

Cockcroft Institute

Education Programme Syllabus

2025/26, semester 1 (Oct 2025 – Jan 2026)

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General Information

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.

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 2024/2025.
 - 22X modules run in 2025/2026 (i.e. this year).

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 :	The Science and Technology of Particle Accelerators, R. Appleby, G. Burt, J. Clarke, H. Owen, CRC Press (2020) https://www.amazon.co.uk/Science-Technology-Particle-Accelerators/dp/1138499870 (paper) https://library.oopen.org/handle/20.500.12657/101030 (electronic open access)
Supplementary Texts :	Accelerator Physics (3rd Edition), S. Y. Lee, World Scientific (2011) Handbook of Accelerator Physics and Engineering (editors A. Chao, M. Tigner, H Weise, F. Zimmerman), 3rd edition, World Scientific (2023) https://www.amazon.co.uk/Handbook-Accelerator-Physics-Engineering-Third/dp/9811270155

Aims

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

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 (+ 1 workshop)
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 synchrotron 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 Apsimon
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 :	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. Apsimon)

Session 2: Introduction to MADX code, implementation of a periodic FODO lattice, matching, lattice errors and corrections. (O. Apsimon)

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

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

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

Lecturers :	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) 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.

Lecture 2:

c) 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.

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 :	5 Lectures in Semester 1
Assessment :	Attendance only
Recommended Text :	Proceedings of the 2019 CERN Accelerator School course on High Gradient Wakefield Accelerators, Sesimbra, (Portugal), CERN 2020. CERN-ACC-2020-0014.

Supplementary Texts :

Aims

This module covers a brief introduction to plasma-based acceleration and dielectric-based particle acceleration schemes. The fundamental working principle of each acceleration scheme will be discussed.

Learning Outcomes

At the end of this module, students should be familiar with plasma and dielectric accelerating structures, the basics of their physical mechanisms and the latest experimental results. The students will understand the limitations of current RF conventional accelerators and how short-wavelength structures can miniaturize the footprints and costs of conventional 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

2. Laser wakefield acceleration (LWFA)

- 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