AS3013 Computational Astrophysics

SCOTCAT Credits:	15	SCQF level 9	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

The aim of this module is to introduce students to computational methods in astrophysics. Based on a general introduction to the programming language Fortran-90, students are shown how to apply simple numerical algorithms to calculate integrals, iteratively find the roots of non-linear equations, solve systems of ordinary differential equations, and to develop tools for statistical data analysis. Further emphasis is put on the development of skills to make convincing plots from the calculated data. The practical exercises include applications to the initial mass function in star formation, the calculation of orbits for N-body gravitational problems and in mean galactic potentials, and planet transition light-curves. Students gain experience with the basics of numerical accuracy, and the development of problem-solving algorithms in general.

Pre-requisite(s):	Before taking this module you must pass PH2011 and pass PH2012 and pass MT2501 and pass MT2503	
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 3.5-hour supervised or taught sessions (x 10 weeks). Mostly hands-on guided work on computers, but with occasional presentation.	
	Scheduled learning: 77 hours	**Guided independent study:** 73 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 0%, Coursework = 100%	
	As used by St Andrews: Coursework (practical work, the submission of computer code and computational solutions to given problems) = 100%	
Re-assessment pattern:	No Re-assessment available - laboratory based	
Module coordinator:	Dr P Woitke	
Additional information from Schools:	To be confirmed	

AS4010 Extragalactic Astronomy

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				

This module introduces the basic elements of extragalactic astronomy. This includes the morphological, structural and spectral properties of elliptical, spiral, quiescent and star-forming galaxies. We study how galaxy populations change from the distant galaxies in the early Universe into those observed in our local neighbourhood, including the coincident growth of super massive black holes at the centres of massive galaxies. Galaxy formation theory is introduced in relation to the growth of structure in a cold-dark matter Universe, and galaxy evolution in regions of high and low density is investigated. The module includes a look at modern instrumentation used in extragalactic astrophysics. Specialist lecturers from within the galaxy evolution research group will provide a direct link between material learnt in lectures and research currently being undertaken at the University of St Andrews. Students will engage in an assessed mini research project throughout the semester (computer based, in Python).

Pre-requisite(s):	Before taking this module you must (pass AS2001 or pass AS2101) and pass PH2011 and pass PH2012 and pass MT2501 and pass MT2503
Anti-requisite(s)	You cannot take this module if you take AS4022
Learning and teaching methods of delivery:	**Weekly contact**: 1 or 2 x 1hr lectures x 10 weeks, 1 hr tutorial x 6 weeks, 1hr seminar x 3 weeks, 1hr computational hack session x 4 weeks

	Scheduled learning: 29 hours	**Guided independent study:** 121 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 80%, Practical Examinations = 0%, Coursework = 20%	
	As used by St Andrews: 2-hour Written Examination = 80%, continual assessment (Computer Based Assignment) = 20%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr R M Fernandes Tojeiro Reynolds	
Additional information from Schools:	**AS4010 - Extragalactic Astronomy** **Aims & Objectives** To be able to appreciate the various aspects of galaxy formation and evolution, and apply them to outcomes of modern extragalactic research activities. **Learning Outcomes** • be able to obtain galaxy properties from observational evidence • be able to describe the differences in galaxy populations and properties over the course of the Universe in terms of galaxy evolution • be able to describe the formation of galaxies in terms of observational cosmology • be able to apply basic physical principles to galaxy evolution and formation processes • be able to apply material covered in the lectures to current research activities in extragalactic astrophysics **Synopsis** Galaxy Observations: Spectral Energy Distributions and Star Formation Histories Galaxy Observations: Scaling Laws and Dynamics Observational Cosmology Galaxy Formation and Evolution Supermassive Black Holes and Active Galactic Nuclei **Additional information on continuous assessment etc.** Coursework involves a computational exercise based in Python (20%). **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4010.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.	

AS4011 The Physics of Nebulae and Stars 1

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				

This module introduces the physics of astrophysical plasmas, as found in stars and interstellar space, where interactions between matter and radiation play a dominant role. A variety of absorption, emission, and scattering processes are introduced to describe exchanges of energy and momentum, which link up in various contexts to control the state and motion of the matter, to regulate the flow of light through the matter, and to impress fingerprints on the emergent spectrum. The theory is developed in sufficient detail to illustrate how astronomers interpret observed spectra to infer physical properties of astrophysical plasmas. Applications are considered to photo-ionise nebulae, interstellar shocks, nova and supernova shells, accretion discs, quasar-absorption-line clouds, radio synchrotron jets, radio pulsars, and x-ray plasmas. Monte-Carlo computational techniques are introduced to model radiative transfer.

Pre-requisite(s):	Before taking this module you must (pass AS2001 or pass AS2101) and pass PH2011 and pass PH2012 and (pass MT2001 or pass MT2501 and pass MT2503) and pass PH3081 or pass PH3082 or pass MT2003 or (pass MT2506 and pass MT2507)	
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 10 weeks	
	Scheduled learning: 30 hours	**Guided independent study:** 120 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 75%, Practical Examinations = 0%, Coursework = 25%	
	As used by St Andrews: 2-hour Written Examination = 75%, Coursework = 25%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr K Wood	

Additional information from Schools:

AS4011 - The Physics of Nebulae and Stars 1

Overview

The gas that lies between the stars takes many forms. From the dense, cold molecular clouds in which stars are conceived to the rarefied ionized plasma of HII regions, escaping photons carry information about their nature to distant parts of the Universe, a few of which contain astronomers. Astronomers unravel the nature of these gas clouds by catching photons whose last physical interaction was usually with an atom or ion in the cloud itself. The material with which the radiation last interacted imprints clues to its physical nature on this radiation. To find out the temperature, density, chemical abundance and ionization state of the cloud we must understand how matter behaves in a radiation field: how photons and inter-particle collisions can trigger transitions between different excitation and ionization states in atoms and molecules, and how these transitions create or destroy the photons that we eventually see.

Aims & Objectives

To present an introductory account of radiation transfer and its application to gaseous astrophysical systems, including

- The definitions of the basic radiant quantities and the equation of radiation transfer.
- The use of the Boltzmann and Saha equations to compute level populations and ionization equilibria - The Einstein relations and their role in computing line opacities and emissivities,

	• The Planck function and its properties, • The various types of atomic and molecular line transitions and broadening mechanisms encountered in nebulae, • The application of these theories to molecular clouds, HII regions and planetary nebulae. **Learning Outcomes** By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures and will be able to: • Define and use the basic radiant quantities such as specific intensity, mean intensity, flux and radiation pressure of a radiation field; • Differentiate and integrate the Planck function to obtain Wien's Law and the Stefan- Boltzmann Law, • Use the Boltzmann equation, the Saha equation and the Einstein relations to determine level populations and ionization balance both in and out of thermodynamic equilibrium, • Use the equation of radiative transfer to solve for simple geometries how the emergent intensity of a beam of radiation is modified by emitting and absorbing material along its path, • Define the photon mean free path and optical depth, and distinguish between optically thick and optically thin media, • Distinguish between radiatively and collisionally induced transitions, and state their importance in relation to the global energy balance of a body of gas, • Distinguish between natural, collisional and thermal broadening mechanisms in spectral lines, • State the importance of ionization fronts, use the jump conditions to distinguish between R- and D-type fronts, and understand their importance in the evolution of an HII region. • Distinguish between recombination-spectrum formation in Case A and Case B, and use Balmer-line fluxes and line ratios to determine total ionizing flux and interstellar extinction in Case B, • Use simple atomic theory to demonstrate the usefulness of transitions between low-lying levels of common collisionally-excited species as density and temperature diagnostics in emission-line nebulae, • Use radio brightness temperatures of a background source and foreground nebula to determine nebular temperature, • Distinguish the various types of transition for simple molecules, and recognise their importance as coolants in star-forming regions, • Understand basic principles behind Monte Carlo radiation transfer scattering codes including sampling for direction of emission, optical depths, and scattering angles, • Outline a Monte Carlo scattering code and develop Monte Carlo estimators for the intensity moments of the radiation field showing how they relate to formal definitions. **Synopsis** Definitions of basic radiant quantities. Opacity and emissivity. The equation of radiative transfer. Source function and optical depth. Black-body radiation and the diffusion approximation. Atomic and molecular processes: bound-bound, bound-free and free-free transitions, electron scattering, Boltzmann and Saha laws, the Einstein coefficients and their relation to emission and absorption coefficients and to blackbody radiation. Masers. Line-broadening mechanisms. Stromgren spheres, protoplanetary discs. Derivation of jump conditions across ionization fronts using conservation of mass, momentum and energy. Thermal equilibrium between ionization and cooling via photon escape in nebulae. Collisional cooling and detailed balance; hydrogen

	recombination spectrum in Case A and Case B; common line-ratio and radio diagnostics for nebular temperature and density. Rotational and vibrational spectra and selection rules in molecules. Monte Carlo radiation transfer, sampling from probability distributions, estimators for intensity moments of the radiation field, scattering codes. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The 25% continuous assessment is expected to take the form of writing Monte Carlo radiation transfer computer programs, building on what is taught in class. This homework will be issued around week 5 with a deadline around two weeks later. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4011.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

AS4012 The Physics of Nebulae and Stars 2

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
This module develops the physics of stellar interiors and atmospheres from the basic equations of stellar structure introduced in AS2001/AS2101 using the radiative transfer concepts developed in Nebulae and Stars I. Topics include: the equation of state that provides pressure support at the high temperatures and densities found in normal and white-dwarf stars; the interaction of radiation with matter, both in terms of radiation-pressure support in super-massive stars and in terms of the role of opacity in controlling the flow of energy from the stellar interior to the surface; the equation of radiative transfer and the effects of local temperatures, pressures and velocity fields on the continuum and line absorption profiles in the emergent spectrum. Computer-aided tutorial exercises illustrate the computational schemes that represent one of the triumphs of late twentieth-century physics, in their ability to predict the observable properties of a star from its radius and luminosity, which in turn are determined by its mass, age and chemical composition.				
Pre-requisite(s):	Before taking this module you must pass AS4011			
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures occasionally replaced by whole-group tutorials.			
	Scheduled learning: 33 hours		**Guided independent study:** 117 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 75%, Practical Examinations = 0%, Coursework = 25%			
	As used by St Andrews: 2-hour Written Examination = 75%, Coursework = 25%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr P Woitke			
Additional information from Schools:	To be confirmed			

AS4015 Gravitational and Accretion Physics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
This theoretical module is open to both physics and astrophysics students. It aims to explore the basics of gravitational dynamics and its application to systems ranging from planetary and stellar systems to clusters of galaxies. The dynamics responsible for the growth of super-massive black holes in galaxies and the accretion discs in stellar systems are also covered. Starting from two-body motion and orbits under a central-force law, the module describes the calculation of extended potentials and their associated orbits. The use of the virial theorem and the statistical treatment of large numbers of self-gravitating bodies is then developed with application to stellar systems. Applications of these methods are made to several different astrophysical objects ranging from collisions in globular clusters to the presence of dark matter in the universe.				
Pre-requisite(s):	Before taking this module you must pass PH2011 and pass PH2012 and pass MT2501 and pass MT2503 and (pass PH3081 or pass PH3082 or pass MT2506 and pass MT2507)			
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures occasionally replaced by whole-group tutorials.			
	Scheduled learning: 31 hours		**Guided independent study:** 119 hours	

Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%	
	As used by St Andrews: 2-hour Written Examination = 100%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr H Zhao	
Additional information from Schools:	**AS4015 - Gravitational and Accretion Physics** **Aims & Objectives** To present an overview of the importance and relevance of gravitational process in astrophysics, including how gravity relates structures with kinematics and the long-term evolution of such structures due to gravitational interactions. The module also aims to provide a basic understanding of how astrophysical discs work and provide an insight into how compact astrophysical objects form and obtain their characteristic masses be they planets, stars or black holes. **Learning Outcomes** By the end of the module the student should be able to: Apply potential theory to gravitational systems. Relate kinematics to mass distributions in extended objects like clusters and galaxies. Determine how gravitational interactions drive the evolution of self-gravitating systems. Model the structures and evolution of astrophysical discs. Understand the statistical treatment of a large-N system Use the Jeans equations to determine mass distributions from observable properties. Model accretion processes and how these relate to the luminous Universe. **Synopsis** Starting from two-body motion and orbits under a central-force law, the module describes the calculation of extended potentials and their associated orbits. The use of the virial theorem and the statistical treatment of large numbers of self-gravitating bodies is then developed with application to stellar systems. Applications of these methods are made to several different astrophysical objects ranging from collisions in globular clusters to the presence of dark matter in the universe. The physics of accretion and accretion discs is developed with emphasis on disc structures, accretion through the disc and the ability of discs to form smaller mass objects such as planets. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4015.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.	

AS4025 Observational Astrophysics

<table>
<tr><td>SCOTCAT Credits:</td><td>15</td><td>SCQF level 10</td><td>Semester</td><td>1</td></tr>
<tr><td>Academic year:</td><td colspan="4">2021-2022</td></tr>
<tr><td>Availability restrictions:</td><td colspan="4">Not automatically available to General Degree students</td></tr>
<tr><td>Planned timetable:</td><td colspan="4"></td></tr>
<tr><td colspan="5">This is an observational and laboratory-based module that introduces students to the hands-on practical aspects of planning observing programmes, conducting the observations and reducing and analysing the data. The exact topics covered may change annually depending on resource availability; examples include galaxy imaging and exoplanet transits. Sources of data may include telescopes at the University Observatory and/or international observatories. Students gain experience in observation, data analysis, the Linux operating system, standard astronomical software packages and modelling, and report writing</td></tr>
<tr><td>Pre-requisite(s):</td><td colspan="4">Before taking this module you must (pass AS2001 or pass AS2101) and pass PH2011 and pass PH2012 and (pass MT2001 or pass 2 modules from {MT2501, MT2503})</td></tr>
<tr><td rowspan="2">Learning and teaching methods of delivery:</td><td colspan="4">Weekly contact: 2 x 3.5hr x 10 weeks supervised work</td></tr>
<tr><td colspan="2">Scheduled learning: 70 hours</td><td colspan="2">Guided independent study: 80 hours</td></tr>
<tr><td rowspan="2">Assessment pattern:</td><td colspan="4">As defined by QAA:
Written Examinations = 0%, Practical Examinations = 0%, Coursework = 100%</td></tr>
<tr><td colspan="4">As used by St Andrews:
Coursework = 100%</td></tr>
<tr><td>Re-assessment pattern:</td><td colspan="4">No Re-assessment available - laboratory based</td></tr>
<tr><td>Module coordinator:</td><td colspan="4">Professor A C Cameron</td></tr>
<tr><td>Additional information from Schools:</td><td colspan="4">-
AS4025 - Observational Astrophysics
Overview
Astrophysics is an observational, rather than an experimental, science. Nearly all the information that astronomers can gather about the Universe at large and the objects within it comes to us in the form of electromagnetic radiation. In this course students will gain an understanding of the observational work required for astronomical research.
Aims & Objectives
The aim of this module is to familiarise students with a wide range of observational techniques in astronomy and astrophysics. Students will gain practical experience in instrument building planning, documenting and conducting astronomical observations, data analysis, and report writing.
Learning Outcomes
By the end of the module, students should have a comprehensive knowledge of basic ground-based observational techniques and data-analysis methods and be able to:
Plan a set of observations.
Acquire optical images of various astronomical objects, including the necessary calibration data.
Perform photometry using standard astronomical software packages under the Linux operating system.
Carry out the basic reduction and advanced analysis of optical images.
Record and write up results in a professional manner.
Synopsis
This module provides an overview of the practical part of research in observational astronomy. Students learn how to plan observations with telescopes at the university observatory, followed by data reduction and analysis. The exact topics covered may change annually: examples include galaxy imaging, exoplanet transits and constructing</td></tr>
</table>

	and observing with radio telescopes. Further sources of data may be made available from international observatories. Students gain experience in observation, data analysis, the Linux operating system, standard astronomical software packages and modelling, and report writing. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module's work is finished by revision week, so students can expect to commit about 14 hours a week to the module in weeks 1 to 11, including the scheduled afternoon. This module has two assessed assignments, which are likely to be due in weeks 5 and 11. This module is 100% continuously assessed. The continuous assessment is expected to take the form of formal writeups, one for each observing "lab," and lab book quiz(zes). The first writeup is a collaborative small-group report; the other report is written individually by each student. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4025.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

AS4103 Astrophysics Project (BSc)

SCOTCAT Credits:	30	SCQF level 10	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Available only to BSc Astrophysics students, and normally only in their final year.			
Planned timetable:				
The project aims to develop students' skills in searching the physics literature and in research, the evaluation and interpretation of data, and in the presentation of results. There is no specific syllabus for this module. Students taking the BSc degree select a project from a list offered, and are supervised by a member of staff. Project choice and some preparatory work is undertaken in semester one, but normally most of the 30 credits' worth of work is undertaken in semester two. The aim is that students provide the intellectual drive for the project work, and should take on a role similar to that of a research student in the School. Support will be offered by the academic staff member(s) supervising the project and often also by other members of a research team. A pre-project report precedes the research component of the project.				
Pre-requisite(s):	Some projects will need learning from specific modules - please contact potential supervisors.. Entry to final year of BSc Astrophysics programme.. Before taking this module you must pass PH3061 and pass PH2012 and (pass MT2001 or pass MT2501 and pass MT2503) and (pass PH3081 or pass PH3082 or pass MT2003 or pass MT2506 and pass MT2507) and pass AS3013 and pass PH3081 and pass PH3012			
Anti-requisite(s)	You cannot take this module if you take AS5101 or take PH4111 or take PH5101 or take PH5103			
Learning and teaching methods of delivery:	**Weekly contact**: Project students work 'half-time' on their project through semester 2. It is expected that this component of the project work will correspond to ca. 20 hours per week. All students must meet weekly with their project supervisor and attend			

	fortnightly meetings with their peer-support group. Most projects are based in research groups in the School, where members of research teams will provide additional supervision which could range from safety cover to assistance with equipment, computation or analysis, and discussion and interpretation of results.	
	Scheduled learning: 18 hours	**Guided independent study:** 282 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 0%, Coursework = 100%	
	As used by St Andrews: Coursework (Review Article, Project Report, Presentation and Oral Examination) = 100%	
Re-assessment pattern:	No Re-assessment available - Final year project	
Module coordinator:	Dr C J Cyganowski	
Additional information from Schools:	**AS4103 / PH4111 - Astrophysics / Physics Project (BSc)** **Aims & Objectives** This module aims to present students with the opportunity to enhance and develop their research/development skills through extended scientific investigation. The aim is to prepare the student for research and development in a professional environment where reviewing literature effectively, planning, critical thinking and the final presentation of data are key elements. **Learning Outcomes** At the end of this module the student should have: • Developed a level of confidence to plan and work independently in a research/development environment. • Developed their literature review skills to effectively emphasise the relevance and context of a research topic. • Acquired technical skills to record and/or analyse data appropriately or perform appropriate calculations or simulations. • Developed critical thinking skills in order to progress their own work through reasoned evaluation of • Gained experience of the collaborative exchange of ideas in an active research environment. • Have further enhanced their communication and presentation skills to enable them to emphasise the key outcomes of their work effectively and to support their conclusions when questioned. **Synopsis** The module is project-based and the scheme of work will be dictated by the nature of the project itself. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The topic of the project is normally chosen from a list provided by academic staff in semester one. The project often involves working on a topic that is relevant to one of our research groups, exploring or developing new materials for our teaching or investigating pedagogical questions, or developing and trialling new outreach activities. There is some work in semester one liaising with the supervisor to plan ahead to ensure that work can start promptly near the start of semester two. The first week of second semester is spent doing literature research and writing a short pre-project review that is intended to help prepare for the main project work. This document will focus on questions such as 'Why am I going to do this project?', 'What am I going to do?', and 'What evidence/science is there that will help get me there?'. Thus whilst a review of the relevant literature is required, there is also a strong forward-look	

	towards the main part of the project. This pre-project review will have a deadline for submission near to the start of semester two. The main part of the project module is intended to allow the student to use their knowledge and skills to explore some aspect of physics/astrophysics and/or its application, as appropriate to the degree programme. The work may include elements which are experimental, computational, observational, or theoretical. For an astronomy project (AS4103), the majority of the project should be based in the area of astronomy, which may include aspects of pedagogy in astronomy or astronomy-based public engagement. The supervision, experience, and personal reflection should allow these skills to be developed further. The student will meet with their supervisor, and possibly other members of the research group, regularly throughout the semester. In order to provide some additional support students will meet with their peer-support group every two weeks. A project report is submitted towards the end of semester two. Following this, each student will give a presentation on their project work to an assessment panel. This is followed by the student being asked a number of questions about the science and methods etc. associated with their project work. **Accreditation Matters** This module contains students developing skills and experience in project work that is required for IOP accreditation of the degree. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4103.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

AS5001 Advanced Data Analysis

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	This module is intended for students in the final year of an MPhys or MSci programme involving the School, students on MSc Astrophysics, and students on EngD Photonics.			
Planned timetable:				
This module develops an understanding of basic concepts and offers practical experience with the techniques of quantitative data analysis. Beginning with fundamental concepts of probability theory and random variables, practical techniques are developed for using quantitative observational data to answer questions and test hypotheses about models of the physical world. The methods are illustrated by applications to the analysis of time series, imaging, spectroscopy, and tomography datasets. Students develop their computer programming skills, acquire a data analysis toolkit, and gain practical experience by analyzing real datasets.				
Pre-requisite(s):	Familiarity with scientific programming language essential, for example through AS3013 or PH3080. Entry to an MPhys programme in the school or MSc Astrophysics.			
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lectures x 5 weeks, 2 x 1hr office hours x 5 weeks, 1hr Q&A x 5 weeks			
	Scheduled learning: 25 hours		**Guided independent study:** 125 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 0%, Coursework = 100%			
	As used by St Andrews: Coursework = 100%			
Re-assessment pattern:	No Re-assessment available - laboratory based			

<table>
<tr><td>Module coordinator:</td><td>Professor K D Horne</td></tr>
<tr><td>Additional information from Schools:</td><td>AS5001 - Advanced Data Analysis
Overview
Astronomers and other physical scientists fit models to quantitative observational or experimental data in order to answer questions about the physical world. Data are always affected by measurement errors, leaving uncertainty in the answers to questions posed. Probability theory provides a precise language for discussing and expressing those uncertainties. Statistical data analysis provides practical tools for posing questions and teasing answers from the data. Analysis of real datasets is the best way to build expertise in quantitative data analysis.
Aims & Objectives
To develop an understanding of basic concepts and offer practical experience with the techniques of quantitative data analysis.
Learning Outcomes
By the end of the module, students should be comfortable with the concepts of probability theory and statistics, familiar with techniques for quantitative data analysis, and confident in their ability to tackle data analysis problems in physics & astronomy or wherever they may arise in their future work.
Synopsis
Beginning with fundamental concepts of probability theory and random variables, practical techniques are developed for using quantitative observational data to answer questions and test hypotheses about models of the physical world. The methods are illustrated by applications to the analysis of time series, imaging, spectroscopy, and tomography datasets. Students develop their computer programming skills, acquire a data analysis toolkit, and gain practical experience by analyzing real datasets. The module is assessed continuously on the basis of exercises and projects.
Additional information on continuous assessment etc
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.
This module has two homework sets and two projects involving a mix of analytic work and computer analysis of datasets provided.
Homework 1 issued at start of Week 1, due start of Week 4.
Homework 2 issued at start of Week 4 due end of Week 6.
Project 1 issued in Week 6, due at end of Week 9.
Project 2 issued in Week 6, due at end of Week 11.
This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module's work is finished by revision week, so students can expect to commit about 14 hours a week to the module in weeks 1 to 11, including the hours scheduled in lectures and for independent work on the assignments. Students are invited to use whatever programming tools or languages they deem to be most efficient for them in working on the assignments.
MPhys students are reminded that if they choose multiple 'no-exam' modules then they will inevitably have a higher workload per week during weeks 1 to 11 than if they chose modules where some of the 150 hours was spent in the revision and exam weeks.
Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/as5001.html
General Information
Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.</td></tr>
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AS5002 Magnetofluids and Space Plasmas

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	This module is intended for students in the final year of an MPhys or MSci programme involving the School, and for those on the Astrophysics MSc			
Planned timetable:				

This module is aimed at both physics and astrophysics students with interests in the physics of plasmas. The interaction of a magnetic field with an ionized gas (or plasma) is fundamental to many problems in astrophysics, solar- terrestrial physics and efforts to harness fusion power using tokamaks. The syllabus comprises: Solar-like magnetic activity on other stars. The basic equations of magneto-hydrodynamics. Stellar coronae: X-ray properties and energetics of coronal loops. Energetics of magnetic field configurations. MHD waves and propagation of information. Solar and stellar dynamos: mean field models. Star formation: properties of magnetic cloud cores, magnetic support. Physics of accretion discs: transport of mass and angular momentum. Accretion on to compact objects and protostars. Rotation and magnetic fields in protostellar discs. Rotation distributions of young solar-type stars. Magnetic braking via a hot, magnetically channelled stellar wind.

Pre-requisite(s):	Before taking this module you must pass 1 module from {PH3007, MT4510, MT4553} and pass 1 module from {AS3013, PH4030, PH3080, MT3802, MT4112}	
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks	
	Scheduled learning: 30 hours	**Guided independent study:** 120 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%	
	As used by St Andrews: 2-hour Written Examination = 100%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Professor M M Jardine	
Additional information from Schools:	**AS5002 - Magnetofluids and Space Plasmas** **Overview** The interaction of a magnetic field with an ionised gas (or plasma) is fundamental to many problems in astrophysics. Star formation in particular is heavily influenced by the magnetic fields of molecular clouds, and once stars form they can, if they posses a convective region, generate their own magnetic fields by dynamo activity. The behaviour of this magnetic field is at the heart of many of the most interesting observations of young stars and their accretion disks. This module is suitable for physics students as well as astronomers. PH4031 Fluids or MT4509 Fluid Dynamics are recommended as prior study. **Aims & Objectives** To present an account of the theory and observations of magnetic activity in solar-like stars, including an introduction to magnetohydrodynamics, the physics of heating stellar coronae to temperatures of 10^6K, the generation of stellar magnetic fields by dynamo action, the role of magnetic fields in star formation, the physics of accretion disks, stellar spin down by accretion disks and stellar winds. **Learning Outcomes** By the end of the module students should have an understanding of the physics of stellar magnetic fields as presented in the lectures and should be able to • Describe the main observational signatures of magnetic activity • Use the magnetohydrodynamic equations describe the behaviour of simple magnetic field configurations • Give an account of the heating of stellar coronae and derive the scaling relations for pressure, temperature and length of magnetic loops	

	• Describe the main observational features of solar and stellar dynamos and calculate the characteristics of a simple kinematic solution • Use the Virial theorem to explain the characteristics of magnetic support of molecular clouds and the onset of cloud collapse • Demonstrate the role of viscosity in accretion disks and determine the temperature profile of such a disk • Use torque balance in an accretion disk to explain stellar spin-down by star-disk coupling • Use conservation of mass and momentum to derive Parker's wind solution and describe the role of magnetic channelling in a rotating star • Determine the angular momentum loss rate for simple examples **Synopsis** Review of observations of stellar magnetic activity. Equations of magnetohydrodynamics (MHD) Heating of stellar coronae. Reconnection. Energetics of coronal loops and the role of rotation MHD waves and propagation of information. Solar and stellar dynamos (mean field models). Star formation: properties of magnetic cloud cores, magnetic support and the Virial theorem. Accretion disks: transport of mass and angular momentum, role of viscosity. Temperature profiles. Stellar spin down by magnetic star-disk coupling. Rotation distributions of young solar-type stars. Magnetic braking by stellar winds. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5002.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS5003 Contemporary Astrophysics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Available only to MPhys Astrophysics or MSc Astrophysics students.			
Planned timetable:				
This module will provide an annual survey of the latest, most interesting, developments in astronomy and astrophysics at the research level. Emphasis will be placed upon the application of knowledge and expertise gained by students in their other modules to these current research topics.				
Pre-requisite(s):	For MPhys: before taking this module you must pass AS4010, AS4012, PH3061 and PH3081. For MSc: students must have substantial astronomy knowledge and skills.			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 7 weeks, 1hr workshop x 1 week, 1hr Q&A x 1 week			
	Scheduled learning: 29 hours		**Guided independent study:** 121 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%			
	As used by St Andrews: 2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr H Zhao			

Additional information from Schools:	**AS5003 - Contemporary Astrophysics** **Overview** Astrophysics is a constantly changing field in which new observations and theories are continually revising our knowledge and outlook. This course provides a view of research level astrophysics and the opportunity to apply the accumulated knowledge of the astrophysics degree to new problems. **Aims & Objectives** To introduce the students to research level astrophysics including several independent topics of current research. To use the knowledge base, applied to novel problems. To familiarise the students with the process of modelling physics in astrophysical contexts. **Learning Outcomes** The student will be able to use his/her accumulated knowledge and apply it to topics of current astrophysical research. Specifically, the student will be able to comprehend the primary concepts in research level astrophysics topics; formulate an approach to novel and unsolved problems; understand the different techniques and approaches used in various topics; make critical judgement of the merit of research papers in astrophysics. **Synopsis** This is a continually evolving module that introduces the student to two or three main topics of astrophysical research. Topics covered are selected by the teaching staff, and may include dynamics, gravitational lensing, general relativity, cosmological simulations, planet formation and young stellar objects, exoplanets, stellar activity, stellar and planetary atmospheres, interacting binaries, astrophysical discs, active galactic nuclei. **Accreditation Matters** This module may not contain material that is part of the IOP ‘Core of Physics’, but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP ‘Graduate Skill Base’. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5003.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS5101 Astrophysics Project (MPhys)

SCOTCAT Credits:	60	SCQF level 11	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Available only to those in the final year of an MPhys Astrophysics programme.			
Planned timetable:				

The project aims to develop students' skills in searching the physics literature and in research, the evaluation and interpretation of data, and in the presentation of results. There is no specific syllabus for this module.

Students taking the MPhys degree select a project from a list offered, and are supervised by a member of staff. Project choice and some preparatory work is undertaken in semester one, but normally most of the 60 credits' worth of work is undertaken in semester two. The aim is that students provide the intellectual drive for the project work, and should take on a role similar to that of a research student in the School. Support will be offered by the academic staff member(s) supervising the project and often also by other members of a research team. A pre-project report precedes the research component of the project.		
Pre-requisite(s):	Some projects will need learning from specific modules - please contact potential supervisors.. Before taking this module you must pass PH3061	
Anti-requisite(s)	You cannot take this module if you take AS4103 or take PH4111 or take PH5101 or take PH5103 or take PH4796	
Learning and teaching methods of delivery:	**Weekly contact**: Project students work "full-time" on their project through semester 2. It is expected that this component of the project work will correspond to ca. 40 hours per week. All students must meet weekly with their project supervisor and attend fortnightly meetings with their peer-support group. Most projects are based in research groups in the School, where members of research teams will provide additional supervision which could range from safety cover to assistance with equipment, computation or analysis, and discussion and interpretation of results.	
	Scheduled learning: 21 hours	**Guided independent study:** 579 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 0%, Coursework = 100%	
	As used by St Andrews: Coursework = 100%	
Re-assessment pattern:	No Re-assessment available - Final year project	
Module coordinator:	Dr C J Cyganowski	
Additional information from Schools:	**AS5101/ PH5101/PH5103 - Astrophysics / Physics / Theoretical Physics Project (MPhys)** **Aims & Objectives** This module aims to present students with the opportunity to enhance and develop their research skills through extended scientific investigation. The aim is to prepare the student for research in a professional environment where reviewing literature effectively, planning, critical thinking and the final presentation of data are key elements. **Learning Outcomes** At the end of this module the student should have: • Developed a level of confidence to plan and work independently in a research environment. • Developed their literature review skills to effectively emphasise the relevance and context of a research topic. • Acquired technical skills to record and/or analyse data appropriately or perform appropriate calculations or simulations. • Developed critical thinking skills in order to progress their own work through reasoned evaluation. • Gained experience of the collaborative exchange of ideas in an active research environment. • Have further enhanced their communication and presentation skills to enable them to emphasise the key outcomes of their work effectively and to support their conclusions when questioned. **Synopsis**	

	The module is project-based and the scheme of work will be dictated by the nature of the project itself. **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The topic of the project is normally chosen from a list provided by academic staff in semester one. The project usually involves working on a topic that is relevant to one of our research groups, exploring or developing new materials for our teaching or investigating pedagogical questions, or developing and trialling new outreach activities. Project allocations are assigned in semester one, and some work is required before the start of semester two, in reading relevant literature (in discussion with your supervisor), leading to a short pre-project review that is intended to help prepare for the main project work. This document will focus on questions such as ‘Why am I going to do this project?’, ‘What am I going to do’, and ‘What evidence/science is there that will help get me there?’. Thus whilst a review of the relevant literature is required, there is also a strong forward-look towards the main part of the project. This pre-project review will have a deadline for submission near to the start of semester two. The main part of the project module is intended to allow the student to use their knowledge and skills to explore some aspect of physics, theoretical physics or astrophysics, as appropriate to the degree programme. The work may include elements which are experimental, computational, observational, or theoretical. For a theoryproject (PH5103), the majority of the project should involve theoretical/computational work. For an astronomy project (AS5101), the majority of the project should be based in the area of astronomy, which may include aspects of pedagogy in astronomy or astronomy-based public engagement. The supervision, experience, and personal reflection should allow research and related skills to be developed further. The student will meet with their supervisor, and possibly other members of the research group, regularly throughout the semester. In order to provide some additional support students will meet with their peer-support group every two weeks. A project report is submitted towards the end of semester 2. Following this, each student will give a presentation on their project work to an assessment panel. This is followed by the student being asked a number of questions about the science and methods etc. associated with their project work. **Accreditation Matters** This module contains students developing skills and experience in project work that is required for IOP accreditation of the degree. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5101.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH3007 Electromagnetism

SCOTCAT Credits:	15	SCQF level 9	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

The properties of electromagnetic fields will be explored using a variety of mathematical tools (in particular, vector and differential calculus). Topics will include: charge and current distributions, electro- and magnetostatics, materials, electrodynamics, conservation principles and electromagnetic waves. This module builds on knowledge and skills acquired in prior coursework by developing techniques for solving more advanced problems in electromagnetism.

Pre-requisite(s):	Before taking this module you must (pass PH3081 or pass PH3082 or pass MT2506) and pass PH2012 and (pass MT2001 or pass MT2501 and pass MT2503)	
Anti-requisite(s)	You cannot take this module if you take MT4553	
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures and fortnightly tutorials.	
	Scheduled learning: 36 hours	**Guided independent study:** 114 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%	
	As used by St Andrews: Written Examination = 80%, Coursework = 20%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr C R Baily	

Additional information from Schools:

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PH3007 - Electromagnetism

Overview

The properties of electromagnetic fields are explored using a variety of mathematical tools (in particular, vector and differential calculus). Topics include: time-independent charge and current distributions, electric and magnetic properties of matter, electrodynamics, conservation laws, electromagnetic waves and radiation.

Aims & Objectives

This module builds on knowledge and skills acquired in prior courses, to develop more sophisticated techniques for solving problems in undergraduate electromagnetism. The various topics will be presented as part of a coherent theory of classical fields (i.e., as consequences of Maxwell's equations and the Lorentz force law).
The organisation and level of difficulty of the module have been chosen so as to deepen students' understanding of electromagnetic theory, prepare them for practical work in the laboratory, and provide a bridge to more advanced study. Alongside the development of general problem-solving skills and intellectual maturity, emphasis will be placed on conceptual understanding, and deriving physical meaning from mathematical expressions and visual representations.

Learning Outcomes

By the end of this module, students are expected to be able to:

- use Maxwell’s equations in integral form to derive expressions for the fields due to charge/current distributions having planar, cylindrical or spherical symmetry.
- calculate electro-magnetostatic fields by direct integration of Coulomb’s law and the Biot-Savart law; and determine time-independent scalar and

	vector potentials through a variety of techniques (e.g., method of images, multipole expansion). • translate between **E**- & **B**-fields and the auxiliary fields **D** & **H**, in terms of the polarisation and magnetisation of a material; and be able to derive (from Maxwell's equations) and apply the boundary conditions on **E**, **B**, **D** & **H** at the interface of two different linear media. • explain how Poynting's theorem is an expression of local energy conservation, and use its mathematical expression to solve problems involving the transport of energy by electromagnetic fields. • derive wave equations (and their solutions) for electromagnetic fields in free space and in matter, starting from Maxwell's Equations. • determine the boundary conditions for EM waves at the interface of two different linear media, starting from Maxwell's Equations, and apply them to solve for and interpret the reflected and transmitted waves. **Synopsis** Electrostatics: Charge and current distributions; Coulomb's law; Gauss' law; potential theory; linear dielectrics. Magnetostatics: Biot-Savart law, Ampere's law; vector potential; magnetic fields in matter. Electrodynamics: Maxwell's equations; electromagnetic induction; conservation laws for charge and energy; Poynting vector; wave equation; time-dependent potentials and gauge invariance; dipole radiation; reflection and transmission. **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This module is part of the core JH programme, and as such there is a summary of deadlines etc on the School's Students and Staff web pages. There is a class test, likely in week seven, contributing 15% to the module mark, Students have compulsory tutorials every two weeks, with hand-in tutorial work counting for 5% of the module total. **Accreditation Matters** This module contains some material that is or may be part of the IOP 'Core of Physics'. This includes Electrostatics and magnetostatics Gauss, Faraday, Ampère, Lenz and Lorentz laws to the level of their vector expression Maxwell's equations and plane EM wave solution; Poynting vector Polarisation of waves and behaviour at plane interfaces **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph3007.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH3012 Thermal and Statistical Physics

SCOTCAT Credits:	15	SCQF level 9	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

The aim of this module is to cover at honours level the principles and most important applications of thermodynamics and statistical mechanics. The syllabus includes: equilibrium; the equation of state; the classical perfect gas; discussion of experimental results that lead to the three laws of thermodynamics; idealised reversible engines; the Clausius inequality; the classical concept of entropy and its connection to equilibrium; thermodynamic potentials; Maxwell's relations; open systems and the chemical potential; phase transitions and the Clausius-Clapeyron equation for first order transitions; higher order phase transitions; the connection between statistical physics and thermodynamics; the Boltzmann form for the entropy; microstates and macrostates; the statistics of distinguishable particles; the Boltzmann distribution; the partition function; statistical definition of the entropy and Helmholtz free energy; statistical mechanics of two-level systems; energy levels and degeneracy; quantum statistics: Bose-Einstein and Fermi-Dirac distributions; density of states; black-body radiation; Bose-Einstein condensation; Fermi energy; quantum gases and the classical limit; Maxwell-Boltzmann distribution; equipartition of energy; negative temperatures.

Pre-requisite(s):	Before taking this module you must pass 4 modules from {PH2011, PH2012, MT2501, MT2503} and (pass at least 1 module from {PH3081, PH3082} or pass 2 modules from {MT2506, MT2507})	
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.	
	Scheduled learning: 37 hours	**Guided independent study:** 113 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 80%, Practical Examinations = 0%, Coursework = 20%	
	As used by St Andrews: 2-hour Written Examination = 80%, Coursework = 20%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr I Leonhardt	
Additional information from Schools:	To be confirmed	

PH3014 Transferable Skills for Physicists

SCOTCAT Credits:	15	SCQF level 9	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students.			
Planned timetable:				

The aim of the module is to develop the key skills of oral and written communication, information technology, team working and problem solving. This will be done in the context of physics and astronomy, thus extending student knowledge and understanding of their chosen subject. Guidance, practice and assessment will be provided in the preparation and delivery of talks, critical reading of the literature, scientific writing, developing and writing a case for resources to be expended to investigate a particular area of science.

Pre-requisite(s):	Entry to the School's honours programme.	
Anti-requisite(s)	You cannot take this module if you take PH4040	
Learning and teaching methods of delivery:	**Weekly contact**: Through the year there are 8 lectures, 8 tutorials, and about 16 hours of presenting and/or critically evaluating talks.	
	Scheduled learning: 32 hours	**Guided independent study:** 118 hours

<table>
<tr><td rowspan="2">Assessment pattern:</td><td>As defined by QAA:
Written Examinations = 0%, Practical Examinations = 35%, Coursework = 65%</td></tr>
<tr><td>As used by St Andrews:
Coursework on basis of exercises and 2 oral presentations = 100%</td></tr>
<tr><td>Re-assessment pattern:</td><td>No Re-assessment available - Assignment based</td></tr>
<tr><td>Module coordinator:</td><td>Dr B D Sinclair</td></tr>
<tr><td>Additional information from Schools:</td><td>PH3014 - Transferable Skills for Physicists

Overview
This module allows students to practise and extend their knowledge and understanding of physics (including astrophysics) at the same time as gaining important and useful experience in transferable skills. These skills, which are sometimes referred to as professional skills or key skills, are a vital part of the abilities of a graduate (astro)physicist. While many of these skills are developed in 'conventional' modules, concentrating on these skills in this module should ensure that all our students have all these important abilities to a high level. These skills are vital for academic study and research, and for careers in industry, business, and elsewhere. They will help with the final year project report and presentation. Guidance, practice and assessment will be provided in the preparation and delivery of talks, critical reading of the literature, report writing, and developing and writing a case for resources to be expended to investigate a particular area of science.

Aims & Objectives
We intend that this module should strengthen skills in the following areas:

• Using knowledge and solving 'new' problems
• Finding information from books, journals, the web, and people
• Critically evaluating and interpreting information gained from the sources above
• Managing your own learning - Applying initiative
• Communicating orally
• Communicating on paper
• Working as part of a team
• Using a variety of IT skills
• Extending your knowledge and understanding of physics and astronomy

Learning Outcomes
By the end of this module students should be able to

• determine what it is that they do not yet know, but need to know in order to carry out a scientific task
• use bibliographic search engines to find relevant scientific papers
• use the literature and the web to find scientific information
• evaluate critically information from different sources, and use this to inform a scientific argument or overview
• present such an argument or overview on paper and orally
• use PowerPoint appropriately to support a scientific presentation
• work independently and as part of a collaborative team
• know why these outcomes are important, and be confident in their ability to perform these tasks

Synopsis
Overview of the course and its need. The scientific literature, and associated information retrieval. Critical evaluation of material, including a student-comparison of two scientific papers. What makes a good oral presentation?. The production of a</td></tr>
</table>

short talk on one chosen-subject to a small group, followed later in the session by a 20 minute talk on a different subject at a weekend conference (often at the Burn House in the Scottish Hills). Scientific writing, with the production of a 2000-word review article. Team skills. The final assignment in the module involves using all the above skills as each group develops a proposal for a new teaching lab experiment or a research project.

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

This module runs through the teaching weeks of both first and second semester. This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module handbook gives a calendar for the module with suggested hours to be spent on what in which weeks, with most weeks asking for about 7 hours to give the 150 hour total. There are several compulsory tutorials through the two semesters. In semester one students consider two research papers and submit some written work associated with these, with the deadline expected to be in week three. There is then work preparing for and giving a short presentation in week six. The final piece of work for semester one is the writing of a scientific review article on a chosen topic within physics and astronomy, which is submitted around the start of week 11. In semester two the primary assignment for the earlier part of the semester is preparing for a talk to be given at the Module's Conference, which is normally run over a weekend around the end of week five. The final assignment is a group-based proposal for a new teaching lab experiment or some research. This is normally submitted in week nine, with student groups attending panel sessions about this in week eleven.

The assessment breakdown is expected to be

First talk	10%
Burn Conference talk	25% (with 5 of these marks dependent on formal practice talk)
Comparison of two papers	8% for report, 2% for discussion
Review Article	25%
Input to peer review of article plan	4%
Input to peer review of article	3%
Feed forward for Burn talk	3%
Proposal	20%

Accreditation Matters
This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'.

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph3014.html

General Information

	Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/

PH3061 Quantum Mechanics 1

SCOTCAT Credits:	10	SCQF level 9	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				
This module introduces the main features of quantum mechanics. The syllabus includes: early ideas on quantisation, the emergence of the Schrödinger equation, the interpretation of the wave function and Heisenberg's uncertainty relation. The concepts of eigenfunctions and eigenvalues. Simple one-dimensional problems including potential wells and the harmonic oscillator. Solution of the Schrödinger equation for central forces, the radial Schrödinger equation, and the hydrogen atom.				
Pre-requisite(s):	Before taking this module you must pass PH2012 and (pass MT2501 and pass MT2503)			
Co-requisite(s):	null			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 5 weeks, 1hr workshop x 5 weeks			
	Scheduled learning: 30 hours		**Guided independent study:** 70 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 94%, Practical Examinations = 0%, Coursework = 6%			
	As used by St Andrews: 2-hour Written Examination = 80%, Coursework (incl Class Test 14%)= 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr A Kohnle			
Additional information from Schools:	-- **PH3061 - Quantum Mechanics 1** **Overview** Quantum Mechanics is that description of physical phenomena in which the wave and particle aspects of matter and radiation are reconciled in a unified theory. As such it is one of the most fundamental topics in physics. It has widespread applicability in virtually every area of physics from the solid-state to fundamental particles, and is hence an essential item in the 'toolbox' of any practitioner in modern physics. As a theory it has never been shown to be incorrect in any of its predictions if properly employed. However, at a fundamental level it poses many challenges to our understanding, and this is an area of much current research. As well as playing a key role in describing many traditional areas of physics, deeper insights continue to emerge, leading to new applications such as quantum computing, quantum cryptography and quantum information processing. It is hence a topic of continuing fundamental interest and study in its own right as well as being essential for describing many areas of applied physics. The present course is the first in a sequence of four courses that progressively develop the topic to an advanced level. The present course is based on the Schrödinger equation description of quantum mechanics (often referred to as wave mechanics), and is limited to non-relativistic			

	situations. A more formal approach to describing quantum systems based on operator methods is also developed. Applications covering a range of important physical situations are considered, as well as some of the current challenges. Essential mathematical background is developed throughout the course. **Aims & Objectives** To present an introductory account of quantum mechanics (wave mechanics) including important applications and recent progress, in particular: • To develop an intuitive understanding of such basic concepts as the wave function, probability density, operators, eigenfunctions and eigenvalues. • To introduce both the time-independent and time-dependent Schrödinger equations and to develop an understanding of their meaning and how they are utilised. • To apply the Schrödinger equation to a range of important physical situations, develop solutions and discuss their implication. • To introduce the operator formalism and consider a number of its applications. **Learning Outcomes** You will have acquired the ability to: • Write down and solve the Schrödinger equation for simple 1D, 2D and 3D systems, and use the wave functions to calculate expectation values and measurement probabilities for observables such as energy, position and momentum using Cartesian and spherical polar coordinates. • Compare and contrast classical and quantum behaviour for simple 1D, 2D and 3D systems. • Contrast eigenfunctions of an operator with superposition states with respect to that operator. • Explain the relevance of Hermitian and non-Hermitian operators in quantum mechanics, and determine whether or not a given operator is Hermitian. • State the measurement problem in quantum mechanics. • Determine degeneracies of energy levels for simple 2D and 3D systems. • Use properties of ladder operators for the 1D harmonic oscillator to determine wave functions and expectation values. • State properties of the spherical harmonics and their relation to angular momentum. **Synopsis** Historical/Recent Experiments, Uncertainty principle Time-dependent Schrödinger equation, momentum operator and Hamilton operator, time-independent Schrödinger equation, probability interpretation, normalization, expectation values, probability current Wave packets and their propagation; group velocity and spreading The infinite potential well: Eigenfunctions and energy eigenvalues, orthonormality and completeness of eigenfunctions, superposition of states, expansion theorem, Bohr's correspondence principle Properties of Hermitian operators, the commutator, maximal set of mutually commuting operators The 1- and 3-dimensional quantum harmonic oscillator: solution of the Schrödinger equation, discussion of eigenfunctions and eigenenergies, superposition state and wave packet oscillations, solution via ladder operators, Dirac notation The hydrogen atom: Schrödinger equation for the hydrogen atom, discussion of the hydrogen atom solutions, angular momentum

	Additional information on continuous assessment etc. Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This module is part of the core JH programme, and as such there is a summary of deadlines etc on the School's Students and Staff web pages. There is one class test, contributing 14% to the module mark, likely to be in week eight. Successful engagement with a web-based question system counts for 6% of the module mark. Students have compulsory tutorials every two weeks. **Accreditation Matters** This module contains material that is or may be part of the IOP 'Core of Physics'. This includes Heisenberg's uncertainty principle Wave function and its interpretation Standard solutions and quantum numbers, to the level of the hydrogen atom Quantum structure and spectra of simple atoms **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph3061.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/

PH3062 Quantum Mechanics 2

SCOTCAT Credits:	10	SCQF level 9	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				
This module explores more of the key concepts of quantum mechanics, assuming a knowledge of the material in PH3061. The syllabus includes time-independent and time-dependent perturbation theory, including the treatment of degenerate states. The course includes a matrix description of spin, the Bloch sphere representation of spin, systems of interacting spins, and the quantum mechanics of a system of identical particles, which leads to the distinction between fermions and bosons.				
Pre-requisite(s):	Before taking this module you must pass PH3061 and (pass at least 1 module from {PH3081, PH3082} or pass 2 modules from {MT2506, MT2507})			
Learning and teaching methods of delivery:	**Weekly contact**: 2 lectures and fortnightly tutorials.			
	Scheduled learning: 27 hours		**Guided independent study:** 73 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 95%, Practical Examinations = 0%, Coursework = 5%			
	As used by St Andrews: 2-hour Written Examination = 80%, Coursework (incl Class Test 15%) = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr A Kohnle			

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<td>Additional information from Schools:</td>
<td>
PH3062 - Quantum Mechanics 2

Overview
To expand students' basic knowledge gained in PH3061 Quantum Mechanics 1 particularly in approximation methods, time-dependent effects, intrinsic angular momentum ("spin"), and many-particle systems.

Aims & Objectives
• To expand the student's abilities to deal with realistic quantum mechanical problems, in particular (a) those where the single-particle problem does not admit of exact solution, and (b) those where the number of particles is large.
• To reinforce the example cases covered in PH3061 (Quantum Mechanics 1) by using them for practical calculations, particularly in the perturbation theory section of the course.
• To use the language of Dirac notation, and to enable the students to translate freely between it and the more familiar position-basis notation.
• To emphasise the applicability of the methods to common examples of quantum phenomena, e.g. the properties of atoms when irradiated by light.

Learning Outcomes
By the end of the module, the student should:
• be able to use Dirac notation fluently in the context of practical calculations;
• be well acquainted with some approximation methods commonly used in quantum mechanics; - be able to select which method is appropriate for a given problem, and apply it;
• be familiar with the phenomenon of intrinsic angular momentum ("spin"), and the basic mathematical methods used to describe it;
• be able to construct the ground-state wave functions of simple non-interacting many-particle systems as a determinant or permanent of the single-particle wave functions;
• be able to solve simple problems involving the Heisenberg coupling of a small number of spins.

Synopsis
Recap of basic principles, Dirac notation, and maximal sets of mutually commuting operators.
Time-independent perturbation theory (non-degenerate).
Time-independent perturbation theory (degenerate).
Time-dependent perturbation theory; the Fermi golden rule.
The Stern-Gerlach apparatus.
Hilbert space; Matrix representation for spin-1/2; the Pauli matrices. Coupling spins: the two-site Heisenberg model, and how to solve it.
Qubits; Introduction to quantum information.
Indistinguishable particles; symmetries of the wave function; fermionic and bosonic statistics; the Pauli exclusion principle.
Wave functions for particles that don't interact with each other: Slater determinants and permanents.

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.
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</table>

	This module is part of the core JH programme, and as such there is a summary of deadlines etc on the School’s Students and Staff web pages. There is one class test, contributing 15% to the module mark, likely to be in week eight. Successful engagement with a web-based question system counts for 5% of the module mark. Students have compulsory tutorials every two weeks. **Accreditation Matters** This module contains material that is or may be part of the IOP ‘Core of Physics’. This includes First order time independent perturbation theory Pauli exclusion principle, fermions, bosons, and elementary particles Electron theory of solids to the level of simple band structure **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph3062.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/

PH3074 Electronics

SCOTCAT Credits:	15	SCQF level 9	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				
This module provides a basic grounding in practical electronics. It introduces and develops the basic principles underlying the synthesis and analysis of analogue circuits. The module is divided into two parts: passive circuits, beginning with a review of dc circuit theory before moving onto complex impedance, passive ac circuits and diode applications; active circuits and amplifiers, including simple bipolar amplifiers, operational amplifiers and applications.				
Pre-requisite(s):	Before taking this module you must pass PH2011 and pass PH2012 and (pass MT2001 or pass MT2501 and pass MT2503)			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks			
	Scheduled learning: 30 hours		**Guided independent study:** 120 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 75%, Practical Examinations = 0%, Coursework = 25%			
	As used by St Andrews: 2-hour Written Examination = 75%, Coursework = 25%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr P A S Cruickshank			
Additional information from Schools:	To be confirmed			

PH3080 Computational Physics

SCOTCAT Credits:	10	SCQF level 9	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

This module is designed to develop a level of competence in Python, a modern programming language currently used in many physics research labs for mathematical modelling. No prior experience is required. The module starts with a grounding in the use of Python and discusses numerical methods. The main focus is then on the ways in which Python can be used for problem solving in physics and astrophysics.

Pre-requisite(s):	Before taking this module you must pass PH2012 and (pass MT2501 and pass MT2503)	
Anti-requisite(s)	You cannot take this module if you take PH3082	
Learning and teaching methods of delivery:	**Weekly contact**: 2hr lab x 10 weeks, 2 x 1hr Q&A x 10 weeks, 1hr lecture x 1 week.	
	Scheduled learning: 40 hours	**Guided independent study:** 60 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 75%, Coursework = 25%	
	As used by St Andrews: 3-hour Computer-based Examination = 75%, continual assessment = 25%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr M Mazilu	
Additional information from Schools:		

PH3081 Mathematics for Physicists

SCOTCAT Credits:	15	SCQF level 9	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

The module aims to develop mathematical techniques that are required by a professional physicist or astronomer. There is particular emphasis on the special functions which arise as solutions of differential equations which occur frequently in physics, and on vector calculus. Analytic mathematical skills are complemented by the development of computer-based solutions. The emphasis throughout is on obtaining solutions to problems in physics and its applications. Specific topics to be covered will be Fourier transforms, the Dirac delta function, partial differential equations and their solution by separation of variables technique, series solution of second order ODEs, Hermite polynomials, Legendre polynomials and spherical harmonics. The vector calculus section covers the basic definitions of the grad, div, curl and Laplacian operators, their application to physics, and the form which they take in particular coordinate systems.

Pre-requisite(s):	Before taking this module you must pass PH2011 and pass PH2012 and (pass MT2501 and pass MT2503)	
Anti-requisite(s)	You cannot take this module if you take PH3082 or take MT3506	
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3hrs lectures (A) x10 weeks, 1hr workshop x 5 weeks, 1hr tutorial x 4 weeks.	
	Scheduled learning: 34 hours	**Guided independent study:** 116 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 95%, Practical Examinations = 0%, Coursework = 5%	
	As used by St Andrews: 2-hour Written Examination = 80%, continual assessment = 20% (made up of Class Test = 15% and assessed tutorial work = 5%)	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr C A Hooley	
Additional information from Schools:	To be confirmed	

PH3082 Mathematics for Chemistry / Physics

SCOTCAT Credits:	20	SCQF level 9	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Available only to Chemistry and Physics MSci students			
Planned timetable:				

This module consists of the content and assessment of all of PH3081 and the first part of PH3080. The module aims to develop mathematical techniques that are required by a professional physicist or astronomer. There is particular emphasis on the special functions which arise as solutions of differential equations which occur frequently in physics, and on vector calculus. Analytic mathematical skills are complemented by the development of computer-based solutions. The emphasis throughout is on obtaining solutions to problems in physics and its applications. Specific topics to be covered will be Fourier transforms, the Dirac delta function, partial differential equations and their solution by separation of variables technique, series solution of second order ODEs, Hermite polynomials, Legendre polynomials and spherical harmonics. The vector calculus section covers the basic definitions of the grad, div, curl and Laplacian operators, their application to physics, and the form which they take in particular coordinate systems. In the other section of the module students are introduced to the Python language, and shown how this can be used to set up mathematical models of physical systems.

Pre-requisite(s):	Entry to MSci Chemistry and Physics degree programme. Before taking this module you must pass PH2012 and pass MT2501 and pass MT2503	
Anti-requisite(s)	You cannot take this module if you take PH3080 or take PH3081 or take MT3506	
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3hrs lectures x10 weeks, 1hr workshop x 5 weeks, 1hr tutorial x 4 weeks, 2hr lab x 5 weeks, 2 x 1hr Q&A x 5 weeks	
	Scheduled learning: 54 hours	**Guided independent study:** 146 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 71%, Practical Examinations = 0%, Coursework = 29%	
	As used by St Andrews: 2-hour Written Examination = 60%, continual assessment = 40%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr C A Hooley	
Additional information from Schools:	To be confirmed	

PH3101 Physics Laboratory 1

SCOTCAT Credits:	15	SCQF level 9	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

The aims of the module are (i) to familiarise students with a wide variety of experimental techniques and equipment, and (ii) to instill an appreciation of the significance of experiments and their results. The module consists of sub-modules on subjects such as solid state physics, lasers, interfacing, and signal processing and related topics.

Pre-requisite(s):	Before taking this module you must pass PH2012 and (pass MT2501 and pass MT2503)	
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 3.5-hour laboratories.	
	Scheduled learning: 72 hours	**Guided independent study:** 78 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 0%, Coursework = 100%	
	As used by St Andrews: Coursework = 100%	
Re-assessment pattern:	No Re-assessment available - laboratory based	
Module coordinator:	Dr C F Rae	
Additional information from Schools:	To be confirmed	

PH4026 Signals and Information

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				

This module gives an introduction to what are signals and information, and how they are measured and processed. It also covers the importance of coherent techniques such as frequency modulation and demodulation and phase sensitive detection. The first part of the module concentrates on information theory and the basics of measurement, with examples. Coherent signal processing is then discussed, including modulation/demodulation, frequency mixing and digital modulation. Data compression and reduction ideas are illustrated with real examples and multiplexing techniques are introduced. The module concludes with a discussion of basic antenna principles, link gain, and applications to radar.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)	
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.	
	Scheduled learning: 32 hours	**Guided independent study:** 118 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%	
	As used by St Andrews: 2-hour Written Examination = 100%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr P A S Cruickshank	
Additional information from Schools:	To be confirmed	

PH4027 Optoelectronics and Nonlinear Optics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
This module provides an introduction to the basic physics underpinning optoelectronics and nonlinear optics, and its applications including displays and communications. The syllabus consists of: an overview of optoelectronic devices and systems; displays - types of display, liquid crystal displays, organic semiconductors and organic light-emitting diode (OLED) displays; nonlinear optics - propagation of light in anisotropic media, coupled wave equations; second harmonic generation; phase matching; and electro-optic modulators; fibres and telecommunications including modes of planar waveguides, factors limiting data transmission rates and detectors.				
Pre-requisite(s):	Before taking this module you must (pass PH3081 or pass PH3082) or (pass MT2506 and pass MT2507) and pass PH3007			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks			
	Scheduled learning: 30 hours		**Guided independent study:** 120 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%			
	As used by St Andrews: 2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor I D W Samuel			
Additional information from Schools:	To be confirmed			

PH4028 Advanced Quantum Mechanics: Concepts and Methods

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
This module builds on the material of PH3061 and PH3062 Quantum Mechanics 1 and 2 to present some of the important current and advanced topics in quantum mechanics. The mathematics of complex analysis is introduced to allow this to be used for relevant quantum mechanics problems. Scattering theory is developed using partial waves and Green's functions, leading to a discussion of quantum degenerate gases. Advanced topics in perturbation theory including WKB approximation for exploring differential equations. The density matrix formalism as the general state description in open quantum systems is presented; open system dynamics are described within the formalism of the density matrix master equation. Quantum information processing is covered, including concepts such as qubits, quantum entanglement and quantum teleportation.				
Pre-requisite(s):	Before taking this module you must pass PH3061 and pass PH3062 and (pass PH3081 or pass PH3082) or (pass MT2003 or pass MT2506 and pass MT2507)			
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.			
	Scheduled learning: 31 hours		**Guided independent study:** 119 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%			
	As used by St Andrews: 2-hour Written Examination = 100%			

Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr B W Lovett
Additional information from Schools:	**PH4028 - Advanced Quantum Mechanics: Concepts and Methods** **Aims & Objectives** The core idea of the course is to give a clear picture of the modern, 21st century quantum mechanics and to teach basic operational tools in this context. The module will include: • Open quantum systems are covered with the use of density matrix formalism. • Variational theory and WKB approximation. • Entanglement and quantum information and their application. • Quantum scattering. • Complex analysis, importantly introducing the residue theorem which is then used in quantum scattering problems. **Learning Outcomes** By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures and will be able to: • classify and manipulate functions of a complex variable. • use the residue theorem to perform real integrals. • use scattering theory to solve quantum mechanical problems. • Use variational theory and WKB approximation to solve quantum mechanical problems. • use the density matrix as a representation of an open quantum system. Understand and be able to characterise whether a state is pure or mixed. • understand the notion of quantum entanglement and its relationship to Bell's inequalities. • understand sample problems in quantum information, for example, be able to demonstrate via simple calculations in Dirac notation and tensor products how quantum teleportation works. . **Synopsis** • complex analysis; Cauchy-Reimann conditions, Cauchy's integral theorem and formula; Laurent series, residue theorem and principal value. • scattering theory • variational theory. • WKB approximation. • density matrix. Purity of a state. • tensor product notation for multipartite states. • Bell's inequalities and entanglement. • quantum information processing. quantum bit (qubit). quantum teleportation. quantum key distribution. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books**

	Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph4028.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH4031 Fluids

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
This module provides an introduction to fluid dynamics, and addresses the underlying physics behind many everyday flows that we see around us. It starts from a derivation of the equations of hydrodynamics and introduces the concept of vorticity and the essentials of vorticity dynamics. The influence of viscosity and the formation of boundary layers is described with some straightforward examples. The effect of the compressibility of a fluid is introduced and applied to shock formation and to the conservation relations that describe flows through shocks. A simple treatment of waves and instabilities then allows a comparison between theory and readily-observed structures in clouds, rivers and shorelines.				
Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)			
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures and some tutorials.			
	Scheduled learning: 28 hours		**Guided independent study:** 122 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%			
	As used by St Andrews: 2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor C Helling			
Additional information from Schools:	**PH4031 - Fluids** **Aims & Objectives** • To present an introduction to fluid dynamics, focusing particularly on the underlying physics including the use of conservation relations (mass, momentum, energy) to describe flows • a physical understanding of vorticity and its evolution in a flow • the role of viscosity and its effect on flows at boundaries • the use of conservation relations to describe the behaviour of fluids at a shock • the onset of simple instabilities **Learning Outcomes** By the end of the module students will have an understanding of the physics of fluid flow as presented in the lectures and will be able to: • apply conservation relations to determine the properties of given flow patterns • determine the vorticity of a flow and describe its behaviour			

	• use Bernoulli's equation to analyse simple flows - describe the role of viscosity and solve for simple ideal fluid flows • use the shock relations to relate fluid properties on each side of a shock • describe and calculate the onset of simple instabilities **Synopsis** Introduction of Lagrangian and Eulerian derivatives. Derivation of the vector form of the equations of conservation of mass, momentum and energy. Brief review of simple equations of state. Introduction of the concept of vorticity and the essentials of vorticity dynamics. Bernoulli's equation with simple examples. De Laval nozzle flow and transition to supersonic flow. Basic introduction to viscosity and its importance in boundary layers. Reynolds number. Sound waves and formation of shocks. Conservation relations. Simple treatment of instabilities (convection, Rayleigh-Taylor, Kelvin-Helmholtz). **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph4031.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH4032 Special Relativity and Fields

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
The module analyses classical fields in physics such as the electromagnetic field. Fields are natural ingredients of relativity, because they serve to communicate forces with a finite velocity (the speed of light). The module covers the tensor formalism of special relativity, relativistic dynamics, the Lorentz force, Maxwell's equations, retarded potentials, symmetries and conservation laws, and concludes with an outlook to general relativity.				
Pre-requisite(s):	Before taking this module you must pass PH3007 and pass PH3081 and pass PH4038			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 10 weeks			
	Scheduled learning: 32 hours		**Guided independent study:** 118 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 75%, Practical Examinations = 0%, Coursework = 25%			
	As used by St Andrews: 2-hour Written Examination = 75%, Coursework (assessed tutorial questions) = 25%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor N Korolkova			
Additional information from Schools:	To be confirmed			

PH4034 Principles of Lasers

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				

This module presents a basic description of the main physical concepts upon which an understanding of laser materials, operations and applications can be based. The syllabus includes: basic concepts of energy-level manifolds in gain media, particularly in respect of population inversion and saturation effects; conditions for oscillator stability in laser resonator configurations and transverse and longitudinal cavity mode descriptions; single longitudinal mode operation for spectral purity and phase locking of longitudinal modes for the generation of periodic sequences of intense ultrashort pulses (i.e. laser modelocking); illustrations of line-narrowed and modelocked lasers and the origin and exploitability of intensity-induced nonlinear optical effects.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)	
Anti-requisite(s)	You cannot take this module if you take PH5005	
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.	
	Scheduled learning: 33 hours	**Guided independent study:** 117 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 90%, Practical Examinations = 0%, Coursework = 10%	
	As used by St Andrews: 2-hour Written Examination = 90%, Coursework = 10%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr F E W Koenig	
Additional information from Schools:	To be confirmed	

PH4035 Principles of Optics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				

This module formulates the main aspects of physics used in modern optics, lasers and optoelectronic systems. Topics covered include: polarised light and its manipulation, with descriptions in terms of Jones' vectors and matrices; Fresnel's equations for transmittance and reflectance at plane dielectric interfaces; reflection and transmission of multi-layer thin films plus their use in interference filters; interpretation of diffraction patterns in terms of Fourier theory; spatial filters; the theory and use of Fabry-Perot etalons; laser cavities and Gaussian beams.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)	
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks	
	Scheduled learning: 40 hours	**Guided independent study:** 110 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 75%, Practical Examinations = 0%, Coursework = 25%	
	As used by St Andrews: 2-hour Written Examination = 75%, Coursework = 25%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	
Module coordinator:	Dr F E W Koenig	
Additional information from Schools:	To be confirmed	

PH4036 Physics of Music

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				

Musical instruments function according to the laws of physics contained in the wave equation. Wind instruments, the human voice and the acoustics of concert halls can be explained largely by considering waves in the air, but understanding drums, percussion, string instruments and even the ear itself involves studying the coupling of waves in various media. The concepts of pitch, loudness and tone are all readily explained in quantitative terms as are the techniques that musicians and instrument makers use to control them. The module includes a look at how digital audio of musical instrument sounds can be analysed and synthesised using a programming language such a Python.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082	
Learning and teaching methods of delivery:	**Weekly contact**: 2 1hr lectures x 10 weeks, 1hr tutorial/workshop x 10 weeks	
	Scheduled learning: 30 hours	**Guided independent study:** 120 hours
Assessment pattern:	**As defined by QAA:** Written Examinations = 80%, Practical Examinations = 0%, Coursework = 20%	
	As used by St Andrews: Written examinations :80%. Continual assessment: 20%	
Re-assessment pattern:	Oral Re-assessment, capped at grade 7	

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<tr><td>Module coordinator:</td><td>Dr J A Kemp</td></tr>
<tr><td>Additional information from Schools:</td><td>
PH4036 - Physics of Music

Aims & Objectives
To provide a detailed overview of the physics involved in the production, analysing and synthesizing of musical sounds.

Learning Outcomes
By the end of this module, students are expected to be able to:

Derive the wave equation in one, two and three dimensions.
Know expressions for acoustic pressure and volume velocity for acoustic plane waves in free space and in cylindrical pipes.
Derive the specific acoustic impedance in free space and the acoustic impedance in cylindrical pipes and the effect of boundary conditions such as side holes, branches and open or closed ends.
Derive the Fourier series for sine waves, pulse waves, square waves and triangle waves and relate these to sound synthesis and the harmonic series and sound generation in real musical instruments.
Describe beats, perception of roughness, pitch differences in cents and standard musical intervals from the perspective of the relationship between harmonic series, equal temperament and just intonation for standard musical intervals.
Derive approximate frequencies of the formants of the vocal tract and describe the separate roles of the harmonic series and of the formants in forming vowel sounds.
Derive the decibel values associated with spherical waves in free space, absorption of plane waves and diffuse sound fields in rooms.
Develop skills in using computer programming in a language such as Python on digital audio and in report writing.

Synopsis
Beats, Fourier series. Discrete Fourier transform and using Python. Plucked, struck and bowed strings. Air damping. Vibrating membranes and plates. Wave equation in air. Transmission and reflection, losses and radiation. Standing waves, pipes, cross-section changes, side holes. The ear and perception of musical sound. Scales and temperament. Reverberation and architectural acoustics. Case studies on strings, drums, woodwind, brass, and voice. Synthesizing musical sound (additive, subtractive, FM, wave-table and physical modelling).

Accreditation Matters
This module may not contain material that is part of the IOP ‘Core of Physics’, but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP ‘Graduate Skill Base’.

Recommended Books
Please view University online record:
</td></tr>
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	http://resourcelists.st-andrews.ac.uk/modules/ph4036.html **General Information** **Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php**

PH4038 Lagrangian and Hamiltonian Dynamics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
The module covers the foundations of classical mechanics as well as a number of applications in various areas. Starting from the principle of least action, the Lagrangian and Hamiltonian formulations of mechanics are introduced. The module explains the connection between symmetries and conservation laws and shows bridges between classical and quantum mechanics. Applications include the central force problem (orbits and scattering) and coupled oscillators.				
Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507). In taking this module you will need a knowledge of vector calculus			
Anti-requisite(s)	You cannot take this module if you take MT4507			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 lectures and some tutorials			
	Scheduled learning: 44 hours		**Guided independent study:** 106 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 75%, Practical Examinations = 0%, Coursework = 25%			
	As used by St Andrews: 2-hour Written Examination = 75%, Coursework = 25%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr B H Braunecker			
Additional information from Schools:	**PH4038 - Lagrangian and Hamiltonian Dynamics** **Aims & Objectives** To give students a solid grounding and sufficient training in Lagrangian and Hamiltonian techniques in classical mechanics and their applications, including • the Principle of Least Action as the starting point of Lagrangian mechanics • traditional applications of Lagrangian mechanics such as mechanical pendulums, planetary motion, collisions and some non-traditional ones • appreciating the problem-solving power, generality and elegance of Lagrangian and Hamiltonian techniques • understand the fundamental connection between symmetries and conservation laws (Noether theorem) **Learning Outcomes** By the end of the module, students will have a solid knowledge of the central concepts of Classical Mechanics and will have acquired and trained important problem-solving skills. They will be able to			

- establish the Lagrangian, and to derive and solve the equations of motions for many systems subject to the Principle of Least Action
- calculate conserved quantities from symmetries
- calculate the Hamiltonian and establish Hamilton's equations
- be familiar with canonical transformations and Hamilton-Jacobi theory
- understand the concept of phase space and the conservation of phase-space density (Liouville's theorem)
- acquire a deep knowledge of the Hamiltonian formalism that is crucial for the formulation and understanding of quantum mechanics

Synopsis
Review of Newtonian mechanics. Functionals and functional derivatives, Euler-Lagrange equations. Lagrangian, Principle of Least Action, symmetries and conservation laws: energy, momentum, angular momentum, centre of mass. Central forces and orbits, Kepler problem (planetary motion), scattering problems, Rutherford scattering. Hamiltonian formalism, canonical momenta, Hamilton's equations, Poisson brackets, canonical transformations. Application to circuit electrodynamics, filters and transmission lines, classical field theory. Canonical mechanics: symmetries and conservation laws, Noether's theorem, Liouville's theorem, Hamilton-Jacobi formalism.

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

This module is typically taken in JH by theoretical physicists, and in SH by those doing an MPhys in other degree programmes in the School. It is sufficiently core to the programmes that it is included in the summary of deadlines etc on the School's Students and Staff web pages. Five tutorial sheets will be issued over the semester in two week intervals. They contain questions that will deepen the understanding of the current topics in the lectures, and they are required to be handed in for marking. This accounts for 25% of the module mark. Tutorials take the form of 'whole class' tutorials (or are split into several sessions with parts of the class if social distancing is required) where the solutions and underlying physics and problem-solving strategies can be discussed.

Accreditation Matters
This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'.

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph4038.html

General Information
Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH4039 - Introduction to Condensed Matter Physics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Not automatically available to General Degree students			
Planned timetable:				
This module explores how the various thermal and electrical properties of solids are related to the nature and arrangement of their constituent atoms. For simplicity, emphasis is given to crystalline solids. The module covers: the quantum-mechanical description of electron motion in crystals; the origin of band gaps and insulating behaviour; the reciprocal lattice and the Brillouin zone, and their relationships to X-ray scattering measurements; the band structures and Fermi surfaces of simple tight-binding models; the Einstein and Debye models of phonons, and their thermodynamic properties; low-temperature transport properties of insulators and metals, including the Drude model; the physics of semiconductors, including doping and gating; the effect of electron-electron interactions, including a qualitative account of Mott insulators; examples of the fundamental theory applied to typical solids.				
Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507) and (pass PH3061 or pass CH3712)			
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lecture x 10 weeks, 1hr workshop x 9 weeks, 1hr Q&A x 10 weeks			
	Scheduled learning: 49 hours		**Guided independent study:** 101 hours	
Assessment pattern:	**As defined by QAA:** Written Examinations = 100%, Practical Examinations = 0%, Coursework = 0%			
	As used by St Andrews: 2-hour Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr C A Hooley			
Additional information from Schools:	To be confirmed			

PH5004 Quantum Field Theory

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School			
Planned timetable:				
This module presents an introductory account of the ideas of quantum field theory and of simple applications thereof, including quantization of classical field theories, second quantization of bosons and fermions, solving simple models using second quantization, path integral approach to quantum mechanics and its relation to classical action principles, field integrals for bosons and fermions, the relationship between path integral methods and second quantization, solving many-body quantum problems with mean-field theory, and applications of field theoretic methods to models of magnetism.				
Pre-requisite(s):	Before taking this module you must pass PH3012 and pass PH3061 and pass PH3062 and pass 1 module from {PH4038, MT4507} and pass 1 module from {PH4028, MT3503}			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 1hr lectures x 10 weeks, 1hr x 10 weeks tutorials and discussion sessions			
Assessment pattern:	2-hour Written Examination = 85%, Coursework = 15%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr J M J Keeling			
Additional information from Schools:	To be confirmed			

PH5005 Laser Physics and Design

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School			
Planned timetable:				
Quantitative treatment of laser physics including rate equations; transient/dynamic behaviour of laser oscillators including relaxation oscillations, Q-switching, cavity dumping and mode locking; single-frequency selection and frequency scanning, design analysis of optically-pumped solid state lasers; laser amplifiers; unstable optical resonators, geometric and diffraction treatments. An emphasis is placed on how understanding of the laser physics can be used to design useful laser systems.				
Pre-requisite(s):	Before taking this module you must pass PH3007 and pass PH3061 and pass PH3062			
Anti-requisite(s)	You cannot take this module if you take PH4034			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x 1hr lectures x 10 weeks, 1hr workshop x 8 weeks, 1hr Q&A x 2 weeks			
Assessment pattern:	2.5-hour open-notes Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr B D Sinclair			
Additional information from Schools:	**PH5005 - Laser Physics and Design** **Overview**			

	The course is designed to introduce the student to the classical treatment of laser physics providing the necessary quantitative techniques to permit design and prediction .A rate-equation model is used to model the laser system. In this course a number of variations are explored with regard to their applicability and limitations. Learning is assisted through the incorporation into the course of animations and numerical modelling material. (The latter is the 'Psst' software, which may be downloaded free for personal use.) **Aims & Objectives** The course aims to develop a working knowledge and conceptual understanding of important topics in contemporary laser physics at a quantitative level. A key objective is to enable the student to undertake quantitative problem-solving relating to the design, performance and applications of lasers through thereby acquiring an ability to put such knowledge into practice by way of numerical calculations. The aim throughout is to provide a thorough grounding in basic principles and their application, so that by the end of the course the student will have acquired a range of essential skills and knowledge required by a practitioner of laser physics and engineering. Such knowledge of the basics will be of enduring value and relevance. It will enable the student to innovate, design and analyse laser devices and systems at a quantitative level. As well as developing the conceptual framework the course also aims to give a sound perspective of contemporary trends and developments in laser physics, particularly with regard to new schemes for the generation of coherent electromagnetic radiation and the associated devices. **Learning Outcomes** You will have acquired: • A conceptual understanding of the classical approach to laser physics, and a perspective of areas of • An ability through a thorough grounding in the rate equation and strong signal approaches to analyse quantitatively the steady-state and dynamical performance of important contemporary laser devices. • A comprehensive knowledge, including of recent developments, concerning: solid-state lasers (including diode-laser pumped devices), semiconductor lasers, fibre lasers, vibronic and other tuneable lasers, organic lasers, laser amplifiers, and newly emerging gain media. • An ability to both analyse quantitatively and to design such lasers. • A conceptual understanding of such important aspects of laser active media as linewidth determining processes, dispersive/gain properties, spatial and frequency hole-burning. • An ability to both describe quantitatively and analyse such effects. • A thorough grounding in the principles and design of laser resonators, particularly stable cavities. - An ability to analyse quantitatively and design such cavities by using matrix techniques. • Access to and familiarity with numerical modelling tools (including 'Psst') relating to many aspects of laser design and performance. **Synopsis** • Rate Equation Approach to Laser - Steady-State behaviour • Transient effects • Relaxation Oscillations • Q-switching • Diode-laser-pumped solid-state lasers • Optical Amplifier • Linear Gain Regime • Power Extraction • Dispersion & Gain in Laser •

	• Mode Effects • Review of Stable Optical Resonators • Matrix Techniques • Applications • Fibre Lasers • Vibronic Lasers • Tuning Techniques • Linewidth Control • Frequency Stabilisation • Semiconductor Lasers • Ultrafast lasers and diagnostic techniques **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The first part of the module looks at the key underlying ideas of laser physics. After an introduction we look at laser gain. We then turn our attention to laser modes, both longitudinal and transverse. There follows a treatment of time dependence in lasers, based on coupled rate equations, and taking in relaxation oscillations and Q-switching. The remainder of the module looks at how all these ideas can be applied to understand and design various laser systems. We look at a number of case studies. The module then covers ultrashort pulse lasers and semiconductor diode lasers. Tutorials provide a way to practice using these ideas and to discuss questions. A group-based laser design case study with associated feedback allows a more in-depth exploration of design of a particular last system. Laser Design Case Study 20% Open Notes Examination 80% **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5005.html **General Information** **Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/**

PH5011 General Relativity

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or as part of MSc Astrophysics.			
Planned timetable:				
This module covers: inertial frames, gravity, principle of equivalence, curvature of spacetime; basic techniques of tensor analysis; Riemannian spaces, metric tensor, raising and lowering of indices, Christoffel symbols, locally flat coordinates, covariant derivatives, geodesics, curvature tensor, Ricci tensor, Einstein tensor; fundamental postulates of general relativity: spacetime, geodesics, field equations, laws of physics in curved spacetime; distances, time intervals, speeds; reduction of equations of general relativity to Newtonian gravitational equations; Schwarzschild exterior solution, planetary motion, bending of light rays, time delays; observational tests of general relativity; Schwarzschild interior solution, gravitational collapse, black holes.				
Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507). Postgraduates: MSc Astrophysics students must discuss your prior learning with your adviser.			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lecture, 1 x 1hr workshop			
Assessment pattern:	2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr M Dominik			
Additional information from Schools:	**PH5011 - General Relativity** **Overview** The module provides an introduction to Einstein's theory of General Relativity. We lay the necessary grounds of differential geometry and tensor analysis with familiar concepts and non-relativistic mechanics before discussing the fundamental ideas behind Einstein's theory. We show how Newton's forces are being eliminated in favour of curvature of space-time, where matter and curvature are being related by Einstein's gravitational field equations. We find Schwarzschild's solution and discuss implications such as perihelion precession of planets, bending of light, gravitational redshift, time delay, black holes, and gravitational waves. Moreover, we show how General Relativity plays a role in current technology such as satellite navigation. **Aims & Objectives** The module should provide an introduction and applications to the theory of General Relativity, covering the following topics: • the "need" for General Relativity and its historic evolution - fundamental principles of General Relativity • the advanced mathematics required in order to apply the theory - derived predictions and their experimental tests • application of general relativity in science and technology **Learning Outcomes** Students are expected to be able to • understand the fundamental concepts of the theory of General Relativity			

	• practice tensor analysis to describe physical phenomena in curved space-time - derive the equations of motion from a given metric tensor • compute the general-relativistic effects relevant to astronomy • compute the effects of general relativity in modern technology **Synopsis** Curvilinear coordinates: basis and coordinates, reciprocal basis, metric, vector fields, tensor fields, coordinate transformations, affine connection; Tensor analysis: covariant derivative, Riemann tensor, Einstein tensor; Classical mechanics (review): principle of stationary action, Hamilton's equations, Hamilton-Jacobi formalism; Mechanics in curved space: equations of motion, embedding, geodesics, stationary paths, conserved quantities, Hamilton-Jacobi equation; Special Relativity: Minkowski space, light cone, proper time, relativistic mechanics, energy-momentum tensor; General Relativity: principles, Einstein's field equations, cosmological constant, time and distance, synchronisation, Schwarzschild solution; Consequences: relativistic Kepler problem, bending of light, gravitational redshift, time delay, satellite navigation, black holes, cosmological redshift & Friedmann equations, Maxwell's equations in GR, gravitational waves. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5011.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

PH5012 Quantum Optics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School			
Planned timetable:				

Quantum optics is the theory of light that unifies wave and particle optics. Quantum optics describes modern high-precision experiments that often probe the very fundamentals of quantum mechanics. The module introduces the quantisation of light, the concept of single light modes, the various quantum states of light and their description in phase space. The module considers the quantum effects of simple optical instruments and analyses two important fundamental experiments: quantum-state tomography and simultaneous measurements of position and momentum.

Pre-requisite(s):	Before taking this module you must (pass PH3081 or pass PH3082 or pass MT2506 and pass MT2507) and pass PH3061 and pass PH3062 and pass PH4028
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lecture x 10 weeks, 1hr tutorial x 10 weeks
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Professor N Korolkova
Additional information from Schools:	To be confirmed

PH5015 Applications of Quantum Physics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or a postgraduate photonics programme.			
Planned timetable:				

Quantum physics is one of the most powerful theories in physics yet is at odds with our understanding of reality. In this module we show how laboratories around the world can prepare single atomic particles, ensembles of atoms, light and solid state systems in appropriate quantum states and observe their behaviour. The module includes studies of laser cooling, Bose-Einstein condensation, quantum dots and quantum computing. An emphasis throughout will be on how such quantum systems may actually turn into practical devices in the future. The module will include assessment based on tutorial work and a short presentation on a research topic.

Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial/discussion session x 10 weeks, 3 hours student presentations
Assessment pattern:	2-hour Written Examination = 80%, Coursework = 20%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr D Cassettari
Additional information from Schools:	To be confirmed

PH5016 Biophotonics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or a postgraduate photonics programme.			
Planned timetable:				
The module will expose students to the exciting opportunities offered by applying photonics methods and technology to biomedical sensing and detection. A rudimentary biological background will be provided where needed. Topics include fluorescence microscopy and assays including time-resolved applications, optical tweezers for cell sorting and DNA manipulation, photodynamic therapy, optogenetics, lab-on-a-chip concepts and bio-MEMS. Two thirds of the module will be taught as lectures, including guest lectures by specialists, with the remaining third consisting of problem-solving exercises, such as writing a specific news piece on a research paper, assessed tutorial sheets and a presentation. A visit to a biomedical research laboratory using various photonics methods will also be arranged.				
Pre-requisite(s):	Before taking this module you must (pass 1 module from {PH3081, PH3082} or pass 2 modules from {MT2506, MT2507}) and pass 1 module from {PH4034, PH4035}. Pre-requisites are compulsory unless you are on a taught postgraduate programme.			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x1hr lectures x 10 weeks, 1hr tutorial x 10 weeks			
Assessment pattern:	2-hour Written Examination = 80%, Coursework (including presentation)= 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr J C Penedo-Esteiro			
Additional information from Schools:	**PH5016 - Biophotonics** **Overview** The union of photonics and biotechnology presents some of the most exciting scientific and commercial prospects for the 21st century. Largely due to advances in microscopy and the invention of the laser in the 1960s, photonics has touched all aspects of our lives, ranging from home entertainment to optical telecommunications and data storage. Biophotonics is the fusion of photonics and biology that deals with the interaction between light and biological matter. Light is one of the primary tools in biology, and increasingly sophisticated optical instrumentation is used in biological detection and analysis as well as medical treatment. **Learning Outcomes** The key learning outcome is an appreciation for the wide range of photonics technologies that have important roles in the biomedical applications. The students will therefore gain appreciation of the following: • Basic biological and biochemical concepts, such as the structure and function of cells, proteins and • Methods to investigate biological structures with spatial resolutions from angstroms to millimetres and with temporal resolutions from nanoseconds to seconds and beyond. • The nature of the interaction between biological materials (cells, tissue etc.) with light, such as scattering, absorption, fluorescence and Raman. • Optical instrumentation used in biomedical practice, especially for imaging.			

- Advanced light- based techniques such as single-molecule fluorescence, super-resolution methods, light-sheet microscopy, OCT and Raman Spectroscopy to provide multi-modal information.
- Operation of biomedical detection systems such as assays and their detection limits.
- Advanced optical techniques for mechanical manipulation of proteins and DNA such as optical tweezers and the added functionality and information provided by these methods.
- An introduction to optogenetics and how to use light to control biological response, mostly in
- Optical methods to measure forces exerted by cell during the cell life cycle.

Students will also gain transferable skills by developing some of the material themselves via critical study of research papers and materials, presentations and group work.

Synopsis
Imaging at different temporal and spatial scales from molecules to cells including optical coherence tomography, confocal and multiphoton imaging, and imaging beyond the diffraction limit. Overview of Microscopy and relevance for biological inspection. Basics of Cell and Molecular Biology, structure and function of biological structures and samples. Optical scattering, absorption and properties of fluorescent labels including small fluorophores, fluorescence proteins and quantum dots and their use in biological assays and biomedical sensing. New generation imaging methods including super-resolution techniques, light sheet microscopy and single-molecule technologies. Single-molecule DNA sequencing. Force-induced mechanical manipulation of biomolecules and cells using light. Operational principle of optical tweezers and its applications. Different types of beams, how they are generated and their applications. Interaction of light and tissue. Different types of light sources used and their respective advantages and effects, including time-resolved methods/short-pulse lasers. Light as a stimulus in biological samples. Uses of light-sensitive ion channels in optogenetics. Overview of optical methods to measure forces exerted by cells.

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

The coursework includes:

1. News and Views style paper: a 1200-word essay including one or two figures explaining a research paper and placing the topic and findings into context. A list of research papers to choose from will be provided.
2. A 15-20 min presentation on the same topic as the News & Views essay.

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph5016.html

General Information
Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

PH5023 Monte Carlo Radiation Transport Techniques

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or as part of MSc Astrophysics.			
Planned timetable:				
This module introduces the theory and practice behind Monte Carlo radiation transport codes for use in physics, astrophysics, atmospheric physics, and medical physics. Included in the module: recap of basic radiation transfer; techniques for sampling from probability distribution functions; a simple isotropic scattering code; computing the radiation field, pressure, temperature, and ionisation structure; programming skills required to write Monte Carlo codes; code speed-up techniques and parallel computing; three-dimensional codes. The module assessment will be 100% continuous assessment comprising homework questions and small projects where students will write their own and modify existing Monte Carlo codes.				
Pre-requisite(s):	Undergraduates: Before taking this module you must pass PH2012 and pass at least 1 module from {AS3013, PH3080, PH3081, PH3082}.. Postgraduates: MSc Astrophysics students must discuss their prior learning with their adviser			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x 1hr lectures x 5 weeks, 1hr tutorial x 5 weeks, 2hr computer session x 3 weeks.			
Assessment pattern:	Coursework (worksheets = 50%, 3-hour computing test = 25%, 1-hour Class Test = 25%) = 100%			
Re-assessment pattern:	No Re-assessment available - laboratory based			
Module coordinator:	Dr K Wood			
Additional information from Schools:	**PH5023 - Monte Carlo Radiation Transport Techniques** **Learning Outcomes** By the end of the lecture course students will have a comprehensive knowledge of Monte Carlo radiation transport techniques and applying them to write their own computer simulations for photon and neutron transport. • Use random numbers to sample events and processes from probability distribution functions • Understand and the structure of Monte Carlo radiation transfer codes for photon scattering and absorption • Understand the structure of Monte Carlo codes for neutron transport including absorption, scattering, and fission • Understand the concept of Monte Carlo detectors and estimators to determine physical quantities throughout a medium such as photon flux, fluence, radiation pressure • Understand variance reduction techniques to improve signal-to-noise in Monte Carlo simulations; forced first scattering, weighting techniques, Russian roulette, next-event estimators • Understand the structure of Monte Carlo codes for photon and neutron transport in three dimensional density structures • Understand the structure of Monte Carlo codes for neutron criticality calculations			

- Understand the important physical processes required for Monte Carlo simulations of light interacting with biological tissue, photobleaching, and photodynamic therapy
- Be able to write Fortran programs and subroutines to sample from probability distribution functions, both analytic and tabulated
- Be able to write Monte Carlo codes to simulate the transport of photons and neutrons in uniform density structures
- Be able to adapt and modify a publicly available three dimensional Monte Carlo code for specific problems in photon transport

Synopsis
Recap of basic radiation transport processes; introduction to Monte Carlo techniques for sampling from probability distribution functions; outline a simple isotropic scattering computer code. Scattering phase functions (electrons, molecules, dust, biological tissue); techniques for computing internal intensity moments; radiation force and pressure calculations. Techniques for improving signal-to-noise in simulations; weighting schemes; error analysis. Applications of Monte Carlo techniques for medical physics including fluorescence spectroscopy, photobleaching, photodynamic therapy. Application of Monte Carlo techniques for neutron transport and criticality calculations. Monte Carlo radiative equilibrium calculations for gas and dust. Monte Carlo photoionisation calculations. Other applications: radiation transfer through clouds & atmospheric physics; relativistic scattering; polarisation; radiation-hydrodynamics; cosmic ray transport; neutron transport.
Fortran coding skills: basic mathematical functions; if statements; do loops; functions and subroutines; random number generators; iterative techniques
Parallelizing Monte Carlo codes.
Lectures on using and modifying publicly available Monte Carlo codes for scattering, radiative equilibrium, and photoionisation.

Additional information on continuous assessment etc
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module's work is finished by revision week, so students can expect to commit about 14 hours a week to the module in weeks 1 to 11, including the hours scheduled in lectures and in the computing cluster. MPhys students are reminded that if they choose multiple 'no-exam' modules then they will inevitably have a higher workload per week during weeks 1 to 11 than if they chose modules where some of the 150 hours was spent in the revision and exam weeks.

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph5023.html

General Information
Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH5024 Modern Topics in Condensed Matter Physics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Available only to those in the final year of an MPhys or MSci programme			
Planned timetable:	To be arranged			

This module links with ongoing research in this area in the School, and includes the rich structural and electronic phases that can be stabilised at surfaces of materials and the physics of strongly correlated electron materials. It also covers some experimental techniques commonly used to characterise these, such as quantum oscillations, angle-resolved photoemission spectroscopy, and scanning tunnelling microscopy and spectroscopy. There is an emphasis on developing skills in critical reading of the scientific literature, presenting relevant works in class discussions, and performing computations. Tutorial sessions will be used to provide constructive feedback on problem sheets. Full-class discussions in a journal club style will aid in developing understanding of complex topics and critical reading of research papers.

Pre-requisite(s):	Before taking this module you must pass 4 modules from {PH3061, PH3062, PH4039, PH4044} and (pass 1 module from {PH3081, PH3082} or pass 2 modules from {MT2506, MT2507}) and pass 1 module from {PH4037, PH4041} and pass 1 module from {PH3080, PH3082}	
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lectures x 7 weeks, 1hr tutorial x 4 weeks, 3-hr presentation sessions x 2 weeks	
	Scheduled learning: 31 hours	**Guided independent study:** 119
Assessment pattern:	**As defined by QAA:** Written Examinations = 0%, Practical Examinations = 60%, Coursework = 40%	
	As defined by St Andrews: 100% continual assessment - Four take-home tutorial sheets/problem sets with analytic and computational problems (40%) - Journal Club presentation 30% on presentation and contributing to the discussion (answering and asking questions) - Oral Examination (taking place in examination weeks) 30%	
Re-assessment pattern:	No Re-assessment available - assignment based	
Module coordinator:	Prof G P Wahl	

Additional information from Schools:

PH5024 - Modern Topics in Condensed Matter Physics
Overview
This module introduces a range of modern topics in condensed matter physics research and theory. It consists of a series of 21 lectures, practical computational examples providing a numerical approach to solving related physics problems and literature research and journal club presentation sessions covering topics of relevance in modern solid state physics research. Topics covered in this module include topologically non-trivial states, Fermi liquid theory, quantum criticality, and many body problems in condensed matter physics as well as the experimental methods to study these phenomena.
Aims & Objectives
The primary aim of this module is for students to gain an introduction to some of the most exciting developments of recent years in the area of condensed matter physics. Topics covered include
topology, Fermi liquid theory, quantum criticality, many body problems in condensed matter physics and experimental methods to study electronic states.
Learning Outcomes

- An understanding of the topics covered in the module
- An ability to solve problems using a variety of techniques
- An understanding of current research topics in solid state physics
- An ability to critically read scientific literature
- Undertaking a literature search

	• Basic skills in numerical modelling of physics problems • Using a numerical model to understand the physics of a particular problem **Synopsis** Topics covered include: • Electronic states • Fermi liquid theory • Landau Levels, Quantum Hall, and Kondo Effects • Topology • Experimental probes **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. The oral examination will take place within the examination weeks. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5024.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

PH5025 Nanophotonics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Available only to students in a photonics taught postgraduate programme or the final year of an MPhys Honours Programme			
Planned timetable:				
Nanophotonics deals with structured materials on the nanoscale for the manipulation of light. Photonic crystals and plasmonic metamaterials are hot topics in contemporary photonics, and form part of the School's research programme. The properties of these materials can be designed to a significant extent via their structure. Many of the properties of these nanostructured materials can be understood from their dispersion diagram or optical band-structure, which is a core tool that will be explored in the module. Familiar concepts such as optical waveguides and cavities, multilayer mirrors and interference effects will be used to explain more complex features such as slow light propagation and high Q cavities in photonic crystal waveguides and supercontinuum generation in photonic crystal fibres. Propagating and localized plasmons will be explained and will include the novel effects of super-lensing and advanced phase control in metamaterials.				
Pre-requisite(s):	Undergraduates: before taking this module you must take PH3061 and (take PH3081 or take PH3082) and (take PH4027 or take PH4034 or take PH4035). Postgraduates: students should be familiar with Maxwell's Equations of Electromagnetism in differential form.			
Anti-requisite(s)	You cannot take this module if you take PH5183			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 1hr lectures x 10 weeks, 1hr workshop x 10 weeks			
Assessment pattern:	2-hour Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor A Di Falco			

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<td>Additional information from Schools:</td>
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PH5025 - Nanophotonics

Learning Outcomes

Students will be able to:

- Understand and design basic integrated optics devices, including waveguides and cavities
- Use coupled mode theory in time domain to model the interaction of light in integrated devices
- Understand the physics and application of photonic crystals, plasmonic nanostructures and metamaterials

Synopsis

Topics covered include:

- Light propagation in optical waveguides and cavities
- Coupled mode theory
- Photonic crystals
- Applications of photonic crystal technology
- Optics of metals
- Surface plasmon polaritons
- Localised plasmons
- Applications of nanoplasmonics
- Metamaterials and applications

Additional information on continuous assessment etc.

The continuous assessment will be based on 3 assessed tutorials. The solutions will be discussed in dedicated lectures.

General information

Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

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PH5026 Supported Study Module

SCOTCAT Credits:	15	SCQF level 11	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	This module is only available by special permission of the Head of School. It is being provided to help with MPhys students in two different situations:- 1) Those who are on a reduced credit load and so may need to take 15 credits at level 5 in their penultimate year 2) Those who are unexpectedly in need of another 15 credits to be taken with their MPhys project in their final semester.			
Planned timetable:				

On rare occasions a student may need a level 5 module in semester two for their Physics or Astronomy MPhys degree programme, and this module may fulfil that need. This module is available only by special permission from the Head of School of Physics and Astronomy, and is expected to be taken rarely. This module is available only to students studying on an MPhys degree in Physics, Astrophysics, or Theoretical Physics. The topic and intended learning outcomes of this supported study module will be the same as that of one of the existing semester-one undergraduate level-five AS or PH modules that the School is in a position to offer at the time. Reading will be set weekly to cover the necessary content, and in many weeks tutorial sheets will be issued to be completed. This will be discussed in a weekly tutorial. There are no lectures.

Pre-requisite(s):	Before taking this module you must pass PH3061
Learning and teaching methods of delivery:	**Weekly contact**: 1 hour tutorial (11 weeks)
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Additional information from Schools:	To be confirmed

PH5101 - Physics Project (MPhys)

SCOTCAT Credits:	60	SCQF level 11	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Normally available only to those in the final year of an MPhys Physics or MSci Chemistry and Physics degree programme			
Planned timetable:				

The project aims to develop students' skills in searching the physics literature and in research, the evaluation and interpretation of data, and in the presentation of results. There is no specific syllabus for this module. Students taking the MPhys degree select a project from a list offered, and are supervised by a member of staff. Project choice and some preparatory work is undertaken in semester one, but normally most of the 60 credits' worth of work is undertaken in semester two. The aim is that students provide the intellectual drive for the project work, and should take on a role similar to that of a research student in the School. Support will be offered by the academic staff member(s) supervising the project and often also by other members of a research team. A pre-project report precedes the research component of the project.

Pre-requisite(s):	Before taking this module you must pass PH3061, some projects will need learning from specific modules - please contact potential supervisors.	
Anti-requisite(s)	You cannot take this module if you take all modules from AS4103 and take all modules from AS5101 and take all modules from PH4111 and take all modules from PH5103 and take all modules from PH4796	
Learning and teaching methods of delivery:	**Weekly contact**: Project students work 'full-time' on their MPhys project through semester 2. All students must meet weekly with their project supervisor and attend fortnightly meetings with their peer-support group. Most projects are based in research groups in the School, where members of research teams will provide supervision ranging from safety cover to assistance with equipment and discussion of interpretation of results - it is expected that the 40 hours a week will be primarily in this environment.	
	Scheduled learning hours: 21	**Guided independent study hours:** 579
Assessment pattern:	**As used by St Andrews:** Coursework (Review essay, Report, and Oral Examination) = 100%	
	As defined by QAA: Written examinations = 0% Practical examinations = 0% Coursework = 100%	
Re-assessment pattern:	No Re-assessment available - Final year project	
Module coordinator:	Prof P D King	
Additional information from Schools:	**AS5101/ PH5101/PH5103 - Astrophysics / Physics / Theoretical Physics Project (MPhys)** **Aims & Objectives** This module aims to present students with the opportunity to enhance and develop their research skills through extended scientific investigation. The aim is to prepare the student for research in a professional environment where reviewing literature effectively, planning, critical thinking and the final presentation of data are key elements. **Learning Outcomes** At the end of this module the student should have: • Developed a level of confidence to plan and work independently in a research environment.	

- Developed their literature review skills to effectively emphasise the relevance and context of a research topic.
- Acquired technical skills to record and/or analyse data appropriately or perform appropriate calculations or simulations.
- Developed critical thinking skills in order to progress their own work through reasoned evaluation.
- Gained experience of the collaborative exchange of ideas in an active research environment.
- Have further enhanced their communication and presentation skills to enable them to emphasise the key outcomes of their work effectively and to support their conclusions when questioned.

Synopsis
The module is project-based and the scheme of work will be dictated by the nature of the project itself.

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

The topic of the project is normally chosen from a list provided by academic staff in semester one. The project usually involves working on a topic that is relevant to one of our research groups, exploring or developing new materials for our teaching or investigating pedagogical questions, or developing and trialling new outreach activities. Project allocations are assigned in semester one, and some work is required before the start of semester two, in reading relevant literature (in discussion with your supervisor), leading to a short pre-project review that is intended to help prepare for the main project work. This document will focus on questions such as 'Why am I going to do this project?', 'What am I going to do', and 'What evidence/science is there that will help get me there?'. Thus whilst a review of the relevant literature is required, there is also a strong forward-look towards the main part of the project. This pre-project review will have a deadline for submission near to the start of semester two.

The main part of the project module is intended to allow the student to use their knowledge and skills to explore some aspect of physics, theoretical physics or astrophysics, as appropriate to the degree programme. The work may include elements which are experimental,computational, observational, or theoretical. For a theoryproject (PH5103), the majority of the project should involve theoretical/computational work. For an astronomy project (AS5101), the majority of the project should be based in the area of astronomy, which may include aspects of pedagogy in astronomy or astronomy-based public engagement. The supervision, experience, and personal reflection should allow research and related skills to be developed further. The student will meet with their supervisor, and possibly other members of the research group, regularly throughout the semester. In order to provide some additional support students will meet with their peer-support group every two weeks.

A project report is submitted towards the end of semester 2. Following this, each student will give a presentation on their project work to an assessment panel. This is followed by the student being asked a number of questions about the science and methods etc. associated with their project work.

Accreditation Matters

	This module contains students developing skills and experience in project work that is required for IOP accreditation of the degree. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5101.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH5103 - Project in Theoretical Physics (60)

SCOTCAT Credits:	60	SCQF level 11	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Available only to those in the final year of an MPhys programme in Theoretical Physics			
Planned timetable:	To be arranged			

The project aims to develop students' skills in searching the physics literature and in research, the evaluation and interpretation of data, and in the presentation of results. There is no specific syllabus for this module. Students taking the MPhys degree select a project from a list offered, and are supervised by a member of staff. Project choice and some preparatory work is undertaken in semester one, but normally most of the 60 credits' worth of work is undertaken in semester two. The aim is that students provide the intellectual drive for the project work, and should take on a role similar to that of a research student in the School. Support will be offered by the academic staff member(s) supervising the project and often also by other members of a research team. A pre-project report precedes the research component of the project.

Pre-requisite(s):	Before taking this module you must pass PH3061, some projects will need learning from specific modules - please contact potential supervisors	
Anti-requisite(s):	You cannot take this module if you take PH5102 or take PH5101 or take PH4111 or take AS4103 or take AS5101 or take PH4796	
Learning and teaching methods of delivery:	**Weekly contact**: Project students work 'full-time' on their project through semester 2. It is expected that this component of the project work will correspond to ca. 40 hours per week. All students must meet weekly with their project supervisor and attend fortnightly meetings with their peer-support group. Most projects are based in research groups in the School, where members of research teams may provide additional supervision which could range from safety cover to assistance with equipment, computation or analysis, and discussion and interpretation of results.	
	Scheduled learning: 36 hours	**Guided independent study:** 564
Assessment pattern:	**As defined by QAA:** Written examinations = 0% Practical examinations = 0% Coursework = 100%	
	As defined by St Andrews: Coursework (review essay, report, oral examination) = 100%	
Re-assessment pattern:	No Re-assessment available - Final year project	
Module coordinator:	Dr J M J Keeling	

Additional information from Schools:	**AS5101/ PH5101/PH5103 - Astrophysics / Physics / Theoretical Physics Project (MPhys)** **Aims & Objectives** This module aims to present students with the opportunity to enhance and develop their research skills through extended scientific investigation. The aim is to prepare the student for research in a professional environment where reviewing literature effectively, planning, critical thinking and the final presentation of data are key elements. **Learning Outcomes** At the end of this module the student should have: • Developed a level of confidence to plan and work independently in a research environment. • Developed their literature review skills to effectively emphasise the relevance and context of a research topic. • Acquired technical skills to record and/or analyse data appropriately or perform appropriate calculations or simulations. • Developed critical thinking skills in order to progress their own work through reasoned evaluation. • Gained experience of the collaborative exchange of ideas in an active research environment. • Have further enhanced their communication and presentation skills to enable them to emphasise the key outcomes of their work effectively and to support their conclusions when questioned. **Synopsis** The module is project-based and the scheme of work will be dictated by the nature of the project itself. **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The topic of the project is normally chosen from a list provided by academic staff in semester one. The project usually involves working on a topic that is relevant to one of our research groups, exploring or developing new materials for our teaching or investigating pedagogical questions, or developing and trialling new outreach activities. Project allocations are assigned in semester one, and some work is required before the start of semester two, in reading relevant literature (in discussion with your supervisor), leading to a short pre-project review that is intended to help prepare for the main project work. This document will focus on questions such as 'Why am I going to do this project?', 'What am I going to do', and 'What evidence/science is there that will help get me there?'. Thus whilst a review of the relevant literature is required, there is also a strong forward-look towards the main part of the project. This pre-project review will have a deadline for submission near to the start of semester two. The main part of the project module is intended to allow the student to use their knowledge and skills to explore some aspect of physics, theoretical physics or astrophysics, as appropriate to the degree programme. The work may include elements which are experimental,computational, observational, or theoretical. For a theoryproject (PH5103), the majority of the project should involve theoretical/computational work. For an astronomy project (AS5101), the majority of the project should be based in the area of astronomy, which may include aspects of pedagogy in astronomy or astronomy-based public engagement. The supervision,

	experience, and personal reflection should allow research and related skills to be developed further. The student will meet with their supervisor, and possibly other members of the research group, regularly throughout the semester. In order to provide some additional support students will meet with their peer-support group every two weeks. A project report is submitted towards the end of semester 2. Following this, each student will give a presentation on their project work to an assessment panel. This is followed by the student being asked a number of questions about the science and methods etc. associated with their project work. **Accreditation Matters** This module contains students developing skills and experience in project work that is required for IOP accreditation of the degree. **Recommended Books** Please view University online record: **http://resourcelists.st-andrews.ac.uk/modules/ph5101.html** **General Information** Please also read the general information in the School's honours handbook that is available via **st-andrews.ac.uk/physics/staff_students/timetables.php**.