# School of Physics & Astronomy

# Study Abroad Module Handbook 2024/25

**\* IMPORTANT NOTE**: All Semester 1 modules in the handbook are only available for students undertaking a full year study abroad programme.  This is due to the teaching and assessment methods within the School.  We are no longer able to accept Semester 1 only Study Abroad applicants.

# Year 1 Modules (LC)

**Module Title:** Classical Mechanics and Relativity 1 ***\*See note on front page***

**Module Code:** 19748

**Semester:** 1

**Credits:** 10

**Level:** LC

**Module Description:** This module explores Newton's laws and their implications both at fundamental and practical levels. It considers the dynamics of macroscopic objects subject to forces such as gravity, friction and the restoring force of a spring. The concepts of kinetic and potential energy, and work done by a force are discussed and applied to solve simple problems. The module further considers conservation of energy and linear momentum. Finally, we introduce the main conceptual aspects of special relativity.

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**Module Title:** Classical Mechanics and Relativity 2

**Module Code:** 33945

**Semester:** 2

**Credits:** 10

**Level:** LC

**Pre-requisites**: LC Classical Mechanics and Relativity 1 - (03 19748)

**Module Description:** This module develops the principles of mechanics and of special relativity, introduced in the first year. In this second phase, Newton's Laws are developed to handle more realistic problems. Starting with point-like particles, techniques are developed for handling many particle systems and extended rigid bodies. Damped simple harmonic motion is described and the behaviour of such a system under a periodic driving force is discussed. The module progresses from translational to rotational motion. Motion under a central, conservative force is described in and the effects of energy and momentum conservation are discussed. Motion in a rotating frame is discussed. In special relativity, the transformations of momentum and energy are reviewed with emphasis on the Lorentz invariants and their use in describing collisions.

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**Module Title:** Quantum Mechanics & Optics and Waves ***\*See note on front page***

**Module Code:** 19718

**Semester:** 1

**Credits:** 10

**Level:** LC

**Module Description:** Quantum Mechanics: Experimental observations of atoms and their interactions with radiation provided the driving force for the invention of Quantum Theory. Quantum Mechanics offers the only model we have that explains the properties for atomic systems. Evidence will be reviewed that leads us to the need and use of Quantum Mechanics. We will see how Schrodinger's wave mechanics and Heisenberg's uncertainty principle can help us to understand atoms. This module concentrates on the concepts and avoids a full mathematical treatment. Optics and Waves: The study of wave motion underpins our understanding of basic physics. We discuss the properties of waves, often taking as an example transverse waves in strings but also illustrating how the results are applicable not only to sound and light but also to quantum mechanics. The study of optics builds directly on our wave concepts. Applications and links to other branches of physics are emphasised.

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**Module Title:** Special Relativity and Probability and Random Processes ***\*See note on front page***

**Module Code:** 19749

**Semester:** 1

**Credits:** 10

**Level:** LC

**Module Description:** The way in which mathematics is used in theoretical physics to describe the physical universe can be beautiful, powerful and take us beyond our intuition. All of these features are illustrated in this module as we investigate Einstein's theory of special relativity and the mathematics of probability which we will use later in quantum mechanics and statistical physics.

One might expect that the combined impact speed of two cars in a head-on collision would be the sum of the two speeds recorded on each car's speedometer just prior to impact. This result (technically called a Galilean transformation) turns out not to be correct - though the error becomes appreciable only as velocities approach the speed of light. In this course we show how the observation that the speed of light is constant leads to the Lorentz transformation: a new set of rules which relate experiments done in moving laboratories. They lead to predictions which have since been verified experimentally such as "moving clocks run slow", "moving rulers shrink" and Einstein's famous equation: E=mc^2. We will also develop the mathematics of dealing with randomness and probability, from discrete outcomes (like the throwing of a dice) to continuous distributions (like heights of adults). Such notions lie at the heart of quantum mechanics, and is the way we deal with complex systems - like the 10^23 atoms in a typical solid. A key concept will be the understanding of probability distribution functions and how they are used to compute averages and variances. We will consider conditional probability and how to combine probabilities ultimately arriving at the central limit theorem. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Electromagnetism & Temperature and Matter

**Module Code:** 19750

**Semester:** 2

**Credits:** 20

**Level:** LC

**Module Description:** Electromagnetism: The main aim of this module is to understand electricity and magnetism using the concept of a field in both static and time-dependent situations. This will lead to an understanding of the integral forms of Maxwell's equations, and of the motion of charged particles in electric and magnetic fields. Temperature and Matter: After a short section on the most fundamental quark and lepton building blocks of matter and the forces which act between them, the main business of this module is to explain some of the thermal and mechanical properties of matter in terms of its atomic / molecular level constituents. This is done through the study of inter-atomic forces and potentials and their implications, the zeroth and first laws of thermodynamics, the Maxwell-Boltzmann and other probability distributions and elementary fluid dynamics. The understanding reached is quantitative, allowing calculations such as: How big is an atom? What is the air pressure at 10,000m? etc. Electric Circuits: Electric circuits are important both in the home and the laboratory. The course will deal with direct current networks of resistors, voltage and current sources. Steady state solutions for alternating current circuits comprised of resitors, inductors and capacitors will be analysed in terms of complex impedances. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

# Year 2 Modules (LI)

**Module Title:** Quantum Mechanics 2 ***\*See note on front page***

**Module Code:** 17273

**Semester:** 1

**Credits:** 10

**Level:** LI

**Pre-requisites**: Quantum Mechanics and Optics and Waves - (03 19718)

**Module Description:** Quantum Mechanics describes the behaviour of matter on sub-microscopic scales and, together with relativity, is one of the two foundations of modern physics. Quantum systems are often described as having both wave-like and particle-like aspects to their behaviour, and are famous for producing results that defy common-sense intuition based on observations at everyday scales. In this module we will introduce Schrodinger's wave equation and use it to investigate the behaviour of simple quantum systems, from a free particle through to single-electron atoms. We will discuss the wavefunction, which describes the state of a system, how to interpret it, and how making a measurement changes the wavefunction. We will illustrate some of the non-intuitive behaviour of quantum systems, show how it arises, and how, in the limit of large energies, it tends towards classical behaviour. We will discuss how mathematical operators are used to represent physical quantities, and see where the Uncertainty Principle comes from. We will introduce the quantum treatment of angular momentum and show how an additional property of the electron (spin) is required to describe atomic states. We will consider the special properties of quantum states consisting of more than one electron, and show how the existence of complex chemistry depends on these.

**Module Title:** Particles and Nuclei & A Quantum Approach to Solids ***\*See note on front page***

**Module Code:** 26017

**Semester:** 1

**Credits:** 10

**Level:** LI

**Pre-requisites:** Special Relativity and Probability and Random Processes - (03 19749), Electromagnetism and Temperature and Matter - (03 19750), LC Classical Mechanics and Relativity 1 - (03 19748)

**Module Description:** Particles and Nuclei:This module introduces the fundamental (as we understand them) constituents of matter and the forces through which they interact. The conservation laws which constrain which reactions are possible are discussed. The experimental evidence leading to and supporting the theories will be discussed. Natural units are explained, and relativistic invariance used to study reaction kinematics. Nuclear binding energies and masses, and the properties of the forces, are used to explain nuclear decays, fission and fusion. A Quantum Approach to Solids: This half of the module will introduce experimental and theoretical bases for explaining observed properties of materials such as heat capacity and conductivity. Following a brief introduction of bonding and crystal structure, a theory of lattice vibrations will be developed and used to explain experimental observations of the heat capacity. This leads naturally to the concept of electrons moving in materials, leading to explanations of metals and semiconductors.

**Module Title:** LI Observational Astronomy

**Module Code:** 29882

**Semester:** 2

**Credits:** 10

**Level:** LI

**Pre-requisites:** Some knowledge of astronomy at the level of LC Introduction to Astrophysics will be helpful, though not essential. Some additional reading will be recommended to students with no prior knowledge of Astronomy.

**Module Description:** Our understanding of the universe and the galaxies, stars, and planets that inhabit it is built on astronomical observations, both from Earth and Space. This course teaches students about physics and practicalities of astronomical observations, by following the passage of light from distant objects through the atmosphere, through the optics of a telescope, detection in the focal plane of the telescope, and measurement of flux recorded by the detector. The course focuses on ground-based optical imaging and spectroscopy to build the core knowledge that then enables students both to understand observations at other wavelengths, and to support their project work in Astro Projects and Observatory Laboratory. The main differences between optical observing, and observing at Gamma-ray, X-ray, infrared, and radio wavelengths are explained and illustrated with examples.

**Module Title:** Structure in the Universe

**Module Code:** 00554

**Semester:** 2

**Credits:** 10

**Level:** LI

**Module Description:** The Universe is full of structure. Most of the matter we can see is gathered into large, hot spheres, accompanied in most cases by planetary systems. The stars are grouped into galaxies, and these in turn are distributed in a network of clusters and filaments. In this lecture module, we will survey the properties of astrophysical structures and try to understand them in terms of the physics at play. We shall pay particular attention to the importance of rotation, and

angular momentum, in systems, e.g., the orbital motions in galaxies and planetary systems. In this context, we will examine the evidence for dark matter in galaxies, and explore in detail the various methods now being used to find extra-solar planets. Finally, we will apply the principles of Newtonian dynamics to examine the expanding Universe, to address basic cosmological questions like how old the Universe is and how fast it is expanding. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Lagrangian and Hamiltonian Mechanics

**Module Code:** 00539

**Semester:** 2

**Credits:** 10

**Level:** LI

**Pre-requisites:** LC Mathematics for Physicists 1A - (03 34459), LC Mathematics for Physicists 1B - (03 34462)

**Module Description:** Newton's conventional formulation of Classical Mechanics focuses attention on the forces acting on a system of particles and the second law of Newton then provides a way of calculating the subsequent position and motion of all the particles making up the system. This process can at times be rather awkward - particularly if there are constraints on the system. If we have, for example, a bead which is constrained to slide along a wire of known shape then the forces which constrain the bead to remain on the wire - the forces of constraint - are usually the reaction forces and they must be calculated using Newton's Laws for motion in say the x, y and z directions. Such a calculation may be awkward. However these constraint forces can be thought of as providing a purely geometrical constraint on the motion of the bead on the wire. If we can get away from having to work out the reaction forces, by using any convenient coordinate which incorporates the geometry of the problem (such as the distance moved along the wire) then we need never alculate the reaction (or constraint) forces. This elegant and beautiful reformulation of classical mechanics due to Lagrange and Hamilton, does exactly this and lies at the centre of the thinking about much modern physics. It allows us to choose any convenient set of coordinates to describe a problem and focuses on energies of a system- usually much easier to write down than the forces. We are thus are provided with a convenient and very practical way of analysing the motion of quite complicated systems. It also provides remarkable insights into the relations between the symmetries in a system and the conservation laws which hold. We can after all observe a conservation law in a scattering experiment and use this to deduce the symmetry of the underlying forces of nature. As a general rule in physics, a reformulation of any problem will usually offer new insights into its solution. We shall see also that the beautiful methods developed by Lagrange and Hamilton for Classical Mechanics are very close in spirit to the outlook of both Quantum Mechanics and Statistical Mechanics and Dirac's classic text on Quantum Mechanics draws heavily on the ideas which we shall develop in this module. Latterly the language and ideas of Lagrangian and Hamiltonian Mechanics have found fruit in the description of the behavior of certain Chaotic systems. The section of the module on the Calculus of Variations provides the mathematical background needed for a study of the General Theory of Relativity in year 4.

**Module Title:** Eigenphysics

**Module Code:** 00746

**Semester:** 2

**Credits:** 10

**Level:** LI

**Pre-requisites:** LC Mathematics for Physicists 1A - (03 34459), LC Mathematics for Physicists 1B - (03 34462)

**Module Description:** The equations describing many important physical phenomena are linear differential equations. For example, in quantum mechanics the Schrödinger equation contains no power of the wavefunction or its derivatives greater than the first, and so is a linear differential equation. Similarly Maxwell's equations contain no power of the electric and magnetic fields or their derivatives greater than the first, and so Maxwell's theory of electromagnetism is also linear. One consequence of a linear theory is that the sum of any two independent solutions is also a solution; this leads to the phenomenon of interference in both optics and quantum mechanics. What is more surprising is that the solutions may be regarded as 'vectors', where the 'angles' between them is important. In this module we shall study the mathematics which underlies and is common to all these different linear systems. The mathematical techniques and ideas are illustrated by drawing on familiar examples from both classical and quantum physics. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Electromagnetism 2

**Module Code:** 00953

**Semester:** 2

**Credits:** 10

**Level:** LI

**Pre-requisites:** Electromagnetism and Temperature and Matter - (03 19750)

**Module Description:** The 19th century saw mankind's greatest advances in the understanding of electricity and magnetism thanks to pure research carried out by the likes of Faraday, Ampere and Maxwell. Indeed, according to Feynman, the most significant event of the 19th century was Maxwell's four equations for electromagnetic fields published between 1855 and 1865. These four equations described the whole of electricity and magnetism and, for the first time, unified the electric and magnetic forces into one theory of electromagnetism. Maxwell also used these equations to show that light was an electromagnetic wave and accurately predicted the velocity of light. His equations also showed that electromagnetic waves were Lorentz invariant some forty years before Einstein.

**Module Title:** Nuclear Physics and Neutrinos

**Module Code:** 17301

**Semester:** 2

**Credits:** 10

**Level:** LI

**Pre-requisites:** LI Particles and Nuclei & A Quantum Approach to Solids - (03 26017)

**Module Description:** Nuclear Physics: This course provides an introduction to the topic of nuclear physics. It will explore what the mass of a nucleus reveals about the strong interaction; examine how the nuclear size and shape is measured, and the key decay mechanisms; alpha, beta and gamma decay and the associated selection rules and Q-values (energy release). The role of nuclear reactions in the synthesis of the elements will be described, including: proton burning, CNO cycle, rp-process, s-process and r-process. The process of energy generation using nuclear fusion and fission will be described together with medical applications and detection of nuclear radiation.

Neutrino Physics: The course provides an introduction to neutrino physics and related issues. It starts with a revision of the foundations of the Standard Model of particle physics (kinematics, particles and forces, conserved quantum numbers). It describes key experiments that demonstrated the existence of the three lepton generations and the finite neutrino mass. The principles and processes involved in the neutrino detection are reviewed. A number of neutrino detection techniques (including water Cherenkov, radiochemical and tracking calorimeter detectors) are discussed. The phenomenon of neutrino mixing and oscillations is introduced. Recent experiments with atmospheric, solar, accelerator and reactor neutrinos and the future developments in the field are presented. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Statistical Physics and Entropy ***\*See note on front page***

**Module Code:** 17296

**Semester:** 1

**Credits:** 10

**Level:** LI

**Pre-requisites:** Electromagnetism and Temperature and Matter - (03 19750)

**Module Description:** The laws of Thermodynamics underpin everything from life itself to the evolution of the universe. Moreover, they also address fundamental problems such as the 'arrow of time'. Although Thermodynamics was developed in the nineteenth century, modern developments have reinforced Einstein's view that it is the only physical theory of universal content which I am convinced will never be overthrown. Whilst statistics allow us to calculate the macroscopic properties of a system from microscopic theory, Thermodynamics has a power all of its own, even when we don't understand the microscopic physics. The central idea that links the two approaches is the concept of entropy, the understanding of which lies at the heart of this module. The main topics are organised as follows. Statistical Physics: Kinetic theory and molecular collisions; Mean free-path, diffusion and the random walk; Binomial, Poisson and Gaussian distributions. Thermal Equilibrium: Microstates, macrostates and Boltzmann entropy; Temperature and the Boltzmann distribution; Equipartition, harmonic oscillators, black-body radiation, stimulated emission and lasers. Classical Thermodynamics: 1st Law and 2nd Law (Clausius & Kelvin); Reversible & irreversible processes; Reversible heat, latent heat and heat capacity; Carnot cycle, heat engines and refrigerators; Functions of state, Gibbs & Helmholtz free energies and enthalpy; Thermodynamics of rubber elasticity, surface tension and liquid-vapour equilibrium; Maxwell Relations and Joule-Kelvin effect; Absolute Zero and the 3rd Law of Thermodynamics. Advanced Topics: Perpetual Motion and Maxwell's Demon; Information, Gibbs entropy and negative temperatures; Introduction to quantum statistics of identical particles. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Electronics

**Module Code:** 17489

**Semester:** 2

**Credits:** 10

**Level:** LI

**Module Description:** The module discusses the basic principles of analogue and digital electronics. It is important to recognise that it is analogue electronics that often provides the interface between a measuring device and the physical world. Therefore the first stage of an electronics circuit is to preserve and amplify a signal faithfully with minimal distortion. When we digitise an analogue signal we trade in our continuous physical signal for one in which only certain values are allowed. This sacrifices some information, but comes with some major advantages, such as errorless data transmission. Digital electronics is at the very heart of the telecommunications revolution that has given us the digital computer, the Internet and, more recently, digital radio and television. The analogue part of the course focuses on the frequency response of simple circuits and on the versatility of operational amplifiers. We shall investigate the advantages and potential problems of negative feedback. We will also look at the problem of noise and signal recovery and the problems associated with the process of analogue-to-digital conversion. Uses of digital electronics ranges from small-scale tasks possible with just a few logic gates up to the complexity of large computer farms. This section starts with an introduction to binary arithmetic, logic gates and the laws of Boolean algebra. Techniques for designing and improving logic are then introduced and illustrated with examples. Various types of logic families will be discussed together with how to make logic gates from semiconductors. Finally, the various types of devices and flip-flops and their applications are explored. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Optics

**Module Code:** 33964

**Semester:** 2

**Credits:** 10

**Level:** LI

**Module Description:** Optical devices are commonplace in the modern world, from digital cameras and optical mice to the Hubble space telescope. This module aims to provide an understanding of the basic optical principles underpinning such devices. A physicist working in research from astrophysics to ultracold atoms, but also in companies in fields such as aerospace, engineering, ICT, biomedical or environmental sciences will encounter optical systems of varying complexity for observation, imaging, manipulation, inspection, testing, quality control and many others. This module aims to provide understanding of the underlying principles and a bridge towards applications at a level appropriate for the professional in this field. It focuses on the design, characterisation and application of optical systems, the effects of polarization and modern applications.

# Year 3 Modules (LH)

**Module Title:** Quantum Mechanics 3 ***\*See note on front page***

**Module Code:** 00498

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites**: LI Mathematics for Physicists 2A - (03 34465), LI Mathematics for Physicists 2B - (03 34469), LI Quantum Mechanics 2 - (03 17273), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** The aim of this module is to give a thorough grounding in the principles of quantum mechanics. It builds on the wave mechanics studied in Years 1 and 2 where the wave nature of matter was introduced as described by the Schrodinger equation. In this module we begin with the fundamental postulates underlying quantum mechanics. We will introduce and consistently use Dirac's notations for doing quantum mechanics which will allow us to study quantum properties like "spin" which have no counterparts in classical physics. This is vital for applications of quantum mechanics such as quantum computing. We will also see how the Schrodinger equation originates. The module will cover fundamental aspects - such as quantum mechanical postulates - as well as applications and approximate, yet powerful, tools like perturbation theory for handling situations where exact results are not possible.

**Module Title:** Statistical Physics ***\*See note on front page***

**Module Code:** 01129

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Statistical Physics and Entropy - (03 17296), LI Quantum Mechanics 2 - (03 17273), Electromagnetism and Temperature and Matter - (03 19750)

**Module Description:** Statistical Mechanics is a fundamental bedrock of both classical and quantum physics. We cannot possibly hope to know all the details of what happens to all 10²³; atoms or molecules making up a sample of macroscopic size - and why should we try to garner so much information? Many of the measurable properties of the world outside us are really averages of microscopic events. The pressure of a gas on the walls of a container is made up of the impact of a vast number of collisions of individual molecules with the wall and we observe the average effect of these collisions as the pressure. In this module we shall study how such an averaging is carried out by means of both time averaging and ensemble averaging. Clearly there may be no point in calculating an average value to represent a typical value of a measurable physical quantity if fluctuations about that average are very large, and so we shall also study the fluctuations of the system about these averages and see how the fluctuations themselves can be important in determining measurable quantities such as specific heats. There are subtle differences between classical systems and those governed by the laws of quantum mechanics and this module will explore these differences and also discuss how the quantum statistics of the particles making up a macroscopic system influence the thermal properties of the system. Many applications of these ideas from condensed matter physics, astrophysics and radiation physics will be given. Finally, if time permits, we shall mention the phenomenon of Bose-Einstein condensation which lies beneath an understanding of superfluidity and superconductivity and which has only recently been realised experimentally in atom traps and has led to the award of the Nobel Prize to Wolfgang Ketterle, Carl Wieman and Eric Cornell in 2001.

**Module Title:** Medical Imaging ***\*See note on front page***

**Module Code:** 06203

**Semester:** 1

**Credits:** 10

**Level:** LH

**Module Description:** An introduction to the physical principles that underpin modern medical imaging modalities: Conventional X-ray radiography, including image intensifiers, digital radiography, computerised tomography. Radioisotope imaging using a gamma-camera, emission computed tomography, positron emission tomography. Ultrasonic imaging, including Doppler techniques. Magnetic resonance imaging.

**Module Title:** Fission and Fusion ***\*See note on front page***

**Module Code:** 01349

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites**: 03 17301 (LI Nuclear Physics and Neutrinos)

**Module Description:** Before looking in detail at the physics of nuclear power there will be a discussion of the role of nuclear power in today's energy market. The module then looks at the physics underpinning the production of electrical power by current fission reactors and proposed fusion reactors. It will introduce the basic nuclear physics of the processes of fission and fusion, putting this in the context of nuclear binding energies. By studying the processes of neutron production, moderation and absorption we will be able to derive a model for the neutron distribution in the core of a fission reactor and use this tocalculate conditions required to sustain a nuclear chain reaction. Control and safety of fission reactors will be examined as will a number of accidents. About a third of the module will be devoted to the study of emerging terrestrial fusion systems, which promise fewer of the radioactive waste products associated with fission reactors. The basic ideas of fusion reactions in plasmas will be discussed as well as current and future reactor designs.

**Module Title:** The Life and Death of Stars ***\*See note on front page***

**Module Code:** 21826

**Semester:** 1

**Credits:** 10

**Level:** LH

**Module Description:** This module is designed to deal with the essential elements of stellar evolution theory. It will consider the equations of stellar structure and their solutions, energy transport and energy generation in stars; equations of state and astrophysical opacities, and key stages of stellar evolution.The topics to be covered are: Introduction Modern methods for observation of Stars Virial Theorem and its Implications for Stellar Evolution Equations of Stellar Structure Hydrostatic Equilibrium Thermonuclear Energy Generation Energy and Transport by Radiation Energy and Transport by Convection Equations of State Solutions to the Equations of Stellar Structure Main Sequence Evolution and Red Giants Compact Objects.

**Module Title:** Scientific Computing Laboratory 1 ***\*See note on front page***

**Module Code:** 30964

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites:** Physics and Communication Skills 2 - (03 01149)

**Module Description:** The Y3 Scientific Computing Laboratory builds upon the computing skills acquired in Y1 and Y2. Students develop their expertise in computing through introductory exercises and then undertake a computational-physics project on an advanced physics topic. To achieve the highest marks, they must demonstrate a solid understanding of both the physics and the computing and execute their project with flare and initiative. The module is taught in a PC cluster for five hours per week using the teaching material provided on Canvas. N.B. Students who take both this module and Scientific Computing Laboratory 2 must attend a different computer lab in each module.

**Module Title:** LH Scientific Computing Laboratory 2 ***\*See note on front page***

**Module Code:** 30966

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites:** Physics and Communication Skills 2 - (03 01149)

**Module Description:** The Y3 Scientific Computing Laboratory builds upon the computing skills acquired in Y1 and Y2. Students develop their expertise in computing through introductory exercises and then undertake a computational-physics project on an advanced physics topic. To achieve the highest marks, they must demonstrate a solid understanding of both the physics and the computing and execute their project with flare and initiative. The module is taught in a PC cluster for five hours per week using the teaching material provided on Canvas. N.B. Theoretical Physics students taking this as a compulsory module must undertake a project in Numerical Modelling. Students who take both this module and Scientific Computing Laboratory 1 must attend a different computer lab in each module.

**Module Title:** Physical Principles of Radar ***\*See note on front page***

**Module Code:** 31150

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites**: LI Mathematics for Physicists 2A - (03 34465), LI Electromagnetism 2 - (03 00953), LI Mathematics for Physicists 2B - (03 34469), LI Statistical Physics and Entropy - (03 17296), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** This module will describe the physical principles of radar systems and their applications. There will be emphasis on the underlying concepts enabling the measurement of target parameters by means of radar with application to ranging, tracking, mapping, and navigation. Specifically, the principles of coherent echolocation, the radar equation, measurement of range, Doppler, range rate, the role of the radar waveform, methods for measuring target location, track smoothing, track estimation and imaging techniques will be introduced, contextualised by real world applications in each case.

**Module Title:** General Physics

**Module Code:** 07811

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** Quantum Mechanics and Optics and Waves - (03 19718), LC Classical Mechanics and Relativity 1 - (03 19748), Electromagnetism and Temperature and Matter - (03 19750)

**Module Description:** The purpose of this module is to improve skills in solving general problems which may come from any area of the undergraduate programme and are often related to 'real life' problems of the sort which students may have to deal with in the outside world. Successful solution of this sort of problem requires; (1) students learn to recognise what is the relevant area of physics, (ii) they have a secure knowledge of the base level physics in all relevant areas. This module is aimed at enhancing student ability in both these areas by a combination of non-assessed problem sheets, directed reading and whole class tutorials. There are 4 class tests which count towards the module mark.

**Module Title:** Biophysics ***\*See note on front page***

**Module Code:** 38944

**Semester:** 1

**Credits:** 10

**Level:** LH

**Module Description:** This module will provide a broad introduction to Biophysics, that is, how the theories and techniques from Physics can be applied to living, biological systems. We assume no prior knowledge of biology and so the module starts with a short introduction to biochemistry and cell biology. The module will then cover how biomolecules can be treated as machines, generating forces and consuming energy drawing on specific examples, for example how the cell skeleton allows cells to migrate. We will then analyse how biomolecules (enzymes) can regulate the chemical reactions that occur in cells and how these can be targeted by drugs, for example to treat disease. Finally, we will explore the electrical properties of nerve cells and how information is transmitted around the body. Along the way, we will learn the operation of key physical instruments used in the life-sciences, for example different types of microscopes and also touch on biological methods such as genetic engineering and cell culture.

**Module Title:** Chaos and Dynamical Systems

**Module Code:** 00607

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LC Mathematics for Physicists 1A - (03 34459), LC Mathematics for Physicists 1B - (03 34462)

**Module Description:** There are physical situations where to a very high accuracy energy is conserved. Examples are planetary (and asteroid) motion in the solar system and some aspects of charged particle motion in particle physics accelerators (before collisions occur!). Simple examples of such Hamiltonian systems are the focus of this module. This module provides an introduction to chaos and dynamical systems in conservative (or almost conservative) systems. Initially the module introduces the landscape of typical non-chaotic dynamical systems in two-dimensional phase-space: elliptic and hyperbolic fixed points, the separatrix, and limit cycles for weakly dissipative systems. Action-angle variables are introduced and tori are shown to be the natural higher dimensional objects for conservative systems. Separation and resonance of time scales forms the middle part of the module, where highly counter-intuitive phenomena are illustrated (pendula oscillating about their maximum of potential energy, for example). The nonlinear pendulum is used as the main example here and the origin of chaos is isolated as the separatrix. Finally maps are constructed which show the nature of chaos clearly: Lyapunov exponents showing the sensitivity to initial conditions; ergodicty and mixing illustrating the basis of equal a priori probabilities in statistical mechanics and the decay of correlations with time in physical variables.

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**Module Title:** Images and Communications

**Module Code:** 17302

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Mathematics for Physicists 2A - (03 34465), LI Mathematics for Physicists 2B - (03 34469), Quantum Mechanics and Optics and Waves - (03 19718), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** Most of us are familiar with the concept of digital image processing. The idea that the camera can never lie is no longer valid. Image processing can be performed directly on an optical image. This course is an introduction to coherent optical image processing through the medium of diffraction; together with an approach to imaging with non-coherent light. Fourier theory underlies much of the mathematics of the course. The second part of the course is concerned with fibre optic communications. A simple introduction using Maxwell's equations will be given to the performance of optical fibres and an overview of optical communications with fibre optics will be explored. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Radiation and Relativity

**Module Code:** 00971

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Mathematics for Physicists 2A - (03 34465), LI Electromagnetism 2 - (03 00953), LI Mathematics for Physicists 2B - (03 34469), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** This module is a first step to the summit of classical physics, the Theory of Relativity. The core of the course is a mathematical description of the physical structure of 'flat' spacetime based on Einstein's relativity principle and the invariance of the speed of light. A natural language for such a description is that of tensors which, being by itself very elegant and powerful, would be necessary in extending (in General Theory of Relativity in the 4th year) the relativity principle to 'curved' spacetime and thus the laws of gravitation. Combining the relativity principle with the invariance of electric charge and using a fully 'covariant' tensor description, the entire Maxwell's electrodynamics, including the emission of radiation, will be "derived" step by step from Gauss' electrostatics. Introduction: incompatibility of Maxwell's equations and Galileo's relativity principle; the Michelson-Morley and Trouton-Noble experiments; the absence of long-range interaction. Einstein's postulates: the principle of relativity and invariance of the speed of light. The invariance of the interval as a mathematic expression of Einstein's postulates. The Lorentz transformations between inertial frames as a consequence of this invariance. Relativistic invariance and covariance. Space-time in special relativity. 4-vectors and 4-tensors. The Minkowski metric and Minkowski space. Proper time. Spacelike and timelike intervals. The Minkowski diagram and world lines. Simple relativistic effects in the space-time description: the time dilation and the Lorentz-FitzGerald contraction. "Paradoxes" of relativity. Vectors and tensors in a metric space. Contra- and co-variant vectors and tensors and linear transformations of coordinates. Scalar invariants. Tensors contractions; Einstein's summation convention. Metric tensor and a distance between points; a scalar product of two vectors. Relativistic mechanics. Energy-momentum 4-vector. The equivalence of mass and energy. 4-forces. 4-momentum conservation law. Electrostatics and Lorentz invariance. Coulomb's law and the electrical Lorentz force. 4-potential and 4-current density; the continuity equation. The Lorentz transformation of an electrostatic field to a moving frame: magnetic fields must exist. Relativistic covariance and invariance of electric charge as the building blocks for electrodynamics. Fields transformations. Relations between electromagnetic fields and potentials. The electromagnetic field tensor. The Lorentz transformations rules for the electromagnetic field as a consequence of its tensor nature. The electromagnetic-field invariants. Homogeneous and inhomogeneous Maxwell's equations in standard and 4-vector form. The dual electromagnetic field tensor. Integral form of Maxwell's equations. Charges in electromagnetic fields. The Lorentz force in 3- and 4-vector form. Motion of an electric charge in uniform electric and magnetic fields. Energy and momentum of the electromagnetic field. Poynting vector. The energy-momentum tensor of the field. Conservation laws for the field. Constant electromagnetic fields. Electrostatic and "magnetostatic" energies of charges and currents. The field of a uniformly moving charge. Dipole and multipole electric and magnetic moments. Electromagnetic waves. Gauge invariance and gauge transformations. The wave equation. Plain and monochromatic plain waves. Doppler's effect. Electromagnetic radiation. (if there is time) The retarded potentials. The field of moving particles. Relativistically covariant Larmor's formula for the emission of radiation. Energy radiation in the nonrelativistic limit. Dipole radiation. Aims: To learn how to formulate and apply the laws of mechanics and electrodynamics in relativistically invariant four-tensor form. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Condensed Matter Physics

**Module Code:** 01123

**Semester:** 2

**Credits:** 10

**Level:** LH

**Module Description:** Condensed matter physics looks at the properties of solids and liquids. In this course, we look at the effects of atomic and electronic interactions on material properties, and see how these effects underpin many modern technologies. This requires the development of a number of physical concepts, based on waves, statistical physics, electromagnetism andquantum mechanics. A: Order and crystalsdifferent manifestations of order, the crystal lattice- position space, diffraction and the reciprocal lattice- momentum space. B: Lattice vibrationsvibrations of a linear chain (ball and spring model), optical and acoustic phonon modes, Debye model for heat capacity in solids. C: Quantum mechanics of electrons in solidsfree electron states, electrons and the crystal lattice, electron bands; why some materials conduct and others insulate. D: Semiconductor behaviour and applicationscarriers in semiconductors - origins and descriptions, carrier motion: mobility, diffusion, semiconductor devices and applications. E: Magnetismtypes of magnetic order; the Weiss model, magnetism in metals; Pauli paramagnetism, magnetic exchange. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Current Topics in Theoretical Physics

**Module Code:** 07813

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Lagrangian and Hamiltonian Mechanics - (03 00539), Complex Variable Theory - (06 18779), LH Quantum Mechanics 3 - (03 00498)

**Module Description:** The module has two distinct aspects. First, in a set of lectures and problem solving classes, we develop knowledge and skills over a range of methods of complex analysis used in theoretical physics. This includes integration in the complex plane, analytical continuation, Green functions methods and using complex variables to derive and study special functions. This part of the module is assessed via five assessed problem sheets. Then in parallel, staff will give a series of seminars on the results of recent research. In recent years this has covered topics such as gauge theories, monopoles, quantum computing and quantum vortices. Students are then asked to develop understanding on a topic related to one of the seminars via directed reading. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Particle Physics

**Module Code:** 19780

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Quantum Mechanics 2 - (03 17273)

**Module Description:** At the most fundamental level, all matter is made from twelve types of elementary fermions (quarks and leptons) and all forces are due to the exchange of elementary bosons (photons, W, Z, gluons). The sub-nuclear world can be explained in a remarkably simple way, known as the Standard Model of Particle Physics. This module introduces the most important ideas from this Standard Model. We will also discuss some of the experimental evidence that supports the Standard Model, notably that resulting from the Large Electron Positron (LEP) Collider at CERN. Topics covered will include the classification of particles and the quark model, quark flavours and colours, quantum chromodynamics and gluons, strong and weak decays, conservation rules, parity and change-conjugation, charmonium, electroweakinteractions and the Higgs particle. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Nuclear Physics

**Module Code:** 21462

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Quantum Mechanics 2 - (03 17273), Nuclear Physics and Neutrinos - (03 17301)

**Module Description:** The nucleus is a collection of neutrons and protons, what else is there to know? Well, perhaps surprisingly, we still do not have a detailed description of the force that binds the nucleus, and we still don't know how the nature and properties of the quarks and gluons within the nucleons influence their interactions. Fundamental questions you might think, and indeed this remains one of the major areas of research in Nuclear Physics. In this module you will discover what we do know about the details of the nuclear force, the strong interaction, and the models which presently employ this force to calculate the properties of light nuclei. This approach cannot yet be extended to heavier nuclei and mean-field theories are required, a particular focus will be the nuclear shell model; the evidence for nuclear shells and the predictive capability of the shell model. The module will use the vehicle of three classes of decay to examine the theory and experimental manifestations of the strong, weak and electromagnetic forces within the nucleus, namely alpha, beta and gamma decay. These processes will also be used to illustrate present areas of contemporary nuclear physics research.

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**Module Title:** Atomic Physics

**Module Code:** 23559

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** LI Mathematics for Physicists 2A - (03 34465), LI Mathematics for Physicists 2B - (03 34469), LI Quantum Mechanics 2 - (03 17273), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** Quantum mechanics was discovered and built in great part by observing how light interacts with matter, in particular with atoms. This has led to the& understanding of the structure of the atom. Today, this knowledge is used to manipulate atoms with laser light, leading to the new field of ultracold atom physics and its applications. The course will use multiple approaches - classical mechanics, thermodynamics, quantum physics - to build the concepts essential to the understanding of modern experiments in atomic physics. It will apply many of the concepts and techniques developed in Quantum Mechanics 3. In particular, it will focus on the following aspects: Spectral decomposition of radiation, finite line width mechanisms, mechanical action of light; Electronic structure of atom, many electron effects, relativistic effects; Quantum theory of light-atom interaction, forbidden transitions, atoms in magnetic fields. Using all these tools and concepts, we will see how one can use lasers to cool a gas of atoms down to 100 microkelvins, and how one can trap these atoms in a magnetic bottle and further cool them down by 'evaporating' them. We will also see how these ultracold atoms can make a clock which won't lose a second in 100 million years! \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Evolution of Cosmic Structure

**Module Code:** 24347

**Semester:** 2

**Credits:** 10

**Level:** LH

**Pre-requisites:** Observational Cosmology - (03 00716)

**Module Description:** The Universe today displays a hierarchy of structures: stars are gathered into galaxies, which are mostly grouped into clusters of varying sizes. These in turn are arranged along cosmic filaments, surrounding large voids. This rich structure is believed to have developed from the small fluctuations in density which we see imprinted on the cosmic microwave background under the driving force of gravity, acting primarily on the dark matter which dominates the mass budget of the Universe. In this course we will study the way in which these structures develop, and the nature of the characteristic objects which emerge. Galaxies and clusters display many scaling relations which give clues to the processes whichformed them. Finally, we will look at the way the observed properties and distribution of these structures can be used to draw conclusions about the fundamental properties of the Universe as a whole, and about its evolution. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Thermal Hydraulics and Reactor Engineering

**Module Code:** 25895

**Semester:** 2

**Credits:** 10

**Level:** LH

**Module Description:** The module designed to equip students with a detailed understanding of thermal processes inside a nuclear reactor. The course covers the following aspects; Heat transfer by conduction, application to fuel elements. Heat transfer by forced convection, empirical correlations, dimensional analysis. Application to gas cooled reactors, maximum can temperature in channel, improvement by finning and by roughening can surface. Flow of compressible fluid with frictionlosses, pressure drop and pumping power. Thermohydraulic design of core, hotspot factors, gagging, significance of pumping power in gas cooled reactors, criteria for fuel element performance, choice of coolant. Boiling heat transfer, burnout, critical heat flux ratio. Two-phase flow, pressure drop correlations. Liquid metal heat transfer, application to sodium-cooled fast reactors. Pressure vessels, analysis of thick walled steel vessels, prestressed concrete vessels.Boilers, use of temperature-enthalpy diagram. Steam cycles, thermodynamic limitations on efficiency, Mollier diagram, wetness problems, superheat, reheat and feed heating. Safety studies by case history e.g. analysis of can temperature rise and duration of typical depressurisation accident.

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**Module Title:** Exoplanets

**Module Code:** 37605

**Semester:** 2

**Credits:** 10

**Level:** LH

**Module Description:** Exoplanets are planets that orbit stars other than the Sun. The first exoplanets were discovered in the 1990s. Since then, thousands of new worlds have been identified, rewriting our understanding of Earth’s position of the Cosmos, forcing a re-evaluation of planet formation processes, and kick-starting the search for evidence of biology beyond the Solar System. Thanks to a number of large observational campaigns using ground and space-based observatories, and rapid theoretical developments, exoplanetary research is one of the most exciting and fastest growing topics in astrophysics, and one where the Birmingham is very active.

This module brings together these recent results. We shall explore detection techniques for exoplanets, the structures and properties of exoplanets, the formation, evolution and dynamics of exoplanet systems, and the underlying planet population in our Galaxy.

**Module Title:** Observational Cosmology ***\*See note on front page***

**Module Code:** 00716

**Semester:** 1

**Credits:** 10

**Level:** LH

**Pre-requisites:** It is preferable, but not essential, to have gained credit in 03 17481 LC Introduction to Astronomy and 03 00554 LI Structure in the Universe as prerequisites

**Module Description:** Observations over the past decade seem to have established that the Universe is very peculiar indeed. On the one hand, it seems that the amount of mass-energy it contains is very close to the critical amount required to make space flat. On the other hand, it appears that only 4% of this matter is the normal matter with which we are familiar. The rest is 'dark matter' (around 30%) which clusters around galaxies, but whose form is unknown, or dark energy (about 70%) which is again very poorly understood, and affects the expansion of the Universe on the very largest scales, driving an accelerating expansion which will eventually make the Universe a very large and lonely place. In this module we will examine the evidence for these strange results. The basic equations which govern the dynamics and curvature of the Universe will be derived, using a Newtonian approximation. These equations will then be applied to interpret observations, and we will discover how the observed properties of distant objects are affected by the geometry and expansion of the Universe. The evidence for the Hot Big Bang and for dark matter, will be reviewed, and we will chart the way in which the Universe has developed through various evolutionary stages, starting from a very uniform initial state, and leading to the structures we observe today.

# Year 4 Modules (LM)

**Module Title:** Exoplanets

**Module Code:** 37604

**Semester:** 2

**Credits:** 10

**Level:** LM

**Module Description:** Exoplanets are planets that orbit stars other than the Sun. The first exoplanets were discovered in the 1990s. Since then, thousands of new worlds have been identified, rewriting our understanding of Earth’s position of the Cosmos, forcing a re-evaluation of planet formation processes, and kick-starting the search for evidence of biology beyond the Solar System. Thanks to a number of large observational campaigns using ground and space-based observatories, and rapid theoretical developments, exoplanetary research is one of the most exciting and fastest growing topics in astrophysics, and one where the Birmingham is very active.

This module brings together these recent results. We shall explore detection techniques for exoplanets, the structures and properties of exoplanets, the formation, evolution and dynamics of exoplanet systems, and the underlying planet population in our Galaxy.

**Module Title:** Advanced Condensed Matter Physics

**Module Code:** 30026

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Mathematics for Physicists 2A - (03 34465), LI Mathematics for Physicists 2B - (03 34469), LI Quantum Mechanics 2 - (03 17273), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** The course aims to introduce Y4 students to a broad range of advanced subjects in Condensed Matter Physics. In the first part of the course, the students will learn in depth about theoretical and experimental approaches used to investigate the optical properties of the condensed matter. The students will be taught about optical response of semiconducting and superconducting materials in the bulk form and when their dimensionality is reduced to 2D and 1D. In the second part of the course, the students will learn about Quantum Hall observed in 2D electronic systems at low temperature and its fundamental importance in quantum electrodynamics. The course also provides background for understanding of the surface states which will be preceded by the presentation of Anderson localisation model. Finally, the course provides an introduction to the new topic of topology in condensed matter. Overall, the course will be kept simple and useful for students with very different backgrounds and motivation.

**Module Title:** The General Theory of Relativity ***\*See note on front page***

**Module Code:** 00563

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites**: [Radiation and Relativity - (03 00971)](https://program-and-modules-handbook.bham.ac.uk/webhandbooks/WebHandbooks-control-servlet?Action=getModuleDetailsList&pgSubj=03&pgCrse=00971&searchTerm=002023)

**Module Description:** The General Theory of Relativity is a major landmark in the development of classical Theoretical Physics. In 1905, Einstein presented his Special Theory of Relativity which we understand to be a theory of the relation between space and time in inertial frames of reference, which are in uniform relative motion with respect to each other with a constant velocity. The requirement that the laws of Physics be the same in all inertial frames leads to the idea that mass is a frame dependent quantity, and hence to a modification of Newton's Laws to take into account the new relations between the space and time coordinates of two inertial frames. In a strict sense it does not deal with accelerations. The General Theory appeared some ten years later in 1915 and represents not only a theory which describes frames of reference in arbitrary motion with respect to each other, but also a theory of gravitation. When two frames of reference are indeed in uniform (unaccelerated) relative motion, it is required that the relations between two such frames of reference become those of the Special Theory. The Special Theory can be thought of as a theory of a flat four dimensional space-time. The General Theory requires that the four dimensional space time be curved, with a curvature determined by any matter which is present: we then experience this curvature as gravity. The analogue in the Newtonian view of physics, is the calculation of potential and fields from mass distributions by using Poisson's equation. In General Relativity objects experiencing gravitational forces are now required to move along optimal paths, called geodesics, in this curved space-time. In this new geometrical way of looking at things, the requirement that motion occurs along an optimal path, takes the place of Newton's second law. In this course we will begin by examining the physical basis of the ideas lying behind General Relativity. These ideas are encapsulated in the Principle of Equivalence. We then need to develop the mathematics of tensor analysis in a curved space-time in order to be able to make accurate statements about the physical and geometrical ideas which lie behind the General Theory and from which predictions can be made. We then use the theory to predict phenomena such as the bending of light near massive objects, the precession of the perihelion of a planet and the gravitational redshift. These latter phenomena provided early experimental tests of the General Theory (tests which have been refined with time) and attracted much public attention at the time. The course then concludes by looking at the cosmological consequences of the General Theory and introduces the idea of Black Holes. The General Theory of Relativity contains very profound physical ideas which are expressed through an elegant geometric structure. Its understanding requires high level skills in handling tensors and differential equations. This beautiful theory is part of the mainstream of physics. In 1932 Dirac married together the Special Theory of Relativity with Quantum Mechanics, but to this day there is no accepted theory of quantum gravity.

**Module Title:** Quantum Mechanics 4 ***\*See note on front page***

**Module Code:** 00672

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Mathematics for Physicists 2A - (03 34465), LI Mathematics for Physicists 2B - (03 34469), LI Differential Equations - (06 25670), LH Quantum Mechanics 3 - (03 00498), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** In this module we begin the task of marrying quantum mechanics with the other foundation stone of modern physics - special relativity. The tests of this theory have come from high energy particle scattering experiments but the implications are apparent even at low energies. We first include magnetic fields into quantum systems via minimal coupling. We then develop an armoury of tools to obtain approximate solutions. We use semiclassical methods (WKB), the variational approach and finally perturbation theory. We apply perturbation theory to both time-dependent and time-independent problems. This naturally leads to ideas of scattering theory where we develop the Born approximation and then the partial wave analysis. Finally we extend the Schrodinger equation to include special relativity via the Klein-Gordon and ultimately the Dirac equation. This leads to the notion of antiparticles and spin. The true understanding of these equations is only made apparent in quantum field theory which is a natural follow up for this module.

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**Module Title:** Fission and Fusion ***\*See note on front page***

**Module Code:** 14991

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites**: 03 17301 (LI Nuclear Physics and Neutrinos)

**Module Description:** Before looking in detail at the physics of nuclear power there will be a discussion of the role of nuclear power in today's energy market. The module then studies the physics underpinning the production of electrical power by fission and proposed fusion reactors, illustrates the interaction between physics design and engineering constraint, and puts the generation of nuclear power into an economic perspective. By studying the processes of neutron production, moderation and absorption we will be able to derive a model for the neutron distribution in the core of a fission reactor and use this to calculate conditions required to sustain a nuclear chain reaction. Control and safety of fission reactors will be examined as will a number of accidents. About a quarter of the module will be devoted to the study of emerging terrestrial fusion systems, which promise fewer of the radioactive waste products associated with fission reactors. The basic ideas of fusion reactions in plasmas will be discussed as well as current and future reactor design.

**Module Title:** Ultracold Atoms and Quantum Gases ***\*See note on front page***

**Module Code:** 30033

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites**: 03 23559 LH Atomic Physics is strongly advised. 03 00498 LH Quantum Mechanics 3 is also advised

**Module Description:** At temperatures close to absolute zero, classical mechanics ceases to be valid and the motion of particles is solely governed by the laws of quantum mechanics, which even allow matter to exhibit a wave-particle duality. To access the ultracold realm tremendous progress has been made in the last three decades and nowadays the field of cold and ultracold atoms is one of the most flourishing in physics. Striking results such as the Bose-Einstein condensation and the superfluid-Mott insulator transition have been achieved, promoting exciting applications particularly in the fields of quantum simulation, quantum computation and sensing. Due to their extraordinary properties, cold atoms systems are also at the core of the emerging quantum technologies, which are attracting huge national and international interest. This module reviews the key concepts and techniques in modern cold and ultracold atoms physics, and also presents research highlights, with a particular focus on the topics in which the School is active. We will see how laser light can be used to cool and trap atoms and how, with the help of magnetic or dipole traps, it is possible to achieve the lowest temperatures in the Universe, just a few billionths of a degree above absolute zero. We will study the extraordinary properties of quantum gases including Bose-Einstein condensates and Fermi degenerate gases. Finally, we will see how ultracold atoms are being used to develop next-generation technologies. The topics covered include: basic elements of light-matter interaction; laser cooling and trapping of neutral atoms; magneto-optical trapping; evaporative cooling; quantum degeneracy: the Bose-Einstein condensate and the Fermi gas; superfluidity of Bose-Einstein condensates; optical lattices; quantum technology: atom clocks, atom interferometry, cavity quantum electrodynamics. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Module Title:** Experimental Particle Physics Techniques ***\*See note on front page***

**Module Code:** 17306

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites**: Particle Physics - (03 19780)

**Module Description:** There are several courses available in Birmingham concerned with our knowledge of the microscopic world through our understanding of particle physics, its laws and theories. However, it is rarely a simple matter to relate these theories to experimental work in the real world. In this module, we investigate how we know what we know, and how we might go about extending our knowledge further. This module gives an introduction to aspects of experimentation in particle physics as currently used in the field. How do you design a detector to look at the products of the collisions of accelerated particles? How do the individual detector components work and how is the essential detector information from the interesting events sifted from amongst the huge data volumes produced? What measurements and observations would you make with the data obtained? How do you relate these observables to the theoretical ideas that you are trying to test? How can statistical analysis be used to determine the significance of your result and how would you assess whether systematic effects are obscuring the real physics? Together with the more theoretical courses available, this module provides a good background for a Year 4 Project or a PhD in particle physics.

**Module Title:** Superconductivity ***\*See note on front page***

**Module Code:** 17307

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites:** Quantum Mechanics and Optics and Waves - (03 19718), LI Statistical Physics and Entropy - (03 17296), Electromagnetism and Temperature and Matter - (03 19750)

**Module Description:** Around half the metallic elements (and many compounds) become superconducting at sufficiently low temperatures. This should not be a surprise - one expects their electrons to adopt an orderly arrangement at low temperatures, and as this module will show, one such possibility is the superconducting state. I shall discuss the observed phenomena of superconductivity, including zero resistance, perfect diamagnetism, lack of entropy, and electron interference effects. These will be used to support the macroscopic theoretical understanding of superconductivity, and will lead to a description of key elements of the BCS microscopic theory of superconductivity. As well as discussing features of superconductors that are important in applications, such as high-field electromagnets, radio-frequency filters, SQUID magnetometers and superconducting electronics, I shall describe some important experiments in superconductivity research, several of which have been performed in Birmingham.

**Module Title:** Current Topics in Particle Physics ***\*See note on front page***

**Module Code:** 17305

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites**: LI Quantum Mechanics 2 - (03 17273), Particle Physics - (03 19780)

**Module Description:** Particle physics is fascinating for its ability to help explain the Universe, starting from a small set of fundamental building blocks and the laws of their interactions. The course gives the chance to study in some depth the current theoretical framework and to examine the latest experimental results in the field of paricle physics.The theoretical framework that describes the interactions of elementary particles is outlined, making the connection with perturbation theory in quantum mechanics. A range of current particle physics experiments are discussed, which make use of this framework to study the known particles, and to seek for new physics beyond the Standard Model. The choice of experiments develops from one year to the next, following the most important current developments in the field. The course begins by discussing the formalism of scattering processes, cross-sections and phase space. The key role of Feynman diagrams is stressed, and illustrated with examples from QED. The weak interaction is looked at in depth, considering both quark and neutrino mixing matrices, and their very different phenomenological manifestations. This leads into a discussion of electroweak unification and how predictions of the Z boson properties arise, as well as an introduction to the Higgs mechanism. The strong interaction has been discussed in an earlier course: in this module the theory of QCD is re-considered in the light of the different renormalisation behaviour resulting from the gluon self-coupling - this leads on to a review of hadronic scattering descriptions using parton densities.

**Module Title:** Observational Cosmology ***\*See note on front page***

**Module Code:** 19915

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Structure in the Universe - (03 00554), LC Introduction to Astrophysics - (03 20521)

**Module Description:** Observations over the past decade seem to have established that the Universe is very peculiar indeed. On the one hand, it seems that the amount of mass-energy it contains is very close to the critical amount required to make space flat. On the other hand, it appears that only 4% of this matter is the normal matter with which we are familiar. The rest is "dark matter" (around 30%) which clusters around galaxies, but whose form is unknown, or dark energy (about 70%) which is again very poorly understood, and affects the expansion of the Universe on the very largest scales, driving an accelerating expansion which will eventually make the Universe a very large and lonely place. In this module we will examine the evidence for these strange results. The basic equations which govern the dynamics and curvature of the Universe will be derived, using a Newtonian approximation. These equations will then be applied to interpret observations, and we will discover how the observed properties of distant objects are affected by the geometry and expansion of the Universe. The evidence for the Hot Big Bang and for dark matter, will be reviewed, and we will chart the way in which the Universe has developed through various evolutionary stages, starting from a very uniform initial state, and leading to the structures we observe today.

**Module Title:** Phase Transitions ***\*See note on front page***

**Module Code:** 21283

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Mathematics for Physicists 2A - (03 34465), LH Statistical Physics - (03 01129), LI Mathematics for Physicists 2B - (03 34469), LI Differential Equations - (06 25670), LI Multivariable & Vector Analysis - (06 25667)

**Module Description:** Statistical mechanics provides the framework for understanding systems with macroscopically large numbers of particles (degrees of freedom). The key is a statistical, probabilistic description of macroscopic systems in terms of only a few parameters. Of particular interest are situations where an infinitesimal change in one of these parameters (e.g., temperature, magnetic field, number of defects, etc) results in a phase transition between different states of matter (phases) - liquid and gaseous, para- and ferromagnetic, conducting and superconducting, metallic and insulating, etc. In this course we will focus at the continuous phase transitions where 'most visible' properties of matter - density, magnetisation, conductivity, etc, exhibit no abrupt changes. On the contrary, their derivatives (compressibility, susceptibility, heat capacity, etc) are discontinuous or divergent at a certain critical point. The characteristic features of critical phenomena in the vicinity of the critical point are their scale invariance and universality. The scale invariance (related to fractal geometry of the critical state) allows us to characterise critical phenomena by a small number of mutually related critical exponents. Universality means the existence of wide classes of very different physical systems exhibiting identical critical behaviour and, in particular, having the same critical exponents. Critical phenomena are ubiquitous in nature, from transitions between different phases of matter to self-organised criticality to biological evolution to financial markets to- most probably - the Big Bang that was at the origin of everything. We will focus mostly on those firmly based on the Gibbs distribution (which is the underlying principle of statistical physics) but also consider percolating systems - a simpler class of scale-invariant system exhibiting critical behaviour.

**Module Title:** Inference from Scientific Data ***\*See note on front page***

**Module Code:** 23560

**Semester:** 1

**Credits:** 10

**Level:** LM

**Module Description:** Data is precious, and the aims of any good observer or experimentalist should be to make best use of it. To do this requires an understanding of statistics. Most undergraduates regard statistics as a boring necessity. This is entirely understandable, since it is often introduced into undergraduate laboratories in the form of a set of rules which must be followed to calculate and propagate errors. In fact there is much more to the subject than this. Much of the scientific enterprise can be regarded as one of making comparisons between models of reality and the data with which they are tested. Moreover the area is the subject of a lively debate between two schools of thought - Bayesians and frequentists - who disagree about the whole role of probability in the analysis of data. Once one understands this, the subject becomes much more interesting. The main aim of the course is to give you the beginnings of such an understanding, and to help you to apply the tools of statistical analysis in your own research problems. Although the techniques introduced are entirely general, they will be illustrated using examples drawn mostly from the lecturer's own field: astronomy. The course is assessed via a variety of practical analysis exercises which are also mostly astronomical in nature. Some interest and experience in astronomy would therefore help you to connect with these examples.

**Module Title:** Nanophotonics ***\*See note on front page***

**Module Code:** 28571

**Semester:** 1

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Electromagnetism 2 - (03 00953)

**Module Description:** Nowadays, to cope with the ever-growing technological developments in optical integrated circuits, sensing and imaging in the area of optics, it becomes essential for us to understand the optical properties of structured photonic materials, which can range from a simple distributed Bragg reflector, a two or three dimensional photonic crystal to a metamaterial made of artificial atoms. This course will start with a brief introduction on the history and the current developments of structured photonic materials. Then, the course will move to the basic concepts, such as photonic band structures and effective media to describe photonic crystals and metamaterials. In this module, the students will also learn some basic numerical techniques in understanding the optical properties of structured materials, including band structure calculation, transfer matrix method and finite element analysis. To the end, the students will be able to apply these techniques to design structured materials with specific requirements, with focused applications on getting a complete photonic band gap, a negative refractive index and a superlens.

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**Module Title:** Relativistic Astrophysics

**Module Code:** 30682

**Semester:** 2

**Credits:** 10

**Level:** LM

**Module Description:** White dwarfs, neutron stars, black holes and the early universe represent the most extreme environments in nature, where quantum mechanics meets general relativity. By the end of the module students should be able to:

* Have a firm grasp of the evolutionary fate of massive stars, including degenerate stars (white dwarfs and neutron stars) and the Chandrasekhar mass.
* Derive the key properties of accretion onto neutron stars and black holes, including the Eddington limit.
* Have a firm understanding of pulsar physics.
* Derive the key properties of tidal disruption events.
* Derive the emission of gravitational waves from binary systems and have a firm grasp of the detectability of gravitational-wave signals.
* Have a firm grasp of the tests of general relativity on all scales (e.g., binary pulsars, gravitational waves).
* Have a firm grounding in the physics of cosmic explosions: supernovae, kilonovae, gamma ray bursts and derive the salient features of their timescales and energetics.
* Have a firm grounding in the concept of cosmic backgrounds.

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**Module Title:** Nuclear Physics

**Module Code:** 01087

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Particles and Nuclei & A Quantum Approach to Solids - (03 26017)

**Module Description:** The nucleus is a collection of neutrons and protons, what else is there to know? Well, perhaps surprisingly, we still do not have a detailed description of the force that binds the nucleus, and we still don't know how the nature and properties of the quarks and gluons within the nucleons influence their interactions. Fundamental questions you might think, and indeed this remains one of the major areas of research in Nuclear Physics. In this module you will discover what we do know about the details of the nuclear force, the strong interaction, and the models which presently employ this force to calculate the properties of light nuclei. This approach cannot yet be extended to heavier nuclei and mean-field theories are required, a particular focus will be the nuclear shell model; the evidence for nuclear shells and the predictive capability of the shell model. The module will use the vehicle of three classes of decay to examine the theory and experimental manifestations of the strong, weak and electromagnetic forces within the nucleus, namely alpha, beta and gamma decay. These processes will also be used to illustrate present areas of contemporary nuclear physics research.

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**Module Title:** Many Particle and Quantum Field Theory

**Module Code:** 01114

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites:** LI Lagrangian and Hamiltonian Mechanics - (03 00539), Quantum Mechanics 4 - (03 00672), LH Quantum Mechanics 3 - (03 00498)

**Module Description:** Quantum Field Theory is the most complete description we have at present of the physical world. One starts with a classical field theory written in Lagrangian form, and then quantises the classical fields to obtain field operators. If one then expands these field operators as a sum over momentum states, the Fourier coefficients are the creation and annihilation operators for corresponding particles. We carry out this canonical quantization for non-interacting spin-0 (Klein-Gordon), spin-1/2 (Dirac), and spin-1 (electromagnetic and Proca) fields. The problem of negative energy states arising in one-particle relativistic wave equations is solved in QFT; they correspond to the absence of positive energy antiparticles. Finally we write down the Lagrangian for quantum electrodynamics (QED) and start the development of perturbation theory via the S-matrix expansion. Many Particle Theory considers the properties of systems with many interacting particles, such as the electron liquid in a metal. The quantum mechanical properties of such systems can in principle be obtained by solving a large Schrodinger equation, but this is not mathematically tractable. The trick is to rewrite the problem in second quantised form using the creation and annihilation operators familiar from QFT. We apply these ideas to various condensed matter systems: superfluids, superconductors, correlated systems, ferromagnets and antiferromagnets.

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**Module Title:** Quantum Optics

**Module Code:** 24318

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites:** LH Quantum Mechanics 3 - (03 00498)

**Module Description:** Quantum optics is the study of the particle nature of light, in the form of photons. Despite the ubiquity of electromagnetic fields, truly quantum behaviour is rare to observe and often subtle to describe. In fact some of the purest quantum optical effects arise from quantum fluctuations in the electromagnetic vacuum, which is classically a trivial, empty state of the field. In the decades since the advent of lasers and nonlinear optics, the study of quantum optics has become important both technologically and in terms of our fundamental understanding of quantum mechanics and light-matter interactions. Topics covered in this course include: quantisation of the EM field; quantum states of light (vacuum state, number states, coherent states, thermal states); squeezing and entanglement; photon statistics and coherence functions; quantum descriptions of instruments and detectors; quantum interference and which-way information; light-matter interactions; nonlinear quantum optics.

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**Module Title:** Evolution of Cosmic Structure

**Module Code:** 24348

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites:** Observational Cosmology - (03 00716)

**Module Description:** The Universe today displays a hierarchy of structures: stars are gathered into galaxies, which are mostly grouped into clusters of varying sizes. These in turn are arranged along cosmic filaments, surrounding large voids. This rich structure is believed to have developed from the small fluctuations in density which we see imprinted on the cosmic microwave background under the driving force of gravity, acting primarily on the dark matter which dominates the mass budget of the Universe. In this course we will study the way in which these structures develop, and the nature of the characteristic objects which emerge. Galaxies and clusters display many scaling relations which give clues to the processes which formed them. Finally, we will look at the way the observed properties and distribution of these structures can be used to draw conclusions about the fundamental properties of the Universe as a whole, and about its evolution.

**Module Title:** Condensed Matter Physics

**Module Code:** 21655

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites**: 03 17301 (LI Nuclear Physics and Neutrinos)

**Module Description:** While much of the physics you have studied to date has been about taking things apart to find the fundamental laws and particles that underpin the universe, condensed matter physics is about putting matter back together again. A key theme will be the idea of the emergence - that to understand complex matter we need to understand the elementary excitations and these are usually different from the bare ingredients of solids (atoms with their associated electrons and nuclei). Emergent excitations include phonons as quantized lattice vibrations and the electron quasiparticle in the metallic state. The course will build on ideas covered in year two and apply many of the concepts of quantum mechanics and statistical physics in year 3. We will be particularly concerned with the affect of periodicity on the properties of waves in crystals (which, by virtue of wave-particle duality, will govern particles too). We will see how to use these properties to measure structure (via scattering experiments), to understand the process of transport in metals, to control properties (via semiconductor doping) and to see the role of Coulomb repulsion and Pauli exclusion in generating magnetism.

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**Module Title:** Physics of Renewable Energy

**Module Code:** 39189

**Semester:** 2

**Credits:** 10

**Level:** LM

**Pre-requisites**: none

**Module Description:** Starting with a review of energy usage, this module complements the module Fission and Fusion, discussing non-nuclear energy generation. Both renewable and current non-renewable methods of energy generation will be considered but the module will have more of an emphasis on renewable generation. Finally, the transmission and storage of electrical energy will be described.