.
- 2XX: Advanced.
  - 21X modules run in 2022/2023.
  - 22X modules run in 2023/2024.
- 3XX: Specialised.
  - 30X modules (SUPA programme) run every year (note: scheduled at different times to main Daresbury course lectures).
  - 31X modules run 2022/2023.
  - 32X modules run 2023/2024.
- 4XX: Complementary (or transferable) skills.

A text that students may find useful to accompany the course is “The Science and Technology of Particle Accelerators” by R. Appleby, G. Burt, J. Clarke and H. Owen (Taylor and Francis, 2020). This is available as free download (open-access) from the following url:

https://doi.org/10.1201/9781351007962

2. Assessment

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

The assessments for these modules use a common format, namely a ‘take-home’ assessment paper consisting of a set of questions with a total mark (for each module) of 50. The pass mark for each module is 50%. Students 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 completed as part of the CI education programme. Whilst it is understood that collaborative working will occur (and is encouraged, to help with developing an understanding of the material), work submitted by an individual should be substantively the efforts of that individual. Any sources used or quoted should be cited, following standard good academic practice. Penalties may apply if there is evidence of plagiarism or other academic malpractice.

3. Transferable Skills Training

All postgraduate research students are expected to complete 2 weeks (80 hours) of complementary or transferable skills training each year. The Cockcroft Institute provides some training in complementary skills in the general lecture programme (module codes ending in 4XX). Students are expected to complete the training requirement using events or resources provided by their home universities or elsewhere. Students should maintain a *personal record* of their complementary skills training, which will be audited by the Head of Education and Training at the end of each academic year.

4. Outreach and Communication

The Cockcroft Institute has set a goal that all postgraduate research students should participate in at least two outreach or public communication events each year during the first two years of their PhD studies. The aims are:

- to provide postgraduate students with experience in communicating their ideas to a range of audiences, including non-specialists;
- to ensure that postgraduates’ work is effectively disseminated to the public and stakeholders, so that we justify our work and its funding.

Events may include giving outreach talks (to schools or community groups), 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.

5. 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.

6. Postgraduate Conference

Each year (usually in October or November) the Institute holds a postgraduate conference at which second- and third-year postgraduate research students present their work in the form of a short talk. Prizes are awarded for the best presentations. New postgraduate research students are expected to attend to see the presentations as part of their overall training. A social event is arranged for the evening.

7. 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.

8. Summary of Training Requirements

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 the core requirement for CI research students. Those working for PhDs within specific programmes (such as EU networks, industrial programmes and so forth) should confirm with their programme manager any additional requirements that they may need to complete.

Table 1: Summary of general PhD training requirements within the Cockcroft Institute. Unless stated otherwise, the numbers shown are for the *total* requirements over the course of the PhD studies.

Training requirement	**Number of hours that should be completed**
1XX-level Introductory Modules	32 hours
21X/22X Advanced Modules	50 hours
31X/32X Options Modules	40 hours
4XX Transferable Skills (TS) Training	80 hours per year
Outreach Activities	4 events
Seminar Attendance	No specific requirement, but attendance at seminars should be recorded
Postgraduate Conference	At least 1
Networking Trip (Strathclyde)	At least 1

9. PhD Research Student 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 of a personal training record. This can be used as a template.

Name: Ms. Joanne Bloggs							
Training Event	*Date Completed*	*Number of Hours*				*Number of Events*	
		1XX	2XX	3XX	4XX	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	**July 2019**	**12**	**15**			**2**	
Required Totals		**32**	**50**	**40**	**80/year**	**4**	

10. Modules Overview

The tables below summarise the modules delivered by the Cockcroft Institute as part of the lecture programme. The syllabus, assessment requirements and other information for each module are given in later sections.

Please note that the details for all modules are subject to change.

1XX: Introductory Modules (Semester 1, October-January)

Introductory modules run every year. All first-year postgraduate students 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 + workshop	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

2XX: Advanced Modules (Semester 2, February-September)

Advanced modules run in alternate years. first and second-year postgraduates are expected to attend.

- 21X modules run in 2022/2023
- 22X modules run in 2023/2024

21X Modules (Semester 2, 2022/2023 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

22X Modules (Semester 2, 2023/2024 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

3XX: Specialised Modules

Specialised modules run in alternate years. Postgraduate students must complete at least 40 hours of Specialised modules over the first and second years of their studies.

- 30X modules (SUPA programme) run every year (note: scheduled at different times to main Daresbury course lectures).
- 31X modules run 2022/2023.
- 32X modules run 2023/2024.

30X Modules (Semester 2, each year)

There are a number of modules offered at Strathclyde as part of the SUPA programme; participants must register for a my.SUPA account. Please consult your PhD supervisor to discuss participation in these modules. Those modules most relevant to the CI education programme have 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

31X Modules (Semester 2, 2022/2023 Session)

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

32X Modules (Semester 2, 2023/2024 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.
CI-ACC-324	Statistics and Data Science for Acc Phys	6 + 3 workshops	Roger Barlow

4XX: Transferable (Complementary) Skills Modules

It is required that all postgraduate researchers complete 2 weeks (80 hours) of transferable (or complementary) skills training each year. CI provides some training opportunities in this area through modules with 4XX codes. Postgraduate students are expected to complete the remainder of the 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 Head of Education and Training at the end of each academic year.

Please note that the programme of 4XX modules is 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

11. Module Information and Syllabus

CI-ACC-101 Introduction to Accelerators

Lecturer	Hywel Owen
Level	Introductory (Postgraduate Year 1)
Prerequisites	Undergraduate electromagnetism
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	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 (editors A. Chao and M. Tigner), 2nd edition, World Scientific (2013)

Aims

This module introduces some key concepts and ideas in accelerator science and technology.

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

- Early history
- DC accelerators
- Linacs, Cyclotrons, Betatrons and Synchrotrons
- Phase stability and strong focusing
- Storage rings and colliders
- Beam cooling
- Synchrotron radiation
- Beam optical systems

Lecture 2: Particle accelerators – types and uses

- 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	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.
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	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) Classical Electrodynamics (J. D. Jackson), Wiley (1998) Electromagnetism (G. Pollack, D. Stump), Pearson (2002)

Aims

The module 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): 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.

Electromagnetism (2 lectures): 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	Louise Cowie
Level	Introductory (Postgraduate Year 1)
Prerequisites	Undergraduate electromagnetism
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	4 Lectures in Semester 1
Assessment	Take-home coursework, to be completed in Semester 2
Recommended Text	
Supplementary Texts	

Aims

This module covers a brief introduction to RF starting with a pillbox cavity to define the key parameters. The module will move on to the RF Power, higher-order modes and technology options.

Learning Outcomes

Students will at the end of this module 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

1. EM theory for RF, RF Cavity basics, equivalent circuits.
2. RF sources, power and reflections, low-level RF control.
3. Cavity types, normal and superconducting RF, gradient limits.
4. Higher order modes, beam-cavity coupling, wakefields, beam break-up.

CI-BEAM-104 Introduction to Beam Dynamics

Lecturer	Ian Bailey
Level	Introductory (Postgraduate Year 1)
Prerequisites	Undergraduate electromagnetism
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	6 Lectures in Semester 1
Assessment	Take-home coursework, to be completed in Semester 2
Recommended Text	K. Wille, "The physics of particle accelerators", Oxford (2001)
Supplementary Texts	A. Chao and M. Tigner (editors), "Handbook of Accelerator Physics and Engineering", 2nd edition, World Scientific (2013)
	S. Y. Lee, "Accelerator Physics" (3rd Edition), World Scientific (2011)
	A. Wolski, "Beam Dynamics in High Energy Particle Accelerators", Imperial College Press (2014)
	A. Larkoski, "Elementary Particle Physics", Cambridge University Press (2019)

Aims

Introductory module on transverse and longitudinal beam dynamics. The module 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)

CI-BEAM-105 Lattice Design and Computational Dynamics

Lecturers	Rob Apsimon and Oznur Mete
Level	Introductory (Postgraduate Year 1)
Prerequisites	Undergraduate electromagnetism
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	10 Lectures in Semester 1
Assessment	Attendance only
Recommended Text	
Supplementary Texts	

Aims

Introductory module on accelerator lattice design and modelling. This module 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)

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	Alex Bainbridge
Level	Introductory (Postgraduate Year 1)
Prerequisites	Undergraduate electromagnetism
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	4 Lectures in Semester 1
Assessment	Take-home coursework in Semester 2
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 module 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:

a) Introduction to:
  - Dipole magnets;
  - Quadrupole magnets;
  - Sextupole magnets;
  - 'Higher order' magnets.

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 injection/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	Guoxing Xia
Level	Introductory (Postgraduate Year 1)
Prerequisites	Undergraduate electromagnetism
Prerequisite for	This module is a prerequisite for all subsequent modules
Number of lectures	4 Lectures in Semester 1
Assessment	Attendance only
Recommended Text	
Supplementary Texts	

Aims

This module covers a brief introduction plasma and dielectric based accelerating structures. The module will move on to the RF Power, Higher order modes and technology options.

Learning Outcomes

Students will at the end of this module 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

1. 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
2. Laser-driven plasma particle accelerators
   - Laser driven electron acceleration
   - Radiation sources based on LWFA
   - Laser driven ion acceleration
3. Beam driven plasma wakefield acceleration PWFA
   - Electron-driven plasma wakefield acceleration
   - Positron-driven plasma wakefield acceleration
   - Proton-driven plasma wakefield acceleration
4. Acceleration using dielectrics
   - Laser driven dielectric acceleration
   - THz driven dielectric acceleration
   - Beam driven dielectric acceleration

CI-ACC-211 Vacuum Systems and Surface Science

Lecturers	Oleg Malyshev, Keith Middleman, Joe Herbert and Reza Valizadeh
Level	Advanced
Prerequisites	
Follow-up Units	
Number of lectures	6 Lectures in Semester 2 (alternate years)
Assessment	Attendance only
Recommended Text	
Supplementary Texts	

Aims

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

CI-ACC-212 Beam Diagnostics

Lecturer	Stewart Boogert
Level	Advanced
Prerequisites	
Follow-up Units	
Number of lectures	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 ion 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

CI-MAG-213 Synchrotron Radiation and Undulators

Lecturer	James Clarke
Level	Advanced
Prerequisites	Undergraduate Electromagnetism
Follow-up Units	
Number of lectures	4 Lectures in Semester 2 (alternate years)
Assessment	
Recommended Text	
Supplementary Texts	

Aims

Learning Outcome

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.

CI-SWA-214 Novel EM Materials for High-Frequency Accelerators

Lecturer	Rosa Letizia
Level	Advanced
Prerequisites	
Follow-up Units	
Number of lectures	6 Lectures in Semester 2 (alternate years)
Assessment	Attendance only (100%)
Recommended Text	
Supplementary Texts	

Aims

This module 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 module, 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
- Effective electromagnetic materials
- Intense fields in dielectrics
- Plasmonic waveguides
- Dielectric laser acceleration
- Computational modelling
- THz acceleration
- Beam driven dielectrics

CI-ACC-221 Particle Sources and Secondary Beams

Lecturer	Dan Faircloth
Level	Advanced
Prerequisites	Undergraduate General Physics and Electromagnetism
Follow-up Units	
Number of lectures	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, 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 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 (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
- 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

CI-RF-222 RF Linear Accelerators

Lecturer	Graeme Burt
Level	Advanced
Prerequisites	Undergraduate Electromagnetism, CI-RF-103
Follow-up 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 module on RF linear accelerators. This module will cover the basics of RF cavities and look at cavity effects, such as beam loading, microphonics and detuning. This module 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

By the end of this module, students will have an understanding of the following topics:

- 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

CI-BEAM-223 Single Particle Dynamics

Lecturer	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
- 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

CI-SWA-224 Particle-Beam Driven Plasma Wakefield Accelerators (PWFA)

Lecturers	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 module 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 module 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 module 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
- 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

CI-ACC-225 Electron Sources

Lecturer	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

CI-RF-311 Wakefields

Lecturer	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 Texts	"RF Linear Accelerators", Wiley & Sons Publishers (1998), by Thomas Wangler "RF Superconductivity for Accelerators", Wiley Publishers (1998), by Hasan Padamsee, Jens Knobloch and Tom Hays "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 "The Physics of Particle Accelerators: An Introduction", Oxford University Press (2000) by Klaus Wille "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 "Particle Accelerator Physics I & II", (study edition) Springer-Verlag (2003) by Helmut Wiedemann

Aims

This module 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 module, 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

Lecturers	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) 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 are 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.

CI-BEAM-313 Collective Effects

Lecturers	Andrzej Wolski and Bruno Muratori
Level	Advanced Options
Prerequisites	Undergraduate electromagnetism 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 Ed. 2015). A.W. Chao, "Physics of Collective Beam Instabilities in High Energy Accelerators", Wiley (1993).

Aims

1. To introduce students to a range of phenomena associated with collective effects in high energy accelerators.
2. 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 module, students should be able to:

1. describe a range of effects from collective interactions on beam behaviour in high-energy particle accelerators, including space charge, scattering and wake field effects;
2. 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;
3. describe some simple models for single-bunch and coupled-bunch instabilities, and use simple formulae to estimate instability thresholds and growth rates;
4. describe the impact of beam-beam interactions in colliders;
5. 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	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 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 and 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	Stephen Jamison
Level	Advanced Options
Prerequisites	Undergraduate Electromagnetism and Optics
Follow-up Units	This module is a prerequisite for all subsequent modules
Classes	4 Lectures + 1 Tutorial in Semester 2 (alternate years)
Assessment	Attendance only (100%)
Recommended Text	
Supplementary Texts	

Aims

This module 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 module 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
- 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

CI-BEAM-321 Practical Accelerator Design

Lecturer	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 module covers a specific method of numerical modelling, particle-in-cell (PIC), which 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

By the end of this module, students will 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
- 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

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

Lecturer	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). A Superintense Laser-Plasma Interaction Theory Primer, Macchi, Andrea (Springer, 2013).

Aims

This module 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

By the end of this module, students will be familiar with 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
    - 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

CI-TS-401 Applications of Accelerators

Lecturers	Graeme Burt, Elaine Seddon and Hywel Owen
Level	Transferable Skills Options
Prerequisites	Undergraduate Electromagnetism, 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 bremsstrahlung, X-ray attenuation in matter, cargo-scanning systems, material separation, linacs for cargo screening, neutron scanning

Applications in 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

Lecturers	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-403 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

CI-TS-404 Communication and Outreach

Lecturer	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

Lecturers	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

CI-TS-406 How to Get Published

Lecturer	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