Course Unit Syllabus

2019 - 2020

This guide lists the syllabuses for the course units taken by undergraduates in the School of Physics and Astronomy for all degree programmes.

Contents

For further information on the degree programme structure please see the Undergraduate Handbook 2019 - 2020

Syllabuses - Overview

This section lists the syllabuses for the course units taken by undergraduates in the school. Please note:

- Physics units, denoted by PHYSXXXXX, are listed in order of their course code number XXXXX.
- Each unit has a credit rating which reflects the effort needed to satisfactorily complete the course. 120 credits are needed for a full year of study.
- A 10 credit unit is expected to require about 100 hours of study in total. Note that some (compulsory) parts of each programme are not credit-weighted.
- Wherever possible syllabuses have been defined from specific textbooks.
- These texts are available in the School Library and in the John Rylands University Library.
- Students will find it useful to purchase some of these texts. However, they are advised to delay any purchase until the beginning of the lecture unit when the lecturer will discuss the merits of the various alternative texts available.
- Pre-requisites in italics are not core courses.

PHYS10071 Mathematics 1 (Core) SEM1

Prerequisites	A-level Mathematics
Follow-up units	This course is a prerequisite for all subsequent physics core courses
Classes	22 lectures in S1, plus workshops
Assessment	Tutorial work and attendance (5%)
	Mid-semester test (10%)
	1 hour 30 minutes examination in January (85%)

Recommended texts

Jordan, D. & Smith, P. *Mathematical Techniques* (OUP)

Tinker, M. & Lambourne, R. *Further Mathematics for the Physical Sciences* (Wiley)

Supplementary texts

Lambourne, R. & Tinker, M. *Basic Mathematics for the Physics Sciences* (Wiley)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued.

Aims

To allow students to develop their mathematical competence with functions, calculus, complex numbers, power series, linear algebra and differential equations to a level where they can cope with the demands of the first year of the physics course and beyond.

Learning outcomes

On completion successful students will be able to:

1. describe the properties of different types of functions and be able to sketch them in both 2D cartesian and polar coordinates.
2. integrate and differentiate functions of one variable using a range of techniques and be able to apply integration and differentiation to a range of physical problems.
3. show how smooth functions can be expressed in terms of power series.
4. explain the properties of complex numbers and construct some basic complex functions.
5. employ matrix notation, carry out matrix algebra and use matrices to solve systems of linear equations.
6. compute the properties of determinants, be able to evaluate them, and use them to test for unique solutions of linear equations.
7. solve first and second order ordinary differential equations using a range of techniques.

Syllabus

1. **Functions and 2D coordinates** (2 lectures)

   Properties of functions. 2D and 3D coordinate systems. Index notation, Sketching functions, logarithmic functions.

2. **Complex numbers** (2 lectures)

   Definition, modulus and argument; addition, multiplication, division; roots of quadratic equations; complex numbers in polar form; De Moivre's theorem; Hyperbolic functions.

3. **Differential Calculus** (3 lectures)

   Review of differentiation, the differential; differentiation of products, functions of functions; maxima, minima and inflexions; partial differentiation; examples and applications from physics.

4. **Power Series** (2 lectures)

   Series, limits of series; binomial expansion; Taylor's and Maclaurin's series expansions.

5. **Integral Calculus** (4 lectures)

   Review of integration; integration by parts, substitution, standard integrals, partial fractions and completing the square; simple line integrals; physical applications.

6. **Linear Algebra** (5 lectures)

   Matrix algebra, inverse matrix. Definition and properties of determinants, scalar triple product, test of unique solution to linear equations. Eigenvalues and eigenvectors, eigenanalysis

7. **Ordinary Differential Equations** (4 lectures)

   Physical motivation. 1st order separable. 1st order homogeneous. 1st order linear: integrating factors. 2nd order with constant coefficients. Physical applications.

PHYS10101 Dynamics (Core) SEM1

Prerequisites	A-level Physics and A-level Mathematics
Follow-up units	PHYS10672, PHYS20401
Classes	22 lectures plus 11 workshop sessions in S1
Assessment	15% for 11 on-line assignments: 1.5% per week on a pass/fail basis (required score for pass is 2/3rds of average mark for the assignment with a minimum of 40%), capped at a total of 15%. Mid-semester test (10%) 1 hour 30 minutes examination in January (75%)

Compulsory Text book

Young, H.D. & Freedman, R.A. *University Physics* (Addison-Wesley)

Recommended texts

Forshaw, J.R. & Smith, A.G. *Dynamics & Relativity* (Wiley)

French, A.P. *Newtonian Mechanics* (Norton)

Halliday, D., Resnick, R. & Walker, J. *Fundamentals of Physics* (Wiley)

Kleppner, D. & Kolenkow, R. *An Introduction to Mechanics* (McGraw-Hill)

Tipler, P.A., *Physics for Scientists and Engineers* (W.H. Freeman and company)

Supplementary maths text

Tinker, M. & Lambourne, R. *Further Mathematics for the Physical Sciences* (Wiley)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued.

Aims

To introduce the fundamental concepts of Newtonian mechanics.

Learning outcomes

On completion successful students will be able to explain the role of, and solve problems involving, the following concepts:

1. frame of reference and its associated coordinate systems.
2. Newton's laws and the motion of simple systems.
3. energy, work, power, momentum, force, impulse, angular velocity, angular acceleration and torque.

4. conservation of energy, momentum, and angular momentum.

Furthermore, they will be able to solve problems involving:

5. the rotation of rigid bodies.
6. motion in a gravitational field.

Syllabus

1. **Linear Dynamics I**

   Differentiation of vectors, velocity and acceleration.

   Inertial frames and Newton I.

2. **Linear Dynamics II**

   Newton II.

   Equations of motion.

   Impulse.

   Forces.

   Action at a distance.

3. **Linear Dynamics III**

   Momentum conservation and Newton III.

   Applications of Newtonian mechanics.

4. **Linear Dynamics IV**

   Conservation principles in physics.

   Kinetic energy and work.

   Potential energy.

   Conservative forces.

5. **Rotational Motion I**

   Torque, vector product, rotation of coordinate axes and angular momentum.

   Polar coordinates.

6. **Conservation laws and isolated systems**

   Conservation of linear momentum.

   Internal forces for a collection of particles.

   Centre of mass.

7. **Angular momentum**

   Angular momentum and Newton II.

   Conservation of angular momentum.

8. **Rotational motion II**

Equation of motion; kinetic energy, angular momentum, moments of inertia, gyroscopes and precession.

9. **Gravitation**

Newton's Law of Gravitation

Kepler's Laws of Planetary Motion

Gravitational Potential Energy

Escape velocity

Satellites

Spherical mass distributions

Tidal forces

PHYS10121 Quantum Physics and Relativity (Core) SEM1

Prerequisites A-Level Physics and Mathematics

Follow up units PHYS10672, PHYS20101 and PHYS20602

Classes 22 lectures in S1

Assessment Tutorial work and attendance (5%)
Mid-semester test (10%)
1 hour 30 minutes examination in January (85%)

Recommended text

Forshaw, J. R. & Smith, G, *Dynamics & Relativity* (John Wiley & Sons)

Young, H. D. & Freedman, R.A., *University Physics* (Addison-Wesley)

Supplementary texts

Cox, B. E. & Forshaw, J. R. *Why does* $E=mc^2$*?* (*and why should we care?)* (Da Capo)

Cox, B. E. & Forshaw, J. R. *The Quantum Universe* (Allen Lane)

Rindler, W. *Relativity: Special, General & Cosmological (Oxford)*

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued.

Aims

1. To explain the need for and introduce the principles of the Special Theory of Relativity.
2. To develop the ability to use the Special Theory of Relativity to solve a variety of problems in relativistic kinematics and dynamics.
3. To explain the need for a Quantum Theory and to introduce the basic ideas of the theory.
4. To develop the ability to apply simple ideas in quantum theory to solve a variety of physical problems.

Learning outcomes

On completion successful students will be able to:

1. Define the notion of an inertial frame and the concept of an observer.
2. State the principles of Special Relativity and use them to derive time dilation and length contraction.
3. Perform calculations using the Lorentz transformation formulae.
4. Define relativistic energy and momentum, and use these to solve problems in mechanics.
5. Perform calculations using four-vectors.

6. Use the ideas of wave-particle duality and the uncertainty principle to solve problems in quantum mechanics.
7. Perform calculations using the quantum wave function of a particle moving in one dimension, including making use of the momentum operator.
8. Use the Bohr formula to calculate energies and wavelengths in the context of atomic hydrogen.

Syllabus

1. Relativity

Galilean relativity, inertial frames and the concept of an observer.

The principles of Einstein's Special Theory of Relativity

Lorentz transformations: time dilations and length contraction.

Velocity transformations and the Doppler effect.

Spacetime and four-vectors.

Energy and momentum with applications in particle and nuclear physics.

2. Quantum Physics

Basic properties of atoms and molecules. Atomic units. Avogadro's number.

The wavefunction and the role of probability.

Heisenberg's Uncertainty Principle and the de Broglie relation.

The momentum operator and the time-independent Schrödinger equation: the infinite square well.

Applications in atomic, nuclear and particle physics: energy levels and spectra and lifetimes.

Physics Core Unit

PHYS10180 Credit Rating: 20

PHYS10280 Credit Rating: 10

Lab Tutor: Dr. M. Lloyd

PHYS10180/PHYS10280 First Year Laboratory (Core) ALL YEAR/SEMESTER 1

Aims and Learning Outcomes These are presented in Appendix 2 of the Undergraduate Handbook

Prerequisites A-level Physics, A-level Mathematics

Follow-up courses PHYS20180 / PHYS20280 Second Year Laboratory

Classes

One day per week throughout the session on either Monday or Thursday. Laboratory times are 11.00-1.00 and 2.00-5.00. Attendance is obligatory.

See also PHYS10181F: Special Topics, which is formally part of First Year Laboratory but is taught and assessed separately from the rest of the First Year Laboratory programme.

Recommended Texts

There are no specific textbooks for First Year Lab. The main first year textbook, Young & Freedman's University Physics, is likely to be useful for understanding the physics behind most of the experiments. Students should also read through the pre-lab material for their experiments on Blackboard before the start of each lab block.

Feedback

Oral feedback will be given by demonstrators during the lab sessions and the assessment interviews at the end of each experiment. An annotated copy of each Lab Report will be returned to the student and the marker will discuss their comments with students. Students are also sent an email copy of each experiment assessment and lab report Feedback & Marksheet.

Organisation

The general first year teaching laboratories are located on the 1st and 2nd floor of the Schuster Annexe. Digital and Circuits labs are in the electronic lab on the 3rd floor of Schuster.

A demonstrator is assigned to each pair of students for the duration of each experiment. The demonstrator gives guidance and instruction and may be consulted at any time during the laboratory hours. Each laboratory has a dedicated technician who maintains the equipment. Various items of equipment and text books can be borrowed from the Lab Technician's office.

The laboratory unit includes modules on Data Analysis (PHYS10181B) and Special Topics in Physics (PHYS10181F), which all students take. Those students not taking PHYS10191 Introduction to Astrophysics and Cosmology will do the PHYS10181L Geometric Optics module as part of their lab package. All students taking the full year lab programme (PHYS10180) will do the Digital Electronics PHYS10180E and Circuits PHYS10182C modules during the course of the year. Arrangements for the PHYS10181B Data Analysis module and details of the lab timetable for the year will be given in the introductory talk during Welcome Week.

Assessment

Student performance on each experiment is assessed by the demonstrator during the course of the experiment and by a final interview. Assessment takes into account: physics understanding, experimental skill and results, quality of data analysis, uncertainties and final results, and quality of notes in lab notebook.
Lab reports are marked by a demonstrator. The assessment takes into account the layout and presentation of the report, content and arrangement of material, and technical writing style.

The final mark for each semester is calculated from a weighted average of the marks for each individual component.

Final Mark for Semester 1:
Experiment A: 15%
Experiment B: 22%
Experiment C: 22%
Report 1: 9%
Report 2: 17%
Special Topics: 15%

Final Mark for Semester 2:
Experiment D: 22%
Experiment E: 22%
Experiment F: 22%
Experiment G: 16%
Report 3: 18%

Late Experiment Assessment Interviews

Experiment assessment interviews must normally be completed during the final day of each lab experiment block. Late interviews are only permitted at the Demonstrator's discretion, for example if a student has an authorised absence on the normal interview day. Any interview not completed before the end of the next lab block will result in a mark of 0 being awarded for that experiment. For Block C (end of semester 1), the late interview deadline will be the end of week 2 of semester 2, and for Block G (end of semester 2) the late interview deadline will be two calendar weeks after the normal interview day.

Late Lab Reports

Reports are treated as coursework and any reports submitted after the published submission deadline are subject to standard University penalties as detailed in Section 10.1 of the Undergraduate Handbook "Where a student has a DASS recommended coursework deadline extension, please note that this will only apply to submission of your final (individual) lab report, not to any reports written jointly with your lab partner".

Work and Attendance Requirements for First Year Laboratory

Attendance at each lab session is compulsory.

The overall pass mark for lab is 40%. Any student who does not achieve the overall pass mark, or who achieves the pass mark but has one or more component marks of 0, may be required to submit further assessments, based on work already carried out, or to complete additional work during the summer resit period as directed by the Lab Tutor.

PHYS10180E Digital Electronics (Core) SEMESTER 1

Prerequisites	A-level Physics
Follow-up units	PHYS20181E
Classes	Three days laboratory in S1, which will include lecture material
Assessment	Ten minute interviews on the third day of laboratory. The credit rating is part of the Laboratory credit rating.

Feedback

Feedback will be offered orally by demonstrators in lab sessions, and orally by demonstrators after the interview. Students will also receive an email copy of the Feedback & Mark sheet after the interview.

Aims

To achieve a basic understanding of logic systems and to use this understanding in simple circuit designs.

Learning outcomes

On completion successful students will be able to:

1. Describe and explain basic logic gates, Boolean algebra and binary numbers.
2. Indicate how particular logical functions may be implemented and design systems to implement simple truth tables.
3. Illustrate how binary addition may be implemented using logic gates.
4. Describe latches and simple memory devices.
5. Categorize the progression from latches to flip-flops and describe the operation of the J-K flip-flop.
6. Be able to use and predict the behaviour of simple circuits involving J-K flip-flops.
7. Explain excitation tables and demonstrate their use to design simple cyclic circuits.

PHYS10181B Data Analysis (Core) SEMESTER 1

Prerequisites A-level Physics, A-level Mathematics

Classes 1 day in weeks 1, and 2 of S1

Assessment The material in this unit is assessed as part of the lab experiment and report assessments

The material is essential for laboratory (PHYS10180/10280).

The credit rating is part of the Laboratory credit rating.

Feedback

Feedback will be offered orally by demonstrators in lab sessions.

Recommended texts

Squires, G.L. *Practical Physics*, 4th edition (Cambridge, 2001).

A data-analysis summary is available on Blackboard.

Aims

1. To develop the appropriate skills and confidence to use computers for the tasks required in laboratory work.
2. To introduce the basic concepts and methods required for laboratory data analysis.
3. To develop sound judgement in interpreting experimental results and uncertainties.
4. To develop the skills required for good scientific communication.

Learning outcomes

On completion successful students will be able to:

1. Use python commands and scripts to manipulate and present experimental data in the form of graphs and tables.
2. Estimate the precision of experimental results, from an understanding of the experimental procedure and from a statistical analysis of repeated measurements.
3. Calculate the uncertainty in quantities derived from experimental results of specified precision.
4. Round numerical values and uncertainties sensibly.
5. Use the method of least squares-fitting and interpret chi-squared, χ^2.
6. Distinguish between random and systematic errors.

PHYS10181F Special Topics in Physics (Core) ALL YEAR

Prerequisites	None
Follow up units	PHYS20811/20821
Classes	6 lectures in weeks 1-5 & 7 of S1
Assessment	Peer assessment of a pamphlet produced through group work
Recommended text	Recommended reading will be given by the lecturers

Feedback

Groups will offer one another written feedback.

Aims

1. To promote awareness of selected topics at the forefront of modern-day research in physics.
2. To introduce and develop group-working skills.
3. To enhance writing and written presentation skills.
4. To develop skills in assessing the quality of one's own and others' work.

Learning outcomes

On completion successful students will be able to:

1. gather information on a subject which goes substantially beyond that provided in lectures.
2. work in a group to produce a piece of work which promotes physics as an interesting area of study.
3. recognise the demands of group work.
4. grade their own and other's work against specified assessment criteria.

Course structure

Students will attend a series of specialist lectures on selected topics at the forefront of modern day research in physics and a session introducing the project and group working. In the weeks following the lectures they will work together in small groups to produce a short booklet on one of the topics discussed in the lectures. The booklet should be designed for students studying A-level physics and aim to convey the excitement of modern-day physics to them. Students will be expected to research beyond the material presented in the lectures in order to produce an informative and attractive piece of work. Each group will assess and grade their own booklet along with a number of booklets from other groups, and these grades will form the basis of the final course assessment.

PHYS10181L Geometric Optics (Core) ALL YEAR

Prerequisites A-level Physics, A-level Mathematics

Classes Three days laboratory.

Assessment See PHYS10280 / 10180 First Year Laboratory

Feedback

See PHYS10280 / 10180 First Year Laboratory

Aims

1. To introduce geometric optics and the use of ray diagrams using lenses and mirrors.
2. To understand how simple optical instruments work.

Students who do not take PHYS10191 Introduction to Astrophysics and Cosmology must take this module as part of their First Year Lab course, as it covers the core Geometric Optics content from that course.

Learning outcomes

On completion successful students will be able to:

1. DRAW ray diagrams to predict the position and size of images in optical systems.
2. Use the mathematical formulae to predict the position and size of images produced by simple lenses.
3. Measure the focal length of lenses and mirrors using various methods.
4. Measure the refractive index of a convex lens.
5. Explain the origin of spherical and chromatic aberrations in lenses.

Syllabus

1. Produce ray diagrams to predict the position and size of the image produced by simple lenses.
2. Use the Thine Lens Formula to calculate the position and size of the image produced by simple lenses.
3. Measure the focal length of a simple convex lens by producing an image of a distant object.
4. Calculate the focal length of a simple lens by making measurements of image and object distance and using the lens equation.
5. Calculate the focal length of a convex lens by making measurements of the magnification.
6. Calculate the focal length of a concave lens using the lens equation.
7. Determine the refractive index of a lens using the lensmaker's equation.
8. Investigate chromatic and spherical aberration.
9. Construct a simple Newtonian telescope.

PHYS10182C Circuits (Core) SEMESTER 2

Prerequisites A-level Physics, PHYS10071

Classes Three days laboratory in S2 which will include lecture material

Assessment Each pair of students is allocated a demonstrator who helps and monitors progress throughout the course. The assessment is on-going and students are given their marks after a short interview in the laboratory at the end of the third day. Theory is examinable as part of PHYS10302 Vibrations and Waves.

Recommended texts The basic theory is adequately covered in the course script. Any good first year textbook on electromagnetism is suitable for further reading. Some material is also covered in PHYS10071 Mathematics 1 and PHYS10342 Electricity and Magnetism.

Feedback

Feedback will be provided to the students after their assessment interviews for each section that they complete.

Aims

To ensure that students can competently use an oscilloscope and to foster an understanding of the way electrical signals are shaped by passive circuit elements.

Learning outcomes

On completion successful students will be able to:

1. Describe the behaviour of capacitors and inductors.
2. Observe and explain transients.
3. Design and build integrating and differentiating circuits.
4. Explain ringing, damping and Q-factors in resonant circuits, including critical damping.
5. Use complex notation and complex impedances for:

   Determination of amplitude and phase

   Resonant circuits

   Low-pass and high-pass filters

   A.C. bridges

Structure

The course is divided into three parts, each consisting of a number of experimental and theoretical tasks. Students are expected to complete a minimum number of these tasks each day. Slightly more demanding experiments may be done by students who quickly complete the minimum requirement.

Syllabus

1. Elementary circuit theory – discrete components, Kirchoffs laws and complex analysis
2. Semiconductor amplifiers – real and ideal systems
3. Positive feedback, oscillators and control loops
4. Analogue – to – digital conversion

PHYS10191 Introduction to Astrophysics and Cosmology (Core) SEM1

An introduction to astronomy with emphasis on the physical processes involved.

Prerequisites	A-level Physics
Follow-up units	PHYS10692 and Astrophysics options in later years
Classes	22 lectures in S1
Assessment	Tutorial work and attendance (5%)
	Mid-semester test (10%)
	1 hour 30 minutes examination in January (85%)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, for which model answers will also be issued.

Recommended texts

Carroll, B.W. & Ostlie, D.A., *An Introduction to Modern Astrophysics* (Pearson)

This book covers considerably more material than covered in this module. This additional material will be valuable for future modules in astrophysics.

Maoz, D, *Astrophysics in a Nutshell, 2nd edition* (Princton University Press)

Most of the topics in the course are covered in this book at the appropriate level, but a few topics are not covered.

Aims

To demonstrate how the basic physical laws explain the properties of astronomical objects and the Universe and how these properties are measured.

Learning outcomes

On completion successful students will be able to:

1. Carry out calculations in using common astrophysical units;
2. Describe and explain the physics of detectors and telescopes including geometric optics;
3. Explain how astronomical distances are measured;
4. Use the basic laws of physics to explain the global properties and basic evolution of stars;
5. Derive Kepler's Laws and apply them with Newton's laws and theorems to a range of astrophysical objects including extrasolar planets;
6. Describe the structure of the Milky Way and other galaxies;
7. Describe the fundamental constituents of the Universe: baryons, dark matter and dark energy, and the observational evidence for their presence;
8. Describe and explain the evolution of our Universe, including the evidence for the Big Bang.
9. Use the equations which describe the evolution of the Universe to derive properties of the Universe.

Syllabus

1. **The Universe and its physics:** A tour of the Universe, its scale and contents; Gravity; Pressure; Radiation

2. **Observational astronomy:** the electromagnetic spectrum; geometrical optics; resolving power, and the diffraction limit; telescopes and detectors; gravitational waves

3. **Distances:** parallax measurements, standard candles

4. **Physics of the Sun and Stars:** blackbody radiation, the Planck, Stefan-Boltzmann and Wien laws, effective temperature, interstellar reddening); hydrogen spectral lines and Doppler effect); Hertzprung-Russell diagram; Freefall and Kelvin-Helmholtz time; nuclear fusion; basic stellar structure (hydrostatic equilibrium, equation of state); white dwarfs, neutron stars, and black holes

5. **Planetary systems:** Kepler's laws; Detection methods of extrasolar planets; search for life elsewhere; SETI.

6. **Galaxies:** Star formation and the interstellar medium; stellar populations; galaxy rotation curves, mass and dark matter; Galaxy collisions; central engines

7. **Cosmology:** Olber’s paradox, Hubble's Law; the age of the Universe; Evolution of the Universe: Madau diagram; Evidence for the Big Bang (blackbody radiation, nucleosynthesis); dark energy and the accelerating Universe.

PHYS10302 Vibrations and Waves (Core) SEM2

Prerequisites PHYS10071, A level Physics

Follow-up units PHYS10182C, PHYS20101, PHYS20171, PHYS20181E, PHYS20312, PHYS20401

Classes 24 lectures in S2

Assessment Tutorial work and attendance (5%)

1 hour 30 minutes examination in May/June (95%)

Recommended texts

Printed summaries will be downloadable.

King G.C., *Vibrations and Waves* (Manchester Physics Series, Wiley, 2009)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued.

Aims

To explore the detailed behaviour of vibrating systems and wave motion in different physical systems.

Learning outcomes

On completion successful students will be able to:

1. describe and quantitively analyse the behaviour of oscillating systems and wave motion.
2. apply the mathematical formalism that describes them.
3. recognise examples of oscillating systems and wave motion across many areas of physics.

Syllabus

1. Simple harmonic motion (SHM): Energy in a vibrating system.
2. Damped SHM, Q values and power response curves.
3. Forced SHM, resonance and transients.
4. Coupled SHM. Normal modes.
5. Waves. The 1-D wave equation.
6. Waves at interfaces. Wave energy and power. Standing Waves.
7. The wave equation in 2-D and 3-D. Superposition.

8. Phase and group velocity. Beats. Dispersion.
9. Intereference and diffraction.
10. The Schrödinger equation: finite wells, potential steps and barriers. Tunnelling.

Examples of vibrating systems and waves will be given in the lectures and on the problem sheets.

PHYS10342 Electricity and Magnetism (Core) SEM2

Prerequisites A-level Physics, PHYS10071

Follow-up units PHYS20141, PHYS30141, PHYS30441

Classes 24 lectures plus workshops in S2

Assessment Tutorial work and attendance (5%)

1 hour 30 minutes examination in May/June (95%)

Recommended texts

Grant, I. S. & Phillips, W. R. *Elements of Physics* (OUP)

Halliday, Resnick, Walker, *Fundamentals of Physics* (Wiley)

Tipler, P. A., *Physics for Scientists and Engineers* (Freeman)

Young, H. D. & Freedman, R. A. *University Physics* (Addison-Wesley)

Supplementary and Further Reading (See comments in lectures)

Dobbs, E. R. *Basic Electromagnetism* (Chapman-Hall)

Duffin, W. J. *Electricity and Magnetism* (McGraw-Hill)

Feynman, *Lectures in Physics Volume 11*

Grant, I. S. & Phillips, W. R. *Electromagnetism* (Wiley)

Griffiths, D. J. *Introduction to Electrodynamics* (Wiley)

Kip, A. F. *Fundamentals of Electricity and Magnetism* (McGraw Hill)

Schey, H. M. *Div, Grad, Curl and All That* (Norton)

Feedback

Feedback will be given by tutors on students' written solutions to examples sheets and model answers will be issued.

Aims

To develop a basic understanding of electric and magnetic fields in free space using the integral forms of Maxwell's laws.

Learning outcomes

On completion successful students will be able to:

1. describe the electric field and potential, and related concepts, for stationary charges.
2. calculate electrostatic properties of simple charge distributions using Coulomb's law, Gauss's law and electric potential.
3. describe the magnetic field for steady currents and moving charges.

4. calculate magnetic properties of simple current distributions using Biot-Savart and Ampere's laws.
5. describe electromagnetic induction and related concepts, and make calculations using Faraday and Lenz's laws.
6. describe the basic physical content of Maxwell's laws in integral form.

Syllabus

1. **Introduction**

   Forces in nature; electric charge and its properties; vectors, fields, flux and circulation.

2. **Electric Fields and Stationary Charges**

   Coulomb's law and superposition; electric field and potential; capacitance; electric dipoles; energy in electric fields.

3. **Magnetic Fields and Steady Currents**

   Magnetic fields; Lorentz force; Biot-Savart and Ampère's laws; magnetic dipoles.

4. **Electrodynamics**

   Electromotive force; electromagnetic induction; Faraday and Lenz's laws; inductance; energy in magnetic fields.

5. **Maxwell's Equations**

   Maxwell's fix of Ampère's law; Maxwell's equations in integral form.

PHYS10352 Physics Core Unit
Dr. P. W. Mitchell and Dr M Godfrey Credit Rating: 10

PHYS10352 Properties of Matter (Core) SEM2

Prerequisites: PHYS10071, PHYS10121
Co-requisite: PHYS10372

Follow-up units: PHYS20252**,** PHYS20352, PHYS40352, PHYS40451, PHYS40752

Classes: 24 lectures in S2

Assessment: Tutorial work and attendance (5%)

1 hour 30 minutes examination in May/June (95%)

Recommended texts:

Young, H.D., Freedman, R. *University Physics* (Addison-Wesley)

Supplementary texts:

Flowers, B.H., Mendoza, E. *Properties of Matter* (Wiley)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly example sheets, and model answers will be issued.

Aims

1. To show how the properties of macroscopic bodies can be derived from the knowledge that matter is made up from atoms.
2. To develop the ideas of classical thermodynamics.

Learning outcomes

On completion successful students will be able to:

1. Describe and explain the first and second laws of thermodynamics, and the concept of entropy;
2. Define and derive the fundamental thermodynamic relation;
3. Use the formalism of thermodynamics and apply it to simple systems in thermal equilibrium;
4. Describe techniques for finding appropriate averages to predict macroscopic behaviour;
5. Apply these techniques to the calculation of the properties of matter.

Syllabus

1. Thermodynamics [12 lectures]

- The First Law: heat, work and internal energy. Functions of state. Reversibility
- The Second Law: from heat engines to entropy.

- Phase transitions: Gibbs Free energy, Clausius-Clapeyron equation, examples of phase transitions including Van der Waals gas.

2. Solids and liquids [6 lectures]

- Interactions between atoms: interatomic potentials and bonding.
- Introduction to crystal structure and Bragg's Law.
- Elasticity; Young, shear and bulk moduli.
- Bernoulli's equation and incompressible fluid flow.
- Liquid surfaces.
- Drag: viscose and turbulent drag forces.

3. Kinetic theory of gases [6 lectures]

- Boltzmann factor.
- Ideal gas equation and internal energy, including internal molecular modes.
- Maxwell velocity distribution, mean speed.
- Gas molecular collisions: mean free path.
- Transport properties of gases; viscosity, thermal conductivity and self-diffusion.

PHYS10372
Dr. D. Binks, Dr. S. Kay &
Dr. D. Pihler-Puzovic

Physics Core Unit
Credit Rating: 10

PHYS10372 Mathematics 2 (Core) SEM2

Prerequisites	PHYS10071
Follow up units	PHYS20141, PHYS20171, PHYS20672, MATH20502
Classes	24 lectures in S2, plus workshops
Assessment	Tutorial work and attendance (5%) 1 hour 30 minutes examination in May/June (95%)

Recommended texts

Martin, B. R. and Shaw, G. *Mathematics for Physicists* (Manchester Physics Series, Wiley).

Riley, K. F., Hobson, M. P. and Bence, S. J. *Mathematical Methods for Physics and Engineering*

Schey, H. M. *Div, Grad, Curl and All that*, 2nd ed. (Norton)

M. Boas, *Mathematical Methods in the Physical Sciences (3rd edition, Wiley)*

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued. Interactive feedback will be offered during the Workshop sessions.

Aims

To acquire the skills in vector calculus needed to understand Electromagnetism, Fluid and Quantum Mechanics. To acquire an introductory understanding of Fourier Series and their use in physics.

Learning outcomes

On completion successful students will be able to:

1. Explain the concepts of scalar and vector fields.
2. Describe the properties of div, grad and curl and be able to calculate the divergence and curl of vector fields in various coordinate systems.
3. Calculate surface and volume integrals in various coordinate systems.
4. Calculate flux integrals and relate them to the divergence and the Divergence Theorem.
5. Calculate line integrals and relate them to the curl and to Stokes' Theorem.
6. Apply the methods of vector calculus to physical problems.
7. Calculate the Fourier series associated with simple functions and apply them to selected physical problems.

Syllabus

1. **Differentiation and integration with multiple variables** (6 lectures)

Partial and total derivatives. Taylor's theorem for multivariable functions. Multiple integration over areas and volume; volumes, masses and moments of inertia. Use of limits in integrals. Methods of evaluation of multiple integrals. Cylindrical and spherical polar coordinates. The Jacobian matrix.

2. **Vector operators: div, grad and curl** (6 lectures)

Scalar and vector fields. Definition and uses of the gradient operator. The method of Lagrange multipliers. Definitions of divergence and curl. Combinations of div, grad and curl. The Laplacian. Vector operators in cylindrical and spherical polar co-ordinates.

3. **The Divergence Theorem, Stokes Theorem, conservative forces** (7 lectures)

Line integrals of scalar and vector fields. Surface integrals and flux of vector fields. Integral expression for divergence. Divergence theorem and its uses. Conservation laws; continuity equation. Integral expression for curl. Stokes' theorem and its uses. Definition of conservative field. Relation to potentials.

4. **Introduction to Fourier Series** (3 lectures)

Rationale for using Fourier series. The Dirichlet conditions. Orthogonality of functions. The Fourier coefficients, symmetry considerations. Examples of Fourier series. Complex representation of Fourier Series.

PHYS10461 Physics in Everyday Life (Option) SEM1

Prerequisites	A-level Physics and A-level Mathematics
Follow up units	Many topics will be met again in physics core and option modules
Classes	22 lectures in S1
Assessment	1 hour 30 minutes examination in January

Recommended text

There is no single recommended text. Where appropriate, examples will be taken from Young, H.D. and Freedman, R.A. *University Physics* (Addison Wesley)

Supplementary reading

Regular issues of New Scientist and Scientific American

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To use physics to explain a variety of phenomena and devices in everyday life

Learning outcomes

On completion successful students will be able to:

1. use the method of dimensions to help solve problems in physics
2. use orders of magnitude and estimations
3. describe and explain the physics basis of various everyday atmospheric phenomena
4. describe and explain the physics underlying various aspects of the human body, including sight and hearing
5. discuss how physics can be applied to sport
6. explain the physics behind a number of devices in modern technology

Syllabus

1. **Everyday life in context** (2 lectures)

   Units, length, energy and time scales in physics; the method of dimensions; estimating; ordering of magnitude.

2. **Physics in the Earth's atmosphere** (6 lectures)

   The Sun; the Earth's atmosphere as an ideal gas; pressure, temperature and density; Pascal's Law and Archimedes' Principle; Coriolis acceleration and weather systems; Rayleigh scattering; the blue sky; the red sunset; refraction and dispersion of light; the rainbow.

3. **Physics in the human body** (5 lectures)

   The eyes as an optical instrument; vision defects; Rayleigh criterion and resolving power; sound waves and hearing; sound intensity; the decibel scale; energy budget and temperature control.

4. **Physics in sports** (5 lectures)

   The sweet spot; dynamics of rotating objects; running, jumping and pole vaulting; motion of a spinning ball; continuity and Bernoulli equations; Bending it like Beckham; the Magnus force; turbulence and drag.

5. **Physics in technology** (4 lectures)

   Microwave ovens; the Lorentz force; the Global Positioning System; CCDs; lasers; displays

PHYS10471 Physics with Theoretical Physics Core Unit
Prof. R. Jones Physics Option Unit
Credit Rating: 10

PHYS10471 Random Processes in Physics (M) (C/O) SEM1

Prerequisites	A-level Physics and A-level Mathematics
Follow-up units	Theoretical Physics units
Classes	22 lectures in S1
Assessment	1 hour 30 minutes examination in January.

Recommended texts

A suitable introduction to probability can be found in:

Chapters 39 and 40 of *Mathematical Techniques*, 3rd edition, Jordan, D. & Smith, P.

Chapters 20 & 21 of *Mathematics for Engineers and Scientists,* Weltner, K., Gorsjean, J., Schuster, P. & Weber, W.

Chapter 3 of *Statistics,* Barlow, R.J.

Feedback

Feedback will be available on students' individual written solutions to examples sheets which will be marked and model answers will be issued, and through an optional mid-semester test.

Aims

To introduce and develop the mathematical skills and knowledge needed to understand and use probability theory in physics.

Learning outcomes

On completion of the course, students will be able to:

1. Be cognizant of and be able use appropriately, the fundamentals of probability theory.
2. Set up and solve models of physical processes involving randomness.
3. Be aware of and be able to critically apply, some of the important probability distributions that are used by physicists.

Syllabus

1. **Elements of probability** (4 lectures)

   Introduction: What is probability?

   How to calculate probabilities: permutations and combinations

   Conditional probability

2. **Probability distributions** (3 lectures)

Discrete random variables; expectation value and variance

Example: the geometric distribution

Continuous random variables; the probability density function

Examples: the uniform distribution; the normal (or Gaussian) distribution

3. **Exponential Probability Distribution** (4 lectures)

Probability of radioactive decay

Probability of collisions in a gas; mean free path

Generalisation: “hazard rate” and survival probability

4. **Poisson Probability Distribution** (5 lectures)

Probability of occurrence of *n* random events

Properties of the Poisson distribution

Gaussian limit of the Poisson distribution

5. **Binomial Probability Distribution** (6 lectures)

Binomial distribution for *n* trials

Irreversible expansion of a gas

Poisson and Gaussian limits of the binomial distribution

Random walks and diffusion

PHYS10622 Physics of Energy Sources SEM2

Prerequisites PHYS10071 and PHYS10121

Follow-up units PHYS30511 and PHYS40422

Classes 23 lectures in S2 or S4

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Jaffe, R.L & Taylor, W. *The Physics of Energy* (Cambridge University Press 2018)

King G. *The Physics of Energy Sources*

Krane K. S. *Introductory Nuclear Physics,* (Wiley 1987)

MacKay, D.J.C*. Sustainable energy – without the hot air* (UIT Cambridge 2009)

Twidell, J. W. & Weir, A. D. *Renewable energy resources,* (Spon 1986)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To understand the physical background and mechanisms associated with power generation and related issues.

Learning outcomes

On completion successful students will be able to:

1. understand the forms of energy, its production, transport and storage
2. understand basic nuclear physics and interactions with matter
3. understand the conditions necessary for sustainable chain reactions in fissile material
4. understand the design criteria for the control of a nuclear reactor
5. understand the principles of nuclear fusion useful in power generation and stellar fusion
6. understand physical ideas and issues associated with renewable forms of energy including solar, wind, waves, tidal and geothermal.

Syllabus

1. **Introduction – Energy requirements and climate impacts** (2 lectures)

   The greenhouse effect.

   Energy requirements, consumption.

2. **Biological forms of energy** (2 lectures)

   Fossil fuels.

   Energy transformation – Power plant.

   Biofuels.

3. **Basic Nuclear Physics** (3 lectures)

   The atom. Radioactivity and decay laws.

   Interaction of radiation with matter.

4. **Nuclear Fission** (3 lectures)

   Principles of nuclear fission.

   Chain reaction dynamics.

   Reactor types and control.

   Current status of nuclear fission as a power source.

5. **Nuclear Fusion** (3 lectures)

   Principle and energetics of nuclear fusion (in stars and on Earth).

   Thermonuclear fusion, fuels, ignition and the Lawson criterion.

   Magnetic and inertial confinement

   Current status of nuclear fusion as a power source.

   Stellar fusion, proton-proton chain and CNO cycle.

6. **Solar Power** (2 lectures)

   Solar thermal

   Solar photovoltaic

7. **Wind, waves, tides** (5 lectures)

   Power from fluids. Nature of wind, wind power. Wind turbines. Betz criterion.

   Principles of water waves, energy and power. Wave power extraction.

   Origin and properties of tides. Tidal stream power and tidal range power.

8. **Energy transportation and storage** (2 lectures)

Energy transportation

Hydro power

Batteries and fuel cells

9. **Review** (1 lecture)

PHYS10672 Physics with Theoretical Physics Core Unit
Prof. R. Battye Physics Option Unit
Credit Rating: 10

PHYS10672 Advanced Dynamics (M) (C/O) SEM2

Prerequisites PHYS10071, PHYS10101, PHYS10121

Follow-up courses PHYS20401, PHYS30441, PHYS30201, PHYS40202, PHYS40481, PHYS40771, PHYS40992.

Classes 24 lectures in S2 or S4

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Barger, V. D. & Olsson, M. G. *Classical Mechanics: a Modern Perspective,* (McGraw-Hill)

Forshaw, J. & Smith, A. G. *Dynamics and Relativity*, (Wiley)

Marion, J. B. & Thornton, S. T. *Classical Dynamics of Particles and Systems*, (Academic)

Spiegel, M. R. *Schaum's Outline of Theoretical Mechanics*, (McGraw-Hill Book Company).

Feedback

Feedback will be provided via solutions to the problem sheets, which will be made available electronically on Blackboard. More detailed feedback will be provided in example classes which are integrated within the 24 lectures.

Aims

To enhance knowledge and understanding of classical mechanics and relativity.

Learning outcomes

On completion successful students will be able to:

1. apply Newton's theory of gravitation to problems of planetary motion and space travel.
2. use inertial forces to explain motion from the viewpoint of rotating frames of reference.
3. derive the general relation between the angular velocity and angular momentum of a rigid body, and use this to solve problems in rotational dynamics.
4. solve problems in relativistic dynamics using the covariant formalism and energy-momentum four vectors.

Syllabus

1. **Preliminaries** (3 Lectures)

   Newton’s laws of motion

   Linear and angular momentum, Force and Torque

   The two-body system

2. **Gravitation** (6 Lectures)

   Force Fields and Potentials

   Newtonian gravity

   Kepler’s Motion in a Central Force Field

   Particle Orbits as Conic Sections and Kepler's laws

3. **Noninertial Frames of Reference** (3 Lectures)

   Motion in Rotating Frames

   Centrifugal and Coriolis Forces

4. **Rigid-Body Motion** (6 Lectures)

   Angular velocity and Angular Momentum

   The Moment-of-Inertia Tensor

   Principal Moments of Inertia

   Euler's Equations

   Free Rotation and Stability

   Gyroscopes

5. **Relativistic Dynamics** (6 Lectures)

   Principles of Special Relativity

   The Covariant Formalism

   Lorentz Transformations and Relativistic Invariance

   Relativistic Momentum and Energy

   Applications to Relativistic Kinematics

PHYS10692 Physics of the Solar System (C/O) SEM2

Prerequisites	A-level Mathematics, PHYS10071 or equivalent, PHYS10191
Follow-up units	Astronomy and astrophysics options in years 2, 3 and 4
Classes	24 lectures in S2 or S4
Assessment	1 hour 30 minutes examination in May/June

Useful references

An Introduction to the Solar System, revised ed., 2011, Rothery, McBride & Gilmour (Cambridge University Press)

Feedback

Students will receive feedback on a number of optional tutorial sheets .

Aims

To show how many Solar System phenomena may be understood in terms of the physics already known to first year students.

Learning outcomes

On completion successful students will be able to:

1. give a qualitative description of the Solar System and to know how the current picture emerged.
2. apply dynamical principles to understand phenomena such as tides and orbits in the Solar System.
3. make simple orbit calculations, based on energy and angular momentum conservation. Understand the basis of Kepler's laws and the Virial Theorem.
4. know what may be deduced about the Sun by considering it as a black body and body in hydrostatic equilibrium.
5. explain the basic principles behind the energy generation in the Sun.
6. gain some knowledge of planetary atmospheres and to understand the origin of the Earth's greenhouse effect.
7. gain some simple knowledge of the internal constitution of the planets.
8. know how planetary ring systems may be formed.
9. know the consequences of impacts in the Solar System.
10. understand in outline how the Solar System is thought to have formed and evolved.

Syllabus

1. **Overview of the Solar System**

   General description and inventory. Coordinates and time keeping.

2. **Gravity**

   Kepler's laws and Newton's law of gravity. Properties of orbits.

   The virial theorem. Tidal forces and tidal friction. Evolution of the Moon.

3. **The Sun**

   Freefall time scale and Kelvin Helmholtz time scale. Hydrostatic equilibrium.

   Nuclear reactions; Neutrinos. Helioseismology.

4. **Planetary atmospheres**

   Albedo and optical depth. Scale height; Escape. Reducing and oxidising atmospheres; Greenhouse effect; Ice ages.

5. **Planetary surfaces**

   Impact craters. Isotope dating.

6. **Planetary interiors**

   Liquid cores; Heat generation;

7. **The formation of the solar system**

PHYS10792 Introduction to Data Science (Option) SEM2

Prerequisites: -

Follow up units: -

Classes: 24 lectures in S2

Assessment: Online example sheets (15%)

1 hour 30 minutes examination in May/June (85%)

Recommended texts:

Barlow, R., *Statistics – A Guide to the Use of Statistical Methods in the Physical Sciences*, Wiley

Cowan, G., *Statistical Data Analysis*, Oxford

Behnke, O., et al, *Data Analysis in High Energy Physics: A Practical Guide to Statistical Methods*, Wiley

Feedback

Feedback is through exercises (via online feedback) and the exam.

Aims

- To introduce basics of statistical methods and modern day advanced data analysis techniques, as required in all fields working with data.
- To deepen the understanding of how data analysis works for small and large data samples.
- To obtain a comprehensive set of tools to analyse data.

Learning outcomes

On completion successful students will be able to:

1. Demonstrate an understanding of the basics of the statistical analysis of data.
2. Explain methods of data analysis and their idea.
3. Apply a set of analysis techniques as required for basic and advanced datasets.
4. Critically assess new results derived from datasets.
5. Use the knowledge of statistical data analysis to understand more advanced and new techniques.

Syllabus

1. Probabilities and Interpretations
2. Probability distributions
3. Parameter Estimation
4. Maximum Likelihood + extended maximum likelihood

5. Least Square, chi2, correlations

6. Monte Carlo basics

7. Probability and confidence level

8. Hypothesis testing

9. Goodness of fit tests

10. Limit setting

11. Introduction to Multivariate Analysis Techniques

PHYS20101 Physics Core Unit
Prof. M. Seymour Credit Rating: 10

PHYS20101 Introduction to Quantum Mechanics (Core) SEM1

Prerequisites	PHYS10071, PHYS10101, PHYS10302 PHYS20171 is recommended as co-requisite
Follow-up courses	PHYS20252, PHYS20352, PHYS30101, PHYS30201, PHYS40202
Classes	22 lectures in S3
Assessment	Tutorial work and attendance (5%) 1 hour 30 minutes examination in January (95%)

Recommended texts

Phillips, A.C. *Introduction to Quantum Mechanics* (Wiley)

French, A.P. & Taylor, E.F. *An Introduction to Quantum Physics* (Thomas Nelson)

For general background reading

ed. Manners, J. *Quantum Physics: an Introduction* (IOP in association with the Open University)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly example sheets, and model answers will be issued.

Aims

To introduce the fundamental ideas of quantum mechanics that are needed to understand atomic physics.

Learning outcomes

On completion successful students will be able to:

1. Understand how quantum states are described by wave functions.
2. Deal with operators and solve eigenvalue problems in quantum mechanics.
3. Solve the Schrödinger equation and describe the properties of the simple harmonic oscillator.
4. Deal with algebra of angular momentum operators and solve the simple eigenvalue problems of an angular momentum in quantum mechanics.
5. Use quantum mechanics to describe the hydrogen atom.
6. Use quantum mechanics to describe the properties of one-electron atoms.
7. Use quantum mechanics to describe the simple multi-electron systems such as helium atom and hydrogen molecule.

Syllabus

1. **Basic Elements of Quantum Mechanics** (2 lectures)

   Time dependent Schrödinger equation and time evolution.

2. **Commutators and compatibility** (2 lectures)

   Operators and quantum states, commutation relations and compatibility of different observables.

3. **The harmonic oscillator** (2 lectures)

   Stationary states, energy levels of simple harmonic oscillator, vibrational states of a diatomic molecule.

4. **Orbital angular momentum** (4 lectures)

   Particle in two dimensions (eigenfunctions and eigenvalues of Lz), particle in three dimensions (eigenfunctions and eigenvalues of L2 and Lz), rotational states of a diatomic molecule.

5. **Particle in a central potential** (2 lectures)

   Motion according to classical physics, quantum states with certain E, L2 and Lz and the radial time-independent Schrödinger equation, energy levels and eigenfunctions for the Coulomb potential.

6. **Hydrogen Atom** (2 lectures)

   Energy levels, size and shape of energy eigenfunctions, effect of finite mass of nucleus, EM spectrum, hydrogen-like systems.

7. **One-electron atoms in more details** (4 lectures)

   Electron spin, Sten-Gerlach experiment, magnetic moments, orbital and total angular momentum. Spin-orbit interaction, perturbation theory (1st order). Zeeman effect. Parity, radiative transitions and selection rules.

8. **Multi-electron atoms** (4 lectures)

   Wave functions of identical particles. Exchange symmetry. Pauli exclusion principle. Energy states of He atom. Hartree theory. X-ray spectra. Hund's rules.

PHYS20141 Electromagnetism (Core) SEM1

Prerequisites	PHYS10071, PHYS10342, PHYS10372
Follow-up units	PHYS20312, PHYS30141, PHYS30441
Classes	22 lectures in S3
Assessment	Tutorial work and attendance (5%) 1 hour 30 minutes examination in January (95%)

Recommended texts

Grant, I.S. & Phillips, W.R. *Electromagnetism* (2nd ed.) (Wiley)

Griffiths, D.J. *Introduction to Electrodynamics* (4th ed.) (Cambridge Uni. Press)

Useful references

Bleaney, B.I. & Bleaney B. *Electricity & Magnetism* (3rd ed.) (Oxford Uni. Press)

Duffin, W.J. *Electricity and Magnetism* (4th ed.) (Duffin, previous eds. McGraw-Hill)

Jackson, J.D. *Classical Electrodynamics* (3rd ed.) (Wiley)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly example sheets, and model answers will be issued.

Aims

To introduce Maxwell's equations and use them to derive properties of electromagnetic waves; to introduce simple models for the interaction of electromagnetic fields with matter.

Learning outcomes

On completion successful students will be able to:

1. Derive Maxwell's equation set from the empirical laws of electromagnetism.
2. Use the fundamental laws of electromagnetism to solve simple problems of electrostatics, magnetostatics and electromagnetic induction in a vacuum.
3. Modify Maxwell's laws to apply in the presence of materials and solve problems involving them.
4. Derive the electromagnetic boundary conditions which apply at the interface between two simple media, and to use them to solve problems involving two or more materials.
5. Explain the properties of plane electromagnetic waves in a vacuum and in simple media and to be able to derive these properties from Maxwell's equations.

Syllabus

1. **Mathematical Preliminaries** (2 lectures)

   Revision of Vector Calculus; Dirac δ-function and point particles; Laplace's & Poisson's equations and their uniqueness theorem.

2. **Maxwells equations in a vacuum** (7 lectures)

   Continuity equation; Integral forms of Maxwell's equations; Differential forms of Maxwell's equations; Potential formulation; Electrostatics and magnetostatics as the time independent limit; Calculation of field configurations; Electric and magnetic dipoles; Connections between electromagnetism and special relativity.

3. **Electromagnetic effects in simple materials** (8 lectures)

   Conductors: mechanisms for conduction; the method of images and the motion of particles near a conductor. *Dielectrics:* capacitance, relative permittivity; polarization & electric susceptibility; mechanism for polarization; electrostatics in a dielectric; Interfaces between dielectrics. *Magnetism:* inductance & permeability; magnetization & magnetic susceptibility; diamagnetism and paramagnetism; magnetostatics. *Ferromagnetism:* ideal ferromagnets; hysteresis.

4. **Electromagnetic waves** (5 lectures)

   Maxwell's equations in free space; Plane waves; Wave solutions for **E** & **B** fields; Poynting vector, irradiance & radiation pressure; Polarization of EM waves; Reflection of EM waves at a perfect conductor; EM waves in the presences of a current; EM waves in a dielectric.

PHYS20161 Introduction to Programming for Physicists (Core) SEM1

Prerequisites None

Follow-up units PHYS20762, PHYS30762

Classes 10 lectures plus 10 half-day laboratory sessions in S3

Assessment 5 online quizzes (25%)
3 individual assignments (10%, 20% and 45%)

Note: Laboratory facilities are not available for resits. A student who has failed may be permitted to submit further assessments, based on laboratory work already carried out, in order to pass the course unit.

Recommended texts Hill, C. *Learning scientific programming with python* (Cambridge Uni. press)

Feedback

Feedback is offered orally by demonstrators in the lab, automated responses in the quizzes, and specific written comments for each assignment.

Aims

The aim of the course is to give a practical introduction to computer programming for physicists assuming little or no previous programming experience.

Learning outcomes

On completion successful students will:

1. Be able to write programs in Python to aid them in practical situations they will face in their degree course and future work in physics or in other fields.

2. Implement basic programming theory to write efficient code.

Syllabus

Elements of Programming – (3 weeks)

1. Introduction to Phython
2. Variable types and lists
3. Operators
4. Input / output
5. Conditional expressions
6. Loops
7. Introduction to debugging, testing and errors

8. Functions

Basic Python libraries and validation – (2 weeks)

1. Python Modules
2. Introduction to math and numpy
3. Numpy arrays, built-in functions and indexing

Introduction to algorithms and visualisation – (3 weeks)

1. Algorithms and their uses
2. Basic manipulation and visualisation of data
3. Read and write files
4. Data validation
5. Root finding
6. Basic optimization algorithms

Introduction to scientific programming libraries – (3 weeks)

1. Advanced uses of numpy and matplotlib
2. Introduction to scipy
3. Using inbuilt functions

PHYS20171 Physics Core Unit
Prof. J. Forshaw Credit Rating: 10

PHYS20171 Mathematics of Waves and Fields (Core) SEM1

Prerequisites	PHYS10071, PHYS10302, PHYS10372
Follow-up units	PHYS30101, PHYS30201, PHYS30141, PHYS30441, PHYS30672
Classes	22 lectures in S3
Assessment	Tutorial work and attendance (5%)
	1 hour 30 minutes examination in January (95%)

Recommended texts

Boas, M.L. *Mathematical Methods for Physical Sciences,* 3rd edn. (Wiley, 2006)

Martin, B.R. & Shaw, G, *Mathematics for Physicists.* (Wiley 2015)

Riley, K.F. Hobson, M.P. & Bence, S.J. *Mathematical Methods for Physics and Engineering,* 3rd edn (Cambridge 2006) [Chapters 12 to 19]

Stephenson, G. *Partial differential equations for scientists and engineers* (Imperial College 1996)

Aims

To introduce and develop the mathematical skills and knowledge needed to understand classical fields and quantum mechanics.

Feedback

Students will receive feedback on their work and performance in this module as a component of their weekly tutorial meeting with their academic tutor.

Learning outcomes

On completion successful students will be able to:

1. Solve partial differential equations using the method of separation of variables.
2. Define the term "orthogonality" as applied to functions, and recognise sets of orthogonal functions which are important in physics (e.g. trigonometric functions and complex exponentials on appropriate intervals, Legendre polynomials, and spherical harmonics).
3. Represent a given function as a linear superposition of orthogonal basis functions (e.g. a Fourier series) using orthogonality to determine the coefficients.
4. State how a Fourier transform differs from a Fourier series, and calculate Fourier transforms of simple functions.
5. Solve eigenvalue problems (differential equations subject to boundary conditions) either in terms of standard functions or as power series.
6. Use partial differential equations to model wave, heat flow and related phenomena.

7. Make basic use of Dirac notation.

Syllabus

1. **Wave problems in one dimension**

   Separation of variables

   Normal modes of a string: eigenfunctions and eigenvalues

   General motion of a string

2. **Fourier series**

   Orthogonality and completeness of sines and cosines

   Complex exponential form of Fourier series

3. **Other PDE's**

   Laplace's equation

   The heat-flow equation

4. **Integral transforms**

   Fourier transform

   Convolutions

   Wave packets and dispersion

5. **Special functions**

   Orthogonal sets of eigenfunctions

   Series solution of differential equations

   Legendre polynomials and related functions

   Bessel functions

6. **Problems in two and three dimensions**

   Normal modes of a square membrane; degeneracy

   Wave guide

   Normal modes of circular and spherical systems

   Heat flow in circular and spherical systems

   Laplace's equation: examples in cartesian and polar coordinates

7. **Dirac notation**

   Vector spaces

   Ket notation

   Inner products and Bras

   Hilbert spaces

Physics Core Unit
Credit Rating: 20
Credit Rating: 10

PHYS20180
PHYS20280
Lab Tutor: Dr. P. Walmsley

PHYS20180/ PHYS20280 Second Year Laboratory (Core) ALL YEAR

Aims and Learning Outcomes

These are presented in Appendix 2 of the Undergraduate Handbook.

Prerequisites	First Year Physics Core, PHYS10180/10280 or equivalent.
Follow-up unit	PHYS30180 / PHYS30280

Classes

One day per week on either Tuesday or Friday throughout the session.

Laboratory times are 10.00-5.00.

There may be reduced supervision over the lunch break, 1.00-2.00.

Attendance is obligatory.

Organisation

The second year teaching laboratory is located on the fourth floor and hosts experiments on general physics, electricity and magnetism, optics, vacuum and astrophysics. Nuclear physics experiments are located on the second floor and the electronics laboratory is on the third floor.

The laboratory unit includes Amplifiers and Feedback PHYS20181E if appropriate for a particular degree programme.

There are 20 laboratory days during the year and seven or eight experiments are performed. There is a mix of experiments designed to last approximately 2, 3 or 4 days.

Four Laboratory Reports (word processed) are required during the year. Submission dates will be posted well in advance and late reports will be penalised.

Feedback

During the conduct of the experiment, oral advice will be given throughout by demonstrators.

During interviews, advice on how to improve the measurement, analysis and presentation of results will be given orally and also written on the assessment sheets, copies of which will be given to the student.

In written reports, detailed comments on how the report might be improved are written on the reports. More general comments are written on the marked sheets, copies of which are returned to the students along with the marked reports. Students are strongly encouraged to collect their marked reports from the markers, when any written comments can be elaborated upon.

Assessment

Student performance on each experiment is assessed by the demonstrator/supervisor during the course of the experiment and by a final interview. Assessment takes into account: physics understanding, experimental skill and results, quality of data analysis, error analysis and final results, innovation, commitment, planning and quality of notes in Laboratory Notebook. For some of the experiments the interview includes a short oral presentation.

The relative weights are: each 2-day experiment (20), each 3-day experiment (30), each 4-day experiment (40), Laboratory reports (20, 20, 30, 30).

Late submissions of lab. Reports

The standard penalties as detailed in Section 10.1 of the UG Handbook will apply.

Late interview

Late penalties will be incurred if an interview is more than one week late. Interviews on S3 experiments must be completed by the end of week 2 of S4 or they will receive zero. Similarly interviews on S4 experiments must be completed by the end of week 13.

Students must satisfy the laboratory work and attendance requirements and obtain a pass (i.e. at least 40%) in order to proceed to the third year. Laboratory facilities are not available for resits. A student who has failed may be permitted to submit further assessments, based on laboratory work already carried out, if these are needed to satisfy work and attendance requirements or to pass.

PHYS20181E Amplifiers and Feedback (Core) ALL YEAR

Prerequisites PHYS10302, PHYS10182C

Follow-up units None

Classes 2 two-hour lectures and 3 days laboratory in S3

Each laboratory session will be preceded by a lecture describing the theoretical details of the experiments

Assessment Laboratory interview on completion of course.

The credit rating is part of the laboratory credit rating.

Feedback

Laboratory pairs will be allocated, and supported by, a demonstrator who will monitor progress and provide continuous feedback. Detailed feedback, with respect to the Learning Outcomes, will be provided after the assessment interview.

Aims

To understand how analogue signals may be amplified, manipulated and generated in a controlled manner, and how they may be interfaced to digital systems for subsequent processing.

Learning outcomes

On completion successful students will be able to:

1. To learn the behaviour of an ideal amplifier under negative (positive) feedback.
2. To be able to apply this to simple amplifier, summer, integrator, phase shifters and oscillator.
3. To test the limitations of a real amplifier.
4. To describe basic methods of analogue-to-digital conversion (ADC).

Syllabus

1. Elementary circuit theory – discrete components, Kirchoffs laws and complex analysis
2. Semiconductor amplifiers – real and ideal systems
3. Positive feedback, oscillators and control loops
4. Analogue-to-digital conversion

PHYS20252 Physics Core Unit
Dr. Y. Xian Credit Rating: 10

PHYS20252 Fundamentals of Solid State Physics (Core) SEM2

Prerequisites: PHYS20101, PHYS10302, PHYS10352, PHYS10372

Follow-up units: PHYS30151, PHYS40352, PHYS40451, PHYS40712, PHYS40752

Classes: 24 lectures in S4

Assessment: Tutorial work and attendance (5%)
1 hour 30 minutes examination in May/June (95%)

Recommended texts:

Eisberg, R.M. & Resnick, R. *Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles* (Wiley)

De Podesta, M. *Understanding the Properties of Matter*, 2nd ed (Taylor & Francis)

Hook, J.R. & Hall, H.E. *Solid State Physics*, 2/e (Wiley)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued.

Aims

To introduce the fundamental principles of solid state physics, taking wave motion in a crystal as the unifying concept; the waves include X rays, lattice vibrations and de Broglie waves of electrons. To show how the form of the electron wave functions, their energies, and their occupation by electrons help us to understand the differences between metals, insulators and semiconductors.

Learning outcomes

On completion, successful students will be able to:

1. Describe how wave motion in periodic structures leads to an understanding of the temperature dependence of specific heat, and calculate the phonon dispersion relation for a chain of atoms;

2. Explain how electron wave functions and energies are changed by the presence of the periodic crystal potential;

3. Demonstrate how the electrical properties of metals, insulators and semiconductors are related to their electronic structure;

4. Explain how simple semiconductor devices (such as the p-n junction) work.

Syllabus

1 **Molecules** (2 lectures)

Molecular orbital theory applied to covalent bonding. H_2^+ion. Hydrogen molecule.

2 **Cyrstal Bonding & Structure** (3 lectures)

Van der Waals, ionic, covalent and metallic bonding and their relation to crystal structure. Lattice, basis and unit cell. Some common 2D and 3D crystal structures. Diffraction of waves by a crystal, Bragg's Law.

3 **Lattice vibrations** (4 lectures)

Einstein model of specific heat. Vibrations of a one-dimensional chain of atoms. Diatomic chain; optical and acoustic modes. Extension to three dimensions; the [first] Brillouin zone; transverse and longitudinal modes. Quantized lattice vibrations [phonons]; crystal momentum of phonons. Debye model of specific heat.

4 **Electrons in solids** (5 lectures)

Effects of exchange antisymmetry for electrons in solids at zero temperature and low temperatures. Free-electron model of a metal; states of free electrons; density of states and Fermi surface; the metallic bond. The Fermi-Dirac distribution function. Weidemann-Franz Law. Electrical and thermal conductivity: scattering of electrons from crystal defects and phonons. Quantum description of electronic heat capacity.

5 **Interaction of electrons with the crystal lattice** (3 lectures)

Wave functions of electrons in a one-dimensional crystal; crystal momentum. Modification of free-electron dispersion relation; energy bands and band gaps. Classification of solids by their electrical properties at zero temperature: metals and insulators. Semi-classical dynamics of electrons; effective mass; holes. Hall effect.

6 **Semiconductors** (4 lectures)

Intrinsic and extrinsic semiconductors, donors and acceptors, *p-n* junction, light emitting diode, solar cell, quantum dots.

7 **Graphene** (1 lecture)

Introduction to the band structure and physical properties of graphene.

PHYS20312 Physics Core Unit
Dr. N. Jackson Credit Rating: 10

PHYS20312 Wave Optics (Core) SEM2

Prerequisites	PHYS20141, PHYS20171
Follow-up units	PHYS30611, PHYS40612, PHYS46111
Classes	24 lectures in S4
Assessment	Tutorial work and attendance (5%) 1 hour 30 minutes examination in May/June (95%)

Recommended texts

Hecht, E., *Optics,* (Addison Wesley)

Smith, F.G. & King, T.A. *Optics and Photonics - An Introduction* (Wiley)

Further Reading

Lipson, S.G., Lipson, H.S. & Tannhauser, D.S., *Optical Physics*, (Cambridge)

Jenkins, F.A. & White, H.E., *Fundamentals of Optics,* (McGraw Hill)

Feedback

Feedback will be offered by tutors on students' written solutions to weekly examples sheets, and model answers will be issued.

Aims

To develop the concepts of wave optics and establish a firm grounding in modern optics.

Learning outcomes

On successful completion students will be able to:

1. Use complex notation competently for wave phenomena
2. Solve problems which require the use of wave representations of electric and magnetic fields in propagating electromagnetic waves
3. Analyse simple examples of interference and diffraction phenomena
4. Explain the principles of operation of, a range of equipment used in modern optics, notably the Michelson interferometer and Fabry-Perot etalon
5. Apply the physics processes involved in producing laser radiation to solve simple problems

Syllabus

1. **Electromagnetism** (2 lectures)

   Recap of Maxwell's equations and the wave equation in a dielectric

   General solutions to the wave equation

   Particular solutions to the wave equation: plane & spherical waves

   Wavefronts, rays, Poynting vector; the time-averaged optical field

   Optical spectra – temporal and spatial frequencies

   Huygens' wavelets and Fermat's principle. Example: gravitational lenses

2. **Polarization** (5 lectures)

   Recap of polarization states; unpolarized and partially polarized light

   Polarization by reflection and scattering; Brewster's angle.

   Polaroid and Malus' law

   Optical anisotropy; wave equation in anisotropic media; birefringence; o- and e-rays; double refraction

   Polarizing beamsplitters and waveplates; Faraday rotators

3. **Interference** (6 lectures)

   Conditions for interference; temporal and spatial coherence

   Young's slits; Lloyd's mirror; multiple slits. Extended sources, outline of radio interferometry.

   The Michelson interferometer, LIGO. Fourier transform spectroscopy

   Thin films; Fabry-Perot etalon: resolution, FSR and finesse.

4. **Diffraction** (6 lectures)

   Fraunhofer diffraction: single and double slit, rectangular and circular apertures, resolution of optical instruments

   Fraunhofer diffraction as a Fourier transform; convolution

   The diffraction grating and spectrometers

   Fresnel diffraction: circular obstacles and half-period zones; straight edges

5. **Lasers** (4 lectures)

   Spontaneous and stimulated emission; absorption; Einstein coefficients

   Rate equations; population inversion and optical gain

   Optical cavities

   Steady state operation; threshold and efficiency

   An example laser system: Nd:YAG

PHYS20352 Physics Core Unit
Dr. J. McGovern Credit Rating: 10

PHYS20352 Statistical Mechanics (Core) SEM2

Prerequisites: PHYS10352, PHYS20101

Follow up units: Many third and fourth year units, especially PHYS30151

Classes: 23-24 lectures in S4

Assessment: Tutorial work and attendance (5%)
1 hour 30 minutes examination in May/June (95%)

Recommended texts:

Mandl, F., *Statistical Physics*, 2nd edition (Wiley)
Bowley, R. & Sanchez, M., *Introductory Statistical Mechanics*, 2nd edition (Oxford)
Zemansky, M.W. & Dittman, R.H., *Heat and Thermodynamics*, 7th edition (McGraw-Hill)
Steane, A.M., *A complete undergraduate course Thermodynamics* (Oxford University Press)
Blundell, S.J., Blundell, K.M., *Concepts in Thermal Physics* (Oxford University Press)

Feedback

Feedback is through weekly tutorials and marked tutorial work.

Aims

- To develop the statistical basis of classical thermodynamics
- To deepen the appreciation of the link between the microscopic properties of individual atoms or other particles and the macroscopic properties of many-body systems formed from them
- To demonstrate the power of statistical methods in different areas of physics
- To use the methods of quantum mechanics and statistical physics to calculate the behaviour of gases of identical particles, and to apply the results to a set of important physical system.

Learning outcomes

On completion successful students will be able to:

4. Explain the basic concepts of statistical mechanics, including entropy, its statistical interpretation and relation to disorder, and the statistical origin of the second law of thermodynamics;
5. Construct the canonical and grand-canonical partition functions for systems in thermal equilibrium, and use them to obtain thermodynamic quantities of interest.
6. Demonstrate an understanding of the implications of the indistinguishability of particles for systems of non-interacting quantum particles.

7. Write down the Bose-Einstein and Fermi-Dirac distribution functions, and apply them to calculate the properties of Bose and Fermi gases, for example in the context of White Dwarf stars and black-body radiation.
8. Explain the physical origin of Bose-Einstein condensation, to characterize it quantitatively, and to discuss experiments confirming Bose-Einstein condensation.

Syllabus

1. The statistical theory of thermodynamics (5 lectures)

Basic of probability theory; microstates and macrostates; the concept of ensembles; the statistical interpretation of entropy and temperature; isolated systems and the microcanonical ensemble

2. Statistical physics of non-isolated systems (8 lectures)

Derivation of the Boltzmann distribution and the canonical ensemble; the independent-particle approximation; the partition function and its connection with thermodynamics; examples of non-interacting systems (paramagnet set of harmonic oscillators – quantum and classical ideal gas, classical and quantum rotors). Equipartition theorem; Density of states. Grand-canonical ensemble and chemical potential.

3. Quantum gases (10 lectures)

Fermi-Dirac and Bose-Einstein distributions. The ideal Fermi gas: Fermi energy. Electronic heat capacity. White Dwarf stars. The ideal Bose gas: Photon gas blackbody radiation (Stefan’s Law and the Planck formula). Bose-Einstein condensation.

Physics with Theoretical Physics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS20401 Lagrangian Dynamics (M) (C/O) SEM1

Prerequisites PHYS10101, PHYS10302, PHYS10372

Follow-up units PHYS30441, PHYS30201, PHYS40202, PHYS40771, PHYS40992

Classes 22 lectures in S3

Assessment 1 hour 30 minutes examination in January

Recommended texts

Kibble, T.W.B. & Berkshire, F.H. *Classical Mechanics*, 5th edition (Longman)

Goldstein, H., Poole, C. & Safko, J. *Classical Mechanics*, 3rd edition (Addison-Wesley)

Landau, L.D. and Lifshiftz, E.M. *Mechanics,* 3rd edition (Pergamon Press)

Feedback

Model answers will be issued within one week of issuing each example sheet. Informal Q&A sessions will be organised to allow students to clarify any questions on the lecture material or on the model answers.

Aims

To introduce the Lagrangian and Hamiltonian formulations of classical mechanics. To develop the knowledge and skills required to solve a variety of dynamical problems involving more than one degree of freedom.

Learning outcomes

On completion successful students will be able to:

1. Choose an appropriate set of generalised coordinates to describe a dynamical system and obtain its Lagrangian in terms of those coordinates and the associated 'velocities'. Derive and solve the corresponding equations of motion. Treat small oscillations as an eigenvalue problem.
2. Apply a variational principle to solve simple problems involving constraints.
3. Appreciate symmetries and how they manifest themselves in terms of constants of the motion.
4. Obtain generalised momenta and thus the Hamiltonian of a dynamical system. Derive and solve the equations of motion in Hamiltonian form.

Syllabus

1. **Introduction**

   Review of Newtonian mechanics: internal forces, external forces, forces of constraint. Rotational problems and polar coordinates.

   Conservation laws and conservative systems.

   Partial derivatives.

2. **Lagrangian Dynamics**

   The energy method plus other conservation laws.

   The Lagrangian and Lagrange's equation.

   Small oscillations and normal modes.

3. **Calculus of Variations**

   Functional minimization.

   The Euler-Lagrange equations.

   Constrained variation.

   Hamilton's principle of least action.

   Lagrangian dynamics.

4. **The Hamiltonian Formalism**

   Legendre transformations.

   Generalized momenta, the Hamiltonian and Hamilton's equations.

   Phase space. Liouville's theorem

5. **Symmetries and Conservation Laws**

   Generators of transformations.

   Poisson brackets.

   Symmetries of the Lagrangian produce constants of motion. Noether's theorem.

6. **Normal Modes from Matrices**

   Normal modes from symmetries.

   Review of mathematics of matrices: eigenvalues and eigenvectors.

   Diagonalizing a matrix using its eigenvectors.

   Small oscillations as eigenvalue problems.

7. **Special Topics**

   Lagrangian for charged particle moving in electric and magnetic fields.

   Continuous systems: the Lagrangian Density.

PHYS20491 Galaxies (C/O) SEM1

Prerequisites	PHYS10191
Follow-up units	PHYS20692, PHYS40992
Classes	22 lectures in S3
Assessment	1 hour 30 minutes examination in January

Recommended texts

Binney, J. & Merrifield, M. *Galactic Astronomy* (Princeton University Press)

Sparke, L.S. & Gallagher, J.S. *Galaxies in the Universe* (CUP)

Combes, F. et.al. *Galaxies and Cosmology* (Springer)

Feedback

Feedback will be provided through comments and solutions to weekly online examples.

Aims

To understand the observed properties of galaxies in the context of the current hierarchical structure formation theory.

Learning outcomes

On completion of the course, students will be able to:

1. Classify galaxies using the Hubble scheme.
2. Discuss critically methods of distance measurement to galaxies.
3. Describe the properties and main components of the Milky Way and compare its properties to external galaxies.
4. Explain how to determine the mass of a galaxy and discuss the implication of this for the existence of dark matter.
5. Describe the winding dilemma and give simple explanations for spiral arms.
6. Describe the properties of galaxy clusters and groups and discuss the interactions between dark matter, gas and galaxies in clusters and groups.
7. Describe the properties of black holes in the centres of galaxies and their influence on the galaxy.
8. Describe the galaxy and dark matter structures that exist in the Universe and compare models for how the structure forms.

Syllabus

1. **Introduction – Our view of galaxies**

   Hubble and de Vaucouleurs classification schemes – the distance ladder and methods of measuring distances to Galaxies - luminosity function of galaxies – surface brightness magnitude – galaxy surveys.

2. **Our Galaxy – The Milky Way**

   principal components and their kinematics – stellar mass function - rotation curve – Oort constants - mass budget and evidence for dark matter – satellite streams – Galactic Centre.

3. **Disk galaxies**

   surface brightness distribution – Tully-Fisher relation: application as a distance measurement – dynamics of disk galaxies – origin of spiral arms- properties of Galactic bars.

4. **Elliptical galaxies**

   composition and structure - surface brightness distribution – King models and comparisons with globular clusters – the fundamental plane – black hole mass versus velocity dispersion relation – dynamics of elliptical galaxies.

5. **Groups, clusters and Galaxy formation**

   membership of galaxy groups and clusters – the Local Group – methods for estimating the mass of groups and clusters – morphology versus density relation for galaxies and for clusters of galaxies – classic and modern views of galaxy formation – open questions.

PHYS20612 Introduction to Photonics (Option) SEM2

Prerequisites PHYS10302, PHYS20141

Follow-up units PHYS30611

Classes 24 lectures in S4

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Milloni, P.W. & Eberly, J.H. *Lasers*

Smith, F.G. & King, T.A. *Optics and Photonics: An introduction* (Manchester Physics)

Wilson, J. & Hawkes, J.F.B. *Optoelectronics: An introduction* (Prentice Hall)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

This course introduces the concepts of photonics (the application and use of light in modern technologies) by discussing 4 broad themes, that of the properties of light, the production of light, the detection of light, and how information is encoded using light and different applications of these technologies. The course builds on the foundations laid in the 1st year and leads onto more advanced courses in lasers and photonics in later semesters. Short and long questions on various aspects of the course (with solutions) will be given during the course. All material will be available on Blackboard and on the school teachweb pages.

Learning outcomes

On completion of the course students should understand:

1. the nature of light and how to manipulate it for applications in photonics and related disciplines.

2. how light can be produced and how the properties of light can be determined.

3. how light can be used in communications systems.

4. application examples which have evolved from photonic techniques.

Syllabus (lectures not necessarily in this order)

1. **Nature of light and how it is manipulated** (7 lectures)

   Wave descriptions (spectrum, superposition, interference effects), photon effects (photoelectric effect, momentum, interaction with matter).

   Characteristics of light (polarization, coherence, monochomaticity), ways to define these mathematically (Stokes parameters, Jones vectors & matrices) and how to determine these characteristics.

2. **How light is produced – the LASER and LED** (8 lectures)

   Einstein A and B coefficients, rate equations, gain and losses, optical feedback, laser threshold, 3 and 4 level lasers, cavity stability, cavity modes, Gaussian beams.

   The LED and laser diode, p-n junction, heterojunction and stripe geometries.

3. **Detection of light radiation** (3 lectures)

   Light detectors: photomutiplier tubes, photodiodes.

   Generic system issues: sources of noise and signal-to-noise ratio, limitations on temporal response and effective bandwidth.

4. **Transmission and modulation techniques** (3 lectures)

   Delivery methods. Basics of optical fibre techniques: step index fibre; acceptance angles, single and multimode fibres, dispersion limitations, transmission characteristics.

   Acousto-optic and electro-optic techniques, LED switching, analogue and digital techniques using lasers, AM, FM, phase modulation techniques.

5. **Applications** (2 lectures)

   A selection of the following applications will be discussed:

   Digital communications

   Display systems (LCD's, plasmas etc)

   Range-finding systems and applications (LIDAR etc)

   More exotic applications (laser trapping, laser tweezering, different forms of measurements)

   Trends and new directions in photonic applications.

PHYS20672
Dr. M. Godfrey

Physics with Theoretical Physics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS20672 Complex Variables and Vector Spaces (M) (C/O) SEM2

Prerequisites	PHYS10101, PHYS10302, PHYS10372
Follow-up units	PHYS30672 and theoretical options in 4th year
Classes	24 lectures in S4
Assessment	1 hour 30 minutes examination in May/June

Recommended texts

Spiegel, M.R. et al. *Schaum's Outline of complex variables,* 2nd Ed. (Schaum's Outlines, 2009)

Riley, K.F. Hobson M.P. & Bence S.J. *Mathematical Methods for Physics and Engineers*, (CUP, 2006)

Boas, M.L. *Mathematical Methods for Physical Sciences,* 3rd edn. (Wiley, 2006)

Arkfen, G.B. and Weber, H.J. *Mathematical Methods for Physicists*, 6th Ed. (Academic Press, 2005)

Feedback

Feedback will be given orally at examples classes during the semester. Solutions to the problem sheets will be provided electronically.

Aims

To introduce students to complex variable theory and some of its many applications. To introduce the concept of vector space and some ideas in linear algebra.

Learning outcomes

On completion successful students will:

1. determine whether or not a given function of a complex variable is differentiable;
2. use conformal mappings of the complex plane to solve problems in 2D electrostatics, fluid flow and heat flow;
3. construct the Taylor-Laurent series for functions that are analytic in an annular region of the complex plane;
4. find the location and nature of the singularities of a function and determine the order of a pole and its residue;
5. use the residue theorem to evaluate integrals of functions of a complex variable, and identify appropriate contours to assist in the summation of series and the evaluation of real integrals;

6. find an orthonormal basis for a given vector space;
7. define the adjoint of a linear operator and determine whether a given operator is Hermitian and/or unitary;
8. use methods from this and prerequisite units to solve previously unseen problems in linear algebra, using Dirac's notation where appropriate.

Syllabus

1. **Complex variables** (8 lectures)

   Functions of a complex variable

   Functions as mappings

   Differentiation, analytic functions and the Cauchy-Riemann equations

   Conformal mappings

   Solutions of 2D Laplace equation in Physics

   Integration in the complex plane

2. **Contour integration** (8 lectures)

   Cauchy's Theorem

   Cauchy's integral formulae

   Taylor and Laurent Series

   Cauchy's Residue Theorem

   Real integrals and series

3. **Vector Spaces** (7 lectures)

   Abstract vector spaces

   Linear independence, basis and dimensions, representations

   Inner products

   Linear operators

   Hermitian and unitary operators

   Eigenvalues and eigenvectors

PHYS20692
Dr. P. Weltevrede

Physics with Astrophysics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS20692 Astrophysical Processes (C/O) SEM2

Prerequisites PHYS10101, PHYS10191, PHYS10352, PHYS20141

Follow-up units Useful for many 3rd and 4th year Astrophysics units

Classes 24 lectures in S4

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Dyson, J.E. & Williams, D.A. *The Physics of the Interstellar Medium* (2nd ed.) (IOP Publishing)

Rosswog, S. & Bruggen, M. *Introduction to High-Energy Astrophysics* (CUP)

Supplementary reading

Draine, B.T., Physics of the Interstellar and Intergalactic Medium, (Princeton)

Longair, M. S. *High Energy Astrophysics*, 3rd edition, (CUP)

Rybicki, G.B. & Lightman, A.P. *Radiative Processes in Astrophysics*

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To provide an introduction to a wide range of fundamental astrophysical processes and their role in modern astrophysics. These processes range from those which control the structure of the interstellar medium to those associated with supermassive black holes in the centre of galaxies. The observational signatures of these processes are identified, which cover the entire electromagnetic spectrum from radio to gamma-ray and include non-photonic tracers such as cosmic rays.

Learning outcomes

On completion successful students will be able to:

1. Explain fundamental physical processes such as
   a) shock waves
   b) accretion
   c) radiative transfer
   d) the physical mechanisms controlling the ionisation and temperature of atoms, molecules and dust and the processes responsible for the formation of complex species in space
1. Apply fundamental physical processes in contexts relevant in astrophysics
2. Describe the sky as seen across the electromagnetic spectrum and the involved radiation mechanisms
3. Relate observations of a wide range of astrophysical sources to their physical conditions.

Syllabus

a) Introduction: observations and astrophysical processes

b) Absorption and emission: radiative transfer and blackbody radiation

c) Grains and molecules in space

d) Shocks waves, supernovae and supernova remnants

e) Spectral lines: their formation and diagnostics

f) The composition and dynamics of the ISM, heating/cooling mechanisms and ionisation

g) Non-thermal emission processes

h) Compact objects and accretion on neutron stars and black holes

i) Supermassive black holes, and Active Galactiv Nuclei

PHYS20762 Physics Option Unit
Dr. Hywel Owen Credit Rating: 10

PHYS20762 Computational Physics (Option) SEM2

Prerequisites	PHYS20161
Follow-up units	PHYS30762
Classes	12 half days in the laboratory in S4, supported by 12 lectures in S4
Assessment	Continuously assessed (3 projects weighted 30%, 35%, 35%). For the first two projects, only commented code will be assessed. For the final projects students will be required to submit a written report and code.
Late Submission	The standard penalties will apply.
Note	Laboratory facilities are not available for resits. A student who has failed may be permitted to submit further assessments, based on laboratory work already carried out, in order to pass the course unit.

Recommended texts

Titus, A.B. *Introduction to Numerical Programming: A Practical Guide for Scientists and Engineers*

Garcia, A.L. *Numerical Methods for Physics* (Prentice Hall 1994)

Feedback

Feedback will be given orally by demonstrators during lab sessions, and written and oral feedback of the written project work will be given.

Aims

To give an introduction to the techniques of computational physics and dynamic high-level scripting programming languages.

Learning outcomes

On completion successful students will be able to:

1. Write programs using dynamic high-level scripting programming languages and carry out data analysis in them.
2. Use classical numerical methods (Euler and higher order) to find solutions of ordinary differential equations.
3. Use Monte Carlo techniques and associated statistical methods.

4. Use numerical solutions to analyse the behaviour of a physical system (such as a driven oscillator).

Syllabus

1. Use of high-level scripting language for data analysis.
    a) Definitions of variables and arrays; scalar and array operations; built in and user-defined functions;
    b) Working with data sets: file input / output. Data visualization and plotting;
    c) Revision of error analysis: X^2 analysis, errors on fitting coefficients, propagation of errors;
    d) Comparison of different high-level languages.

Project 1

2. **Numerical methods and the solution of ordinary differential equations**
    a) Introduction to numerical computing; errors in numerical methods;
    b) Numerical methods for solving ordinary differential equations; Euler's method; higher order methods; symplectic methods;
    c) Implementation of numerical methods;
    d) The linear driven damped oscillator; phase space; conserved quantities; sources of simulation error;
    e) Introduction to nonlinear systems.

Project 2

3. **The Monte Carlo method and its applications.**
    a) Introduction to Monte Carlo methods; Monte Carlo integration; classical problems;
    b) Pseudorandom sampling; methods of generating samples with given probability density;
    c) Applications of Monte Carlo methods;
    d) Statistical errors.

Project 3

PHYS20811
PHYS20821
Prof. G. A. Fuller
and staff from University Careers Service

Physics Core Unit
Credit Rating: 0

PHYS20811/ PHYS20821 Professional Development (Core) SEM1

Professional Skills for Physicists

Components: 1st Year vacation essay including presentation
Online Advanced Writing Skills module
Managing My Future sessions: Interview Technique
Online Professional Ethics for Physicists module

Assessment: For the full course unit (PHYS20811)

Assessed Vacation Essay and presentation	55%
Managing My Future: Interview Technique	25%
Online Professional Ethics for Physicists module	20%

Direct-entry students into second year who have not written a vacation essay will be assessed solely on Managing My Future (60%) and the online modules (40%).

Aims

- To develop the skills of written and oral communication, and interview technique required for career development.
- To foster an understanding of ethical issues in science.
- To increase awareness of equality and diversity issues.

Feedback

Feedback will be given on the Managing My Future activity. Written Feedback will be provided on the vacation essay and presentation.

Learning outcomes

On completion successful students will be able to:

1. Communicate, both orally and in writing, a scientific subject to a scientifically literate audience.

2. Recognise the requirements necessary to be successful in interviews for graduate jobs and careers.
3. Recognise and appraise ethical issues associated with their work and the work of others, assess whether action is needed and identify any necessary appropriate actions.

Syllabus

1. Written Communication

a) By week 1 of semester 3 all students will be required to complete a short module on Scientific Writing in Blackboard. The topics include Sentence Structure and Punctuation, Word Choice and Grammar, Academic Style, Conventions and Characteristics, Improving Readability, Writing Paragraphs, Critical Reading, Summarising, Paraphrasing and Referencing, Phraseological and Rhetorical Awareness, Review and Revision, and The Process of Writing.

b) Vacation Essay

Submission of an essay of between 1500 and 1800 words on a physics-related subject selected from a list or otherwise approved by the 1st Year Tutor. The deadline for submission is during Week 1 of Semester 3. The exact deadline is announced at the end of Semester 2. The essay should convey knowledge and understanding of a physics-related topic in a measured but informal way at a level to educate and interest a fellow physics student.

Failure to complete the online module will result in a recorded mark of zero for the Vacation Essay.

2. **Managing My Futures: Interview Technique**

Students will complete an online interactive interview exercise. Details, including the deadline for completion, will be circulated in September 2019.

3. **Ethics**

Students will be required to complete an online module "Professional Ethics for Physicists" covering plagiarism (briefly) and academic good practice, honesty and data integrity, ethical issues for physicists (for example the potential sociological or environmental impact of new technologies weapons, nuclear power, nuclear weapons) and whistle-blowing.

PHYS20872 Theory Computing Project (Core) SEM2

Follow-up units	3rd year lab. and 4th year projects
Classes	3 weeks in the computer lab. 2 afternoons per week in S4 followed by 7 weeks of independent project work.
Assessment	A written report (50% of the mark), presentation (25%) and short interview (25%)
Late submission	The standard penalties will apply.
Note	Facilities are not available for resits. A student who has failed may be permitted to submit further assessments, based on work already carried out, in order to pass the course unit.

Organisation

The first three weeks of the course will be delivered in a computer cluster with three short assessments of the work done. These are not marked, but must be rated satisfactory before progressing onto the project. Projects are taken in pairs and supervised by an academic; there is a total of 7 weeks to finish the projects, after which a report will have to be submitted. The work is then assessed on the report, as well as by a short talk and an interview.

Recommended texts

As set out in the project booklet, or suggested by the supervisor.

Feedback

Feedback will be offered orally by the supervisors during regular project meetings (normally once a week), and orally and in writing for all reports and interviews.

Aims

To develop the ability to investigate problems in theoretical physics through literature study, computation and mathematical analysis.

Learning outcomes

On completion the successful student will be able to:

1. quickly gain access to relevant literature for a given problem.

2. start the analysis of a theoretical problem they have not met before.
3. use appropriate computational tools to tackle problems in theoretical physics.
4. present their work verbally in a succinct and clear manner.
5. give a detailed explanation of their work in a report.
6. defend their work to an expert.

Further details

Past projects include:

4. The Ising ferromagnet;
5. Neutron stars;
6. Numerical solutions of the Schrödinger equation
7. Scars in wave functions;
8. Simulation of road traffic;

The students will be provided with a detailed project booklet at the start of the project.

PHYS30051 Physics Option Unit
Dr A. Principi Credit Rating: 10

PHYS30051 Condensed Matter Physics (Option) SEM1

Prerequisites PHYS10352, PHYS20252

Follow up units PHYS40451, PHYS40732, PHYS40752

Classes 22 lectures in S5

Assessment 1 hour 30 minutes exam in January

Recommended texts

C. Kittel, *Introduction to Solid State Physics* 8th edition (Wiley)

P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics* (Cambridge)

R. A. L. Jones, *Soft Condensed Matter* (Oxford)

Useful references

N. W. Ashcroft and N.D. Mermin, *Solid State Physics* (Thomson Press)

J.R. Hook and H.E. Hall, *Solid State Physics*, (Wiley)

Feedback

Feedback will be offered by examples class tutors based on examples sheets, and model answers will be issued.

Aims

To introduce important concepts in condensed matter physics, one of the most active areas of research in modern physics that govern the behaviour of materials in the world around us. This includes a detailed description of periodicity in solids and how it governs electronic properties. Use this quantum mechanical description to understand the emergence of magnetic order and magnetic transition in solids. Generalise the concept of ordering and phase transitions to soft matter. To become familiar with the language of condensed matter physics, enabling the understanding of research papers.

Learning Outcomes

On completion successful students will be able to:

1. construct reciprocal lattices of simple crystal structure, and relate them to x-ray diffraction data.

2. calculate band structures for simple 2D and 3D tight-binding models and construct nearly-free electron approximations
3. use the nearly-free-electron approximation to calculate equilibrium properties
4. use the semiclassical dynamics of electrons in solids to interpret magneto-conductance data and its relation with the Fermi surface.
5. describe and make use of the relationship between bonding and electronic structure of semiconductors, metals and insulators.
6. apply Landau and mean-field theories to describe phase transitions in condensed matter.

Syllabus

1. Reciprocal space in crystallography (2 lectures)

- Revision of crystal structure. The reciprocal (Fourier) space and its properties. (1 lecture)
- Interpretation of x-ray diffraction data; the structure factor. Brillouin zones. (1 lecture)

1. **Probing the electronic structure of solids** (10 lectures)

- Bloch theorem and Brillouin zones (2 lectures)
- Detailed description of the nearly-free electron model of electronic structure; modifications to the band structure and Fermi surface near zone boundaries. (1 lecture)
- The Kronig-Penney model and the tight binding method. (2 lectures)
- Graphene. Introduction to heterostructures based on 2D materials. (2 lectures)
- Semiclassical dynamics of Bloch electrons; magneto-conductance oscillations as a probe of electronic structure. Failure of the semiclassical approximation (2 lecture)
- Pauli paramagnetism and Landau diamagnetism in the free electron model. (1 lecture)

3. Phase transitions in condensed matter (9 lectures)

- Introduction to phase transition; concept of order parameter and of phase diagram; order of a phase transition; critical exponents and concept of universality. (2 lectures)
- Introduction to mean-field theory of phase transitions, mean-field solution of the 1D Ising model; comparison with the exact result. (2 lectures)
- Landau theory. Example of a second order transition: magnetism. Ferromagnetic ground-state (1 lecture)
- Exchange interaction between magnetic moments; Heisenberg model; magnons. (2 lectures)
- Example of a first order transition: van der Waals fluid. Phase diagram. Critical point. (2 lectures)
- Revision, connection with further condensed matter units and research. (1 lecture)

PHYS30101 Applications of Quantum Physics (Core) SEM1

Prerequisites PHYS20101

Classes 22 lectures in S3

Assessment 1 hour 30 minutes examination in January

Recommended text

Rae, A. I. M. Quantum Mechanics (Chapman and Hall)

Supplementary reading

Gasiorowicz, S. Quantum Physics (Wiley)

Mandl, F. Quantum Mechanics (Wiley)

Miller, D.A.B. Quantum Mechanics for Scientists and Engineers (Cambridge)

Feedback

Feedback will be offered by tutors in examples classes. These classes will be based on weekly examples sheets; solutions will be issued.

Aims

To develop basic concepts of quantum mechanics and apply them to a variety of physical systems.

Learning outcomes

On completion successful students will be able to:

1. Describe the features of quantum-mechanical tunnelling and calculate the probability of tunnelling through a barrier.
2. Solve simple eigenvalue problems, calculate expectation values and probabilities for systems of trapped particles and describe features arising from the associated shell structure.
3. Apply the basic concepts of quantum mechanics to two-state systems to solve eigenvalue problems, calculate expectation values and probabilities.
4. Add angular momenta in quantum mechanics and apply to the fine-structure of atomic energy levels.
5. Calculate first-order shifts in energy levels produced by external fields.

6. Define entangled states in quantum mechanics and use these to describe simple ideas of quantum information.

Syllabus

1. **Reminder of the Basic Concepts of Quantum Mechanics** **(1 lecture)**

2. **Barriers and tunnelling** **(3 lectures)**
   Applications to nuclear physics and solid-state physics.
   Simple descriptions of resonant tunnelling in layered semiconductors.

3. **Trapped particles** **(6 lectures)**
   Eigenvalue problems for quantum dots, quantum wires and quantum wells – shell structure and magic numbers.
   First-order perturbation theory.

4. **Spin and other two-state systems** **(5 lectures)**
   Angular momentum and ladder operators.
   Quantum mechanical representations of intrinsic spin.
   Adding angular momenta.
   Other two-state systems.

5. **Atoms and magnetic fields** **(3 lectures)**
   Magnetic fields in atoms: spin-orbit coupling and fine structure.
   Atoms in magnetic fields: Zeeman effect and Landé g-factor.
   Spectra and selection rules.
   Precession and NMR.

6. **Quantum information** **(4 lectures)**
   Measurement in quantum mechanics.
   Entanglement.
   Quantum cryptography, teleportation and computing.

PHYS30121 Physics Core Unit
Dr. L. Cawthorne and Prof. Y. Peters Credit Rating: 10

PHYS30121 Introduction to Nuclear and Particle Physics (Core) SEM1

Prerequisites	PHYS10121 and PHYS20101
Follow-up units	PHYS40222, PHYS40322, PHYS40422, various fourth year courses
Classes	22 lectures in S5
Assessment	1 hour 30 minutes examination in January

Recommended texts

B. R. Martin, *Nuclear and Particle Physics: An Introduction,* 2nd ed. (Wiley)

Supplementary reading

Wong, S. S. M. *Introductory Nuclear Physics* (Wiley)

Krane, K. S. *Introductory Nuclear Physics* (Wiley)

Martin B. R. and Shaw, G. *Particle Physics* (Wiley)

Perkins, D. H. *Introduction to High Energy Physics* (CUP)

Feedback

Feedback will be offered by tutors in example classes. These classes will be based on weekly example sheets; solutions will be issued.

Aims

To introduce the fundamental constituents of matter and the forces between them, and to explore how these lead to the main features of the structure and interactions of subatomic systems (particles and nuclei).

Learning outcomes

On completion successful students will be able to:

1. outline the basic constituents of matter and the fundamental forces between them.
2. represent elementary processes by simple Feynman diagrams.
3. use symmetries and conservation laws to identify the forces responsible for particular reactions and decays.
4. use the quark model to explain the patterns of light hadrons.
5. use simple models to explain the patterns of nuclear masses, sizes and decays.
6. apply the independent-particle model to simple ground-state properties of nuclei.

Syllabus

1. **Basic concepts**

   Quarks, hadrons and leptons

   Strong, electromagnetic and weak forces

   Symmetries and conservation laws

   Parity and charge conjugation

   Feynman diagrams and exchange forces

   Decay rates and scattering cross sections

   Quark model for light hadrons

   Parity violation in the weak interaction

2. **Nuclei**

   Nuclear forces

   Nuclear sizes

   Semi-empirical mass formula

   Nuclear stability

   Alpha decay

   Shell model

3. **Particles**

   Three generations

   Flavours and flavour mixing

   Quark model with three flavours

   Heavy-quark hadrons

   CP violation

   The origin (s) of mass

PHYS30141 Physics Option Unit
Dr. H. Owen Credit Rating: 10

PHYS30141 Electromagnetic Radiation (Option) SEM1

Prerequisites	PHYS20141, PHYS20312
Follow-up units	None
Classes	22 lectures in S5
Assessment	1 hour 30 minutes examination in January

Recommended texts

Bekefi, G. & Barrett, A.H. *Electromagnetic vibration, waves and radiation,* (MIT)

Grant, I. & Phillips, W.R. *Electromagnetism,* (MPS, Wiley, 2nd edition)

Smith, G.S. *An Introduction to Classical Electromagnetic Radiation*, (CUP 1997)

Feedback

Feedback will be offered by examples class tutors based on examples sheets, and model answers will be issued.

Aims

To develop an understanding of the production, scattering and transmission of electromagnetic waves.

Learning outcomes

On completion successful students will be able to:

1. Use Maxwell's equations to describe the propagation of electromagnetic waves in vacuum.
2. Explain in detail how accelerated charges produce electromagnetic radiation, particularly in antennas
3. Show with calculations how waves are propagated in dielectrics, conductors and plasmas.
4. Describe and calculate the properties of waves undergoing reflection and refraction at boundaries, and the scattering of waves by free and bound electrons.
5. Explain the properties of electromagnetic fields when guided by transmission lines and waveguides, and calculate numerically their important parameters.
6. Describe and calculate the properties of sources of electromagnetic radiation, including cyclotron radiation, synchrotron radiation, Bremsstrahlung and Cerenkov radiation.

Syllabus

1. **The Electromagnetic Field** (3 lectures)

Maxwell's equations for E, B, Charge conservation

Potentials in electromagnetism

Energy in the electromagnetic field

Poynting's Theorem

Electromagnetic plane waves

Polarisation. Radiation Pressure

2. **Sources of Radiation** (3 lectures)

Potentials in electromagnetism (dynamic fields)

Retarded potentials

Radiation from accelerated charge – the Larmor formula

Hertzian dipole radiation. Antennae.

3. **Radiation in matter** (5 lectures)

Maxwell's equations in media

Plane waves in matter. Refractive index

Radiation in dielectrics – dispersion

Radiation in conductors and plasmas

4. **Reflection, Refraction & Scattering** (4 lectures)

Boundary conditions

Normal and Oblique incidence reflection from a dielectric

Fresnel's equations. Total internal reflection

Reflection from metallic surface

Scattering from free electrons - Thomson scattering

Scattering by atoms - Rayleigh scattering

5. **Guided Radiation** (4 lectures)

Transmission lines. Characteristic impedance Z_o. Matching

Rectangular waveguide. Cut off frequency. Energy flow.

Attenuation in guides.

6. **Sources of Radiation** (3 lectures)

Cyclotron and Synchrotron Radiation

Bremmstrahlung

Cerenkov Radiation

Physics Core Unit

PHYS30180 Credit Rating: 20

PHYS30280 Credit Rating: 10

Lab Tutor: Dr. P. Parkinson

PHYS30180/ PHYS30280 Third Year Laboratory (Core) ALL YEAR

Feedback

Feedback will be offered:

Verbally by demonstrators in lab sessions

Verbally and in writing by demonstrators, when they mark each experiment during the interview

In writing for all lab reports.

Aims and Learning Outcomes:

These are presented in Appendix 2 of the Undergraduate Handbook.

Prerequisites PHYS20101, PHYS20141, PHYS20161, PHYS20171, PHYS20252, PHYS20312, PHYS20352

Follow-up courses

4th year projects or postgraduate research.

Classes

Laboratory work is divided into four consecutive blocks, A and B in S5 and C and D in S6. Each block spans six weeks and is worth 10 credits. Lab blocks comprise 8 full days in the lab on Tuesdays and Thursdays, 9.00am to 5.00pm, over four weeks, followed by an interview assessment in the fifth week and a written report completed during weeks five and six.

MPhys students usually perform one experiment in each semester (Block A or B + Block C or D). BSc students will usually perform either two experiments in S5, and a dissertation (PHYS30880) during S6, or dissertation and experiment in S5 and an experiment in S6.

Students in some degree programmes (such as Physics with Theoretical Physics) take only one experimental block, as indicated on the programme pages.

Students may express a preference as to which blocks they take. However, the final choice of blocks for each student will be made by the Laboratory Tutor for logistic reasons. Experiments will be assigned beforehand by the Laboratory Tutor on the basis of student requests.

Students will usually work in pairs on their experiment and will be given a great deal of freedom in the way they perform the experiments, but demonstrators will discuss the experiments with them at the beginning and will be available to assist and advise at all stages. A minimum level of attendance is mandatory, as described in more detail on the blackboard pages.

Assessment

Assessment is comprised of two components. The first is through a **presentation and interview** on completion of each experiment. The presentation is made jointly by the student pair. This component will take into account the following: experimental skill and record keeping, the oral presentation, understanding of the relevant physics, quality of the results and the analysis, originality and initiative.

The second component of assessment is through **written reports** of each experiment. Independent written reports are completed individually by each student and are assessed individually. Each written account must be in word-processed form with strict length limits. The credit split for the interview/report is 70/30. Dates for interviews and deadlines for written reports will be published well in advance and late penalties will apply.

An appeals procedure exists for the written report. All assessments must be attempted to pass the laboratory course.

Late submissions and over - length lab reports:

The standard late penalties as detailed in Section 10.1 of the Undergraduate handbook will apply.

A 3 page limit (A4 using a minimum 11pt text and 2cm margin) for the report is in force. Penalties will be applied for over-length reports on a sliding scale:

- 3 - 3.5 pages - 5 marks deducted
- 3.5 - 4 pages - 15 marks deducted
- Over 4.5 pages - a mark of zero to be awarded

Late interviews

20 marks will be deducted if an interview is not booked by the end of the fourth week. If an interview is not booked by the end of the fifth week, or if students fail to show up for an arranged interview they will be awarded zero. If a student arrives more than 15 minutes late for an interview, the demonstrator may choose to cancel the interview and apply penalties as above.

Please note that you are required to pass the lab (>40%) in order either to progress to year 4 of an MPhys course, or to graduate with an honours BSc. Students who fail lab may be awarded an ordinary BSc degree.

Induction to the Laboratory Course

All 3rd year students will attend a presentation by the Laboratory Tutor at the beginning of the year. Full and extensive documentation on the organisation, philosophy and methods of assessment are available on the accompanying blackboard pages.

PHYS30201 | Physics with Theoretical Physics Core Unit
Prof. M. Birse | Physics Option Unit (in place of PHYS30101)
Credit Rating: 10

PHYS30201 Mathematical Fundamentals of Quantum Mechanics (M) (C/O) SEM1

Prerequisites	PHYS20101, PHYS20672 or MATH10212
	PHYS20252 is recommended but not essential.
Follow-up units	PHYS40202 and fourth year courses
Classes	22 lectures in S5
Assessment	1 hour 30 minutes examination in January

Recommended texts

Shankar, R. *Principles of Quantum Mechanics* 2nd ed. (Plenum 1994)

Gasiorowicz, S. *Quantum Physics*, 3rd ed. (Wiley, 2003)

Mandl, F. *Quantum Mechanics* (Wiley, 1992)

Griffths, D. J. *Introduction to Quantum Mechanics,* 2nd ed (CUP, 2017)

Feedback

Feedback will be available on students' solutions to examples sheets through examples classes, and model answers will be issued.

Aims

To develop an understanding of quantum mechanics and in particular the mathematical structures underpinning it.

Learning outcomes

On completion of the course, successful students should be able to:

1. Use Dirac notation to represent quantum-mechanical states and manipulate operators in terms of their matrix elements
2. Solve a variety of problems with model and more realistic Hamiltonians, demonstrating an ability to use the mathematical underpinnings of quantum mechanics.
3. Work with angular momentum operators and their eigenvalues both qualitatively and quantitatively.
4. Use perturbation theory and other methods to find approximate solutions to problems in quantum mechanics, including the fine-structure of energy levels of hydrogen.

Syllabus

1. **The Fundamentals of Quantum Mechanics** (6 lectures)

   Postulates of quantum mechanics

   Time evolution: the Schrödinger equation and the time evolution operator

   Ehrenfest's theorem and the classical limit

   The simple harmonic oscillator: creation and annihilation operators

   Composite systems and entanglement

7. **Angular Momentum** (7 lectures)

   General properties of angular momentum

   Electron spin and the Stern-Gerlach experiment

   Higher spins

   Addition of angular momentum

   Vector Operators

8. **Approximate methods I: variational method and WKB** (3 lectures)

   Variational methods

   WKB approximation for bound states and tunneling

9. **Approximate methods II: Time-independent perturbation theory** (5 lectures)

   Non-degenerate and degenerate perturbation theory

   The fine structure of hydrogen

   External fields: Zeeman and Stark effect in hydrogen

10. The Einstein-Poldosky-Rosen "paradox" and Bell's inequalities (1 lecture)

PHYS30392
Dr S. Kay

Physics with Astrophysics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS30392 Cosmology (C/O) SEM2

Prerequisites PHYS10191, PHYS10121, PHYS10071, PHYS10101, PHYS10302, PHYS10352, PHYS10372, PHYS20352

Follow up units PHYS40992, PHYS40771, PHYS40772

Classes 22 lectures in S6

Assessment 1 hour 30 minutes examination in May/June

Recommended text

Liddle, A., *An Introduction to Modern Cosmology* 2nd ed. (Wiley)

Ryden, B., *Introduction to Cosmology* (Addison Wesley)

Useful references

Harrison, E., *Cosmology: the Science of the Universe,* 2nd ed. (CUP)

Hawley, J.F and Holcomb, K.A., *Foundations of Modern Cosmology* (Oxford)

Peacock, J.A., *Cosmological Physics,* (CUP)

Serjeant, S., *Observational Cosmology* (CUP)

Supplementary reading

Weinberg, S., *The First Three Minutes,* Updated ed. (Basic Books)

Feedback

Feedback will be offered by examples class tutors based on examples sheets, and model answers will be issued.

Aims

1. To provide a broad overview of modern physical cosmology.
2. To make clear the connections between basic physical ideas and modern cosmology.

Learning outcomes

On completion of the course, students should be able to:

1. Explain the concepts of the expansion and curvature of space.
2. Summarize the main evidence in favour of the Big Bang, inflation, dark matter and dark energy.

3. Relate the density of the universe to its rate of expansion and understand how this relation is modified by a cosmological constant.
4. Solve for the scale factor a(t) in different epochs of the Universe's history.
5. Make quantative calculations of physical processes in the early universe.
6. Relate observed to physical properties of distant objects given the luminosity and angular size distances.
7. Describe the main events of the Universe's history and locate them approximately in time and redshift.

Syllabus

1. **Basic observations of the Universe** (6 lectures)

1.1 What is cosmology?

1.2 Olber's paradox

1.3 Expansion and acceleration of the Universe

1.4 Cosmic Microwave Background

1.5 Large-scale structure

1.6 Dark matter in galaxies and clusters of galaxies

2. **FRW Universe Model** (8 lectures)

2.1 Review of Newtonian gravity

2.2 Geometry of the spacetime

2.3 Dynamical equations

2.4 Solutions for the scale factor

2.5 Distances measures in the FRW Universe

2.6 Cosmological puzzles and inflation

3. **Thermal History of the Universe** (6 lectures)

3.1 Review of statistical mechanics and natural units

3.2 Cosmological freeze-out

3.3 Recombination

3.4 Neutrino decoupling – relativistic freeze-out

3.5 WIMP decoupling – non-relativistic freeze-out

3.6 Nucleosynthesis

3.7 Baryogenesis

3.8 Brief history of time!

4. **Precision Cosmology** (2 lectures)

4.1 Standard model of cosmology

4.2 Measurement of parameters using the CMB & P(k)

4.3 Beyond the standard model : curvature, dark energy & massive neutrinos

PHYS30441 Electrodynamics (M) (C/O) SEM1

Prerequisites	PHYS20141, *PHYS20401* (useful but not essential)
Follow-up units	PHYS40481, PHYS40682, PHYS40771, PHYS40772
Classes	22 lectures in S6
Assessment	1 hour 30 minutes examination in January

Recommended texts

Heald, M.A. & Marion, J.B. *Classical Electromagnetic Radiation*, (Academic Press, London 1995)

Griffiths, D.J., *Introduction to Electrodynamics* (Benjamin Cummings; 3rd edition (December 30, 1998))

Supplementary reading

Feynman, The Feynman Lectures on Physics, Vol II (Addison Wesley, 1964)

Jackson, J.D., *Classical Electrodynamics,* (John Wiley & Sons, 3rd edition 1999)

Schwartz, M., *Principles of Electrodynamics,* (Dover Publications, 1972)

Feedback

Feedback will be offered by examples class tutors based on examples sheets, and model answers will be issued. A few optional sessions will provide extra problem solving opportunities and cover a few interesting “extra-curricular” topics.

Aims

To cover theoretical aspects of electromagnetic fields and radiation.

Learning outcomes

On completion successful students will be able to:

1. use scalar and vector potentials, and explain the concept of gauge invariance;
2. demonstrate the compatibility of electrodynamics and special relativity;
3. use Lorentz covariant formalism (scalars, 4-vectors and tensors) in the context of electrodynamics and special relativity;.
4. solve Poisson's equation and the inhomogeneous wave equation;
5. distinguish between radiation fields and other electromagnetic fields;

6. calculate the radiated power produced by accelerating charges.

Syllabus

1. **Electromagnetic Field Equations** (7 lectures)

   Maxwell's equations and wave solutions. Definition of scalar and vector potentials. Electro- and magnetostatics and Poisson’s equation; multipole expansions. Electrodynamics in Lorentz Gauge; the inhomogeneous wave equation and the retarded time.

2. **Electromagnetism and Relativity** (7 lectures)

   Covariant and contravariant formalism of Lorentz transformations; Scalars, four vectors and tensors; relativistic dynamics. Consistency of Maxwell's equations and relativity. Electromagnetic field tensor and electrodynamics in covariant form.

3. **Accelerating Charges** (6 lectures)

   Lienard-Wiechert potentials; Power radiated from an arbitrarily moving charge. Larmor’s power formula; synchrotron radiation; bremsstrahlung.

4. **Harmonically Varying Sources** (2 lectures)

   Multipole radiation: electric (Hertzian) and magnetic dipole radiation; slow-down of pulsars. Rayleigh and Thomson scattering.

PHYS30471 Physics Option Unit
Prof. F. Bezrukov Credit Rating: 10

PHYS30471 Introduction to Nonlinear Physics (M) (Option) SEM1

Prerequisites PHYS10101, PHYS10302, PHYS10372, PHYS20171.

Classes 22 lectures in S5.

Assessment 1 hour 30 minutes examination in January.

Recommended texts

Strogatz, S.H. *Nonlinear Dynamics and Chaos,* (Addison Wesley 1994).

Useful references

Baker, G.L. & Gollub, J.P. *Chaotic Dynamics: An Introduction,* (CUP 1996), Second edition

Jordan, D.W. & Smith, P. *Nonlinear Ordinary Differential Equations,* (OUP 1999), Third edition

Supplementary reading

Gleick, J. *Chaos: Making a New Science,* (Heinmann 1998)

Stewart, I. *Does God play Dice? The Mathematics of Chaos,* (Penguin 1990)

Feedback

While students will not be required to hand in solutions to example sheets, I will give feedback on written solutions, should students wish to hand in work. Model answers will be issued. One or two Question & Answer sessions may be arranged.

Aims

To introduce the concepts required for understanding 'real world' nonlinear phenomena using a variety of mathematical and laboratory models.

Learning outcomes

On completion successful students will be able to:

1. describe the key concepts of nonlinear dynamics.
2. analyse simple one and two-dimensional nonlinear systems.
3. apply the basic numerical methods relevant to nonlinear systems
4. explain the origin and key features of chaotic behaviour

Syllabus

1. **Introduction** - overview of the course introducing some of the basic ideas. (1 lecture)
   General introduction and motivation; examples of linearity and nonlinearity in physics and the other sciences; modelling systems using iterated maps or differential equations.

2. **General features of dynamical systems** - the structures that may arise in the analysis of ordinary differential equations. (10 lectures)
   Systems of differential equations with examples; control parameters; fixed points and their stability; phase space; linear stability analysis; numerical methods for nonlinear systems; properties of limit cycles; nonlinear oscillators and their applications; the impossibility of chaos in the phase plane; bifurcations: their classification and physical examples; spatial systems, pattern formation and the Turing mechanism; strange attractors and chaotic behaviour.

3. **The logistic map** - period doubling and chaos in a simple iterated map. (4 lectures)
   Linear and quadratic maps; graphical analysis of the logistic map; linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; universality and the Feigenbaum numbers; chaotic behaviour and the determination of the Lyapunov exponent; other examples of iterated maps.

4. **Fractals** - complex geometrical objects of which strange attractors are examples. (4 lectures)
   How long is the coastline of Britain? Artificial fractals: the Cantor set and von Koch curve; fractal dimensions; iterations of the complex plane and the Mandelbrot set; how fractals arise in the description of dynamical systems.

5. **Further aspects of chaotic dynamics** - exploring the basic ingredients of chaos. (3 lectures)
   Fractal structures in simple maps; how strange attractors come about; the evolution of phase space volumes in chaotic and non-chaotic systems; mixing and information entropy.

PHYS30511 Physics Option Unit
Dr. G. Xia Credit Rating: 10

PHYS30511 Nuclear Fusion and Astrophysical Plasmas (Option) SEM1

Prerequisites PHYS20141, PHYS20171, PHYS20352

Classes 22 lectures in S5

Assessment 1 hour 30 minutes examination in January

Recommended texts

Chen, F.F. *Plasma Physics and Controlled Fusion* (Plenum Publishers)

Gurnett, D.A. and Bhattarcharjee A. *Introduction to Plasma Physics with Space and Fusion applications (*Cambridge U.P.)

Inan, U.S. and Gołkowski. M. Principles of Plasma Physics for Engineers and Scientists (Cambridge U.P.)

Supplementary reading

Baumjohann, W. & Treumann, R.A. *Basic Space Plasma Physics* (Imperial College Press)

Friedberg, J. *Plasma Physics and Fusion Energy (*Cambridge U.P.)

Goedbloed, H. & Poedts, S. *Principles of Magnetohydrodynamics with Applications to Laboratory and Space Plasmas* (Cambridge U.P.)

Golub, L. and Pasachoff, J.M. *The solar corona* (Cambridge U.P.)

McCracken,G. and Stott,P. *Fusion: the energy of the universe* (Elsevier)

Stacey, W.M. *Fusion* (Wiley)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, and model answers will be issued.

Aims

To introduce the concept of plasma as the fourth state of matter, and to show why the study of plasma is important in contemporary physics; to give a grounding in the theory explaining the basic properties of the plasma state; to develop an understanding of the principles of fusion research as well as some plasma phenomena observed in space and astrophysics.

Learning outcomes

On completion of the course, students should be able to demonstrate an understanding of:

1. the basic concepts, parameters and modelling approaches of plasma physics.
2. single particle motion in plasmas.
3. the macroscopic (fluid) plasma model, including simple magnetohydrodynamic descriptions of equilibrium, Alfven waves and magnetic reconnection.
4. the reactions and power balance relevant to controlled nuclear fusion and the principles of various approaches to controlled fusion.
5. the physics behind such phenomena as the Earth's radiation belts, solar and stellar coronae, solar and stellar flares, the solar wind and its interaction with planetary magnetospheres.

Syllabus

1. **Introduction to fusion and astrophysical plasmas**

   What is a plasma? Overview of natural and man-made plasmas. Fusion reactions and energetics; the Lawson criterion. Magnetic confinement fusion devices; the tokamak. Inertial confinement and lasers. Magnetic fields and activity in the heliosphere.

2. **Basic concepts and parameters of plasma physics**

   Quasi-neutrality and Debye length. Plasma frequency. Collisions. Magnetic fields.

3. **Single particle motion in non-uniform magnetic and electric fields**

   Drift approximation and guiding-centre theory. Magnetic moment and mirroring. The Earth's magnetic field and radiation belts. Particle orbits and confinement in tokamaks.

4. **The magnetohydrodynamic description**

   Fluid model of plasmas, equations of MHD. Magnetic Reynolds number, ideal MHD. Magnetostatic equilibrium and force-free magnetic fields; solar prominences and loops, pinches, tokamaks. Alfven waves. Instabilities. The solar wind. Magnetic reconnection; solar and stellar flares, planetary magnetospheres, reconnection in fusion plasmas. The structure of the Earth’s magnetosphere.

PHYS30611
Prof. A. J. Murray

Physics with Photonics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS30611 Lasers and Photonics (Core) SEM1

Prerequisites *PHYS20612*

Follow-up units PHYS40631, PHYS46111

Classes 24 lectures in S5

Assessment 1 hour 30 minutes examination in January

Recommended texts

Milloni, P.W. & Eberly, J.H. *Lasers*

Saleh, B.E.A., Teich, M.C. *Fundamentals of Photonics* (Wiley)

Siegman, A.E. *Lasers* (University Science Books)

Smith, F.G. & King, T.A. *Optics and Photonics: An introduction* (Manchester Physics)

Wilson, J. & Hawkes, J.F.B. *Optoelectronics: An introduction* (Prentice Hall)

Yariv, A. *Introduction to Optical Electronics* (Wiley)

Feedback

Feedback & exercises will be available through examples presented during the lectures together with answers available via Blackboard, and through working through the solution of selected examples in the lectures.

Aims

This course follows on from PHYS20612, thereby providing a solid background for the physics and operation of different types of lasers and photonic principles, together with examples of their use in scientific research.

Learning outcomes

On completion of the course, students will be able to:

1. Demonstrate how a laser operates, and how optical feedback is used to ensure lasing.
2. Explain line broadening and how this is of relevance to laser operation.
3. Demonstrate how the concepts of laser thresholds, gain and the oscillation conditions can be derived using rate equations.
4. Review multi-mode laser operation, including higher order cavity modes.

5. Describe the operation and output characteristics of a selection of laser sources.
6. Review applications of lasers and photonics in scientific research.

Syllabus

1. Basic laser physics: Einstein A and B coefficients; induced and spontaneous transitions; systems in thermal equilibrium; population inversion.

2. Homogeneous and inhomogeneous broadening: Doppler; natural; pressure; Gaussian and Lorentzian lineshapes and widths, the Voigt Profile.

3. Develop the processes that lead to lasing from a single atom – laser field interaction using density matrices, through to the solutions for many atoms in a gain medium.

4. Gain saturation: homogeneous and inhomogeneous; saturation intensity.

5. Laser oscillation: oscillation conditions; threshold conditions; passive cavity frequencies.

6. 3 and 4 level lasers: power to maintain threshold, output coupling & optimization.

7. Multi-mode laser oscillation.

8. Laser cavities and modes: Gaussian modes; high order transverse modes; frequencies of oscillation; Laguerre-Gaussian modes, mode stability.

9. Examples of different laser systems: CW, pulsed, tunable.

10. Applications and examples of lasers & photonics used in research.

PHYS30632 Physics Option Unit
Dr J. Matthews, Dr M. Montemurro and Dr. L. Parkes Credit Rating: 10

PHYS30632 Physics of Medical Imaging (Option) SEM2

This course is designed to demonstrate how imaging methods utilize physical principles to address problems in clinical diagnosis, patient management and biomedical research.

Prerequisites	The equivalent of the following core physics courses: PHYS10071, PHYS10121, PHYS10302, PHYS10342, PHYS20141, PHYS20171, PHYS20312
Follow-up units	Postgraduate research
Classes	23 lectures in semester 6
Assessment	1 hour 30 min examining in May/June

Recommended texts

Because of the breadth of the material, students will be provided with a reading list and/or detailed notes as appropriate.

Feedback

Example exam questions on the lecture content will be provided and model answers will be issued.

Aims

To illustrate, using medical imaging, how physics is applied to the problems of clinical measurement, diagnosis, patient management and biomedical research.

To provide an understanding of the phenomena and processes of medical imaging.

Learning outcomes

On completion of the course, students will be able to:

1. Describe the process of image acquisition and reconstruction for a range of medical imaging modalities
2. Relate the properties of medical images to the underlying physical processes
3. Predict the effect of a change in acquisition parameters and conditions on the appearance of the reconstructed image

4. Design image acquisition strategies and calculate relevant parameters to achieve a specified outcome
5. Compare the advantages and disadvantages of different medical imaging modalities and their configuration for a particular clinical application

Syllabus

1. **Introduction to medical imaging** (1 lecture)

   The role of physics in medical imaging and the range of imaging methods.

2. **Ultrasound imaging** (2 lectures)

   Transducers, properties of the ultrasound beam, interaction of the beam with the patient, acoustic impedance, scanning modes, Doppler ultrasound and flow imaging.

3. **X-ray imaging and X-ray CT** (4 lectures)

   X-ray tubes and the generation of X-rays, X-ray spectrum, interaction of X-rays with the patient, attenuation, image receptors, X-ray image properties, measurement noise, contrast, resolution, X-ray computed tomography (CT), 2-D and 3-D imaging, filtered back projection, Hounsfield Units.

4. **Image mathematics and introductory image processing** (2 lectures)

   Digital image representation, Fourier reconstruction methods, iterative reconstruction, modulation transfer functions, 2D convolution, image filtering and noise reduction, image segmentation, image registration.

5. **Positron emission tomography (PET) and single photon emission computed tomography (SPECT)** (4 lectures)

   Radioisotopes, radiotracers and molecular imaging, scintillators, gamma cameras, resolution, sensitivity, collimators, coincidence, PET-CT and SPECT-CT, tracer kinetic modeling.

6. **Magnetic resonance imaging (MRI)** (7 lectures)

   Basic concepts of MR physics, spin polarization, resonance, relaxation, spin echoes, gradient echoes, spatial encoding using magnetic field gradients, k-space and image reconstruction, relaxation enhancement, MRI scanner hardware, functional MRI, MR spectroscopy.

7. **Other imaging modalities in medical research** (3 lectures)

Electric and magnetic fields in the brain, magnetoencephalography, electrical impedance tomography, electroencephalography,

23 lectures in total including revision and worked examples

PHYS30652 Physics of Fluids (Option) SEM2

Prerequisites: PHYS20171

Classes: 23 lectures in S8

Assessment: 1 hour 30 minutes examination in May/June

Recommended texts:

Acheson, D.J. *Elementary Fluid Dynamics,* (OUP)

Tritton, D.J. *Physical Fluid Dynamics*, (OUP)

Guyon E, Hulin J-P, Petit L. and Mitescu C.D., Physical hydrodynamics, (OUP)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To enable the student to understand this area of classical physics with an emphasis on applications.

Learning outcomes

On completion successful students will be able to:

1. describe the key concepts in fluid dynamics
2. solve the Navier-Stokes equations in specific scenarios
3. apply key concepts in the viscous limit to specific scenarios such as lubrication, Stokes settling and swimming
4. apply key concepts in the inviscid limit to specific scenarios such as boundary layers, irrotational flow, vorticity, lift and aerofoils

Syllabus

1. Basic concepts and governing equations of fluids

Fluids as continua; streamlines and pathlines; conservation of mass and the equation of continuity; rate of change following the fluid; conservation of momentum and the stress tensor; the constitutive equations and the Navier-Stokes equations.

2. Unidirectional flows

Boundary conditions for viscous flow; unidirectional flows in two dimensions; Poiseuille and Couette flow; some exact solutions of the Navier-Stokes equations; Poiseuille flow in a tube; flow down an inclined plane; examples of unsteady flows.

1. Dynamical similarity and the Reynolds number

Dynamical similarity and the Reynolds number; scaling of the Navier-Stokes equations

2. Viscous flows

Stokes flow past a sphere; flow reversibility; swimming at low Reynolds number; lubrication theory; viscous penetration depth.

3. Inviscid flows

Governing equations and boundary conditions; Bernoulli's equation; vorticity and its physical meaning; Kelvin's theorem; potential flow; the stream function; irrotationnal flows in various geometries; flow around aerofoils; lift force.

4. Boundary layer theory

Prandtl's boundary layer theory; Blasius flow; boundary layer separation.

5. Hydrodynamic instabilities and turbulence

Examples of hydrodynamic instabilities; pathways to turbulence; the Kolmogorov spectrum.

Physics with Theoretical Physics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS30672 Mathematical Methods for Physics (M) (C/O) SEM2

Prerequisites	PHYS20171
	In addition, *PHYS20672* is desirable but not essential.
Follow-up units	Theoretical physics courses in 4th year
Classes	23 lectures in S6
Assessment	1 hour 30 minutes examination in May/June

Recommended texts

Arfken, G.B. Weber, H.J. *Mathematical Methods for Physicists* (Academic Press)

Riley, K.F. Hobson, M. P. & Bence, S. J. *Mathematical Methods for Physics and Engineering* (CUP)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

The aim of this course is to achieve an understanding and appreciation, in as integrated a form as possible, of some mathematical techniques which are widely used in theoretical physics.

Learning outcomes

On completion successful students will be able to:

1. Describe the basic properties of the eigenfunctions of Sturm-Liouville operators.
2. Derive the eigenfunctions and eigenvalues of S-L operators in particular cases.
3. Recognize when a Green's function solution is appropriate and construct the Green's function for some well-known physical equations.
4. Recognize and solve particular cases of Fredholm and Volterra integral equations.
5. Solve a variational problem by constructing an appropriate functional, and solving the Euler-Lagrange equations.

Syllabus

1. **Ordinary differential equations and Sturm-Liouville theory** (9 lectures)

   Linear second-order ODEs: singular points, boundary conditions. Hermitian Sturm-Liouville operators: properties of eigenvalues and eigenfunctions. Orthogonal and generalised-orthogonal polynomials. Generating functions, recurrence relations, series solutions. Fourier and Laplace transform methods. Recap of special functions.

2. **Green's functions** (6 lectures)

   Definition. Example: electrostatics. Construction of Green's functions: the eigenstate method; the continuity method. Initial-value problems and causality. Partial differential equations: The Fourier transform method; retarded Green’s functions. Quantum scattering in the time-independent approach and Born approximation (perturbation theory).

3. **Integral equations** (5 lectures)

   Classification: integral equations of the first and second kinds; Fredholm and Volterra equations. Simple cases: separable kernels; equations soluble by Fourier transform; problems reducible to a differential equation. Eigenvalue problems: Hilbert-Schmidt theory, resolvant kernel. Neumann series solution (perturbation theory).

4. **Calculus of variations** (5 lectures)

   Recap of Functionals: stationary points and the Euler-Lagrange equation; the functional derivative. Constrained variational problems; Lagrange's undetermined multipliers. The isoperimetric problems. The catenary. Variable end-points. The Rayleigh-Ritz method. The completeness theorem for Hermitian Sturm-Liouville operators (if time).

PHYS30692
Dr. P. Leahy

Physics with Astrophysics Core Unit
Physics Option Unit
Credit Rating: 10

PHYS30692 Stars and Stellar Evolution (C/O) SEM2

Prerequisites PHYS10191, PHYS20141, PHYS20352, PHYS30151

Follow-up units PHYS40591, PHYS40691, PHYS40771

Classes 23 lectures in S6

Assessment 1 hour 30 minutes examination in May/June

Recommended text

Prialnik, D. *An Introduction to the Theory of Stellar Structure and Evolution* (CUP 2000)

Useful references

Clayton, D.D. *Principles of Stellar Evolution and Nucleosynthesis* (University of Chicago 1984)

Phillips, A.C. *The Physics of Stars* (Wiley 1994)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, and model answers will be issued.

Aims

To apply the fundamental physics laws to understand the physics of stellar structure.

Learning outcomes

On completion successful students will be able to:

1. describe the basics of observational classification of stars in terms of spectral type, luminosity class, and the Hertzsprung-Russell diagram
2. assemble a set of equations of stellar structure from the physics of pressure balance, conservation of mass and luminosity, and the transport of energy
3. contrast the different versions of the equation of state in stellar interiors with respect to the contributions to the pressure of radiation, degenerate and non-degenerate gases
4. predict the dominant form of energy transport inside stars, based on the opacity to the transfer of radiation
5. identify the networks of nuclear reactions that operate in stellar cores, with reference to the core temperature, composition, stellar mass, and evolutionary state

6. outline, with respect to the initial mass and composition, the key phases of stellar evolution and the endpoints of such evolution

7. manipulate equations derived from analytical approximations to the stellar structure equations

Syllabus

1. **Observed properties of stars**

   Measurement of stellar distances, luminosities, temperatures. Masses and radii. The Hertzsprung-Russell diagram.

2. **Equations of Stellar structure**

   Time scales. Fundamental equations: mass conservation, hydrostatic equilibrium, energy transport. The virial theorem. Radiative transport and convection.

1. **Equations of State**

   Pressure as function of temperature and density for: Photons, Ideal gas, Degenerate electron gas. Mean molecular weight. Ionization.

4. **Additional equations: opacity and energy generation**

   Sources of opacity. Energy generation. Nuclear fusion: cross sections and reaction rates. The Gamow peak. Temperature dependence of nuclear reactions. Neutrinos.

5. **Stellar modelling**

   Limits to the mass. Solving the coupled equations. Simple analytic stellar models: polytropes and other relations. Numerical models. The Eddington luminosity. Dimensional analysis and mass-radius relations. The HR diagram.

6. **Early stellar evolution**

   The Hayashi line. Onset of nuclear burning. Main sequence evolution. Life times.

7. **Post-main sequence evolution**

   Isothermal cores. Shell burning. Degeneracy: the helium flash. The RGB and the AGB. Mass loss. White dwarfs. Core collapse. Supernovae.

PHYS30732 The Physics of Living Processes (Option) SEM2

Prerequisites	PHYS10101, PHYS10352, PHYS20352
Follow-up units	PHYS40411, PHYS40631, PHYS40652, PHYS40732
Classes	24 lectures in S6
Assessment	Tutorial work (5%) 1 hour 30 minutes examination in May (95%)

Recommended texts

Waigh, T.A. *The Physics of Living Processes: a Mesoscopic Approach* (Wiley 2014)

Supplementary reading

Alberts, B. *Essential Cell Biology* (Garland 2008)

Alon, U. *Introduction to Systems Biology* (CRC 2007)

Cotterill, R. *Biophysics: An Introduction* (Wiley 2002)

Hobbie, R.K., Roth B.J. *Intermediate Physics for Medicine and Biology* (Springer 2007)

Nelson, P. *Physical Models of Living Systems* (Freeman, 2015)

Phillips, R. Kondev J., Theriot, J., Garcia H.G., *Physical Biology of the Cell* (Garland, 2013)

Waigh, T.A. *Critical Questions in Biological Physics* (IOP 2017)

Recommended website

Biologicalphysics.iop.org

Feedback

Tutorial solutions for the example sheets will be marked every week and model answers will be provided.

Aims

To introduce the topic of biological physics and to develop an understanding of some physical tools to solve problems in the life sciences.

Learning outcomes

On completion of the course, students should be able to:

1. Describe the main domains within a cell and the major types of biological molecule to provide a broad overview of molecular biophysics.
2. Analyse the behaviour of biological materials using models from soft condensed matter physics to allow quantitative predictions to be made.
3. Compare the main experimental techniques used in biological physics, appraise their usage to solve biological problems and demonstrate an understanding from the perspective of the underlying physical principles.
4. Construct and interpret a range of basic models that underpin systems biology based on the activity of transcription networks.
5. Explain the basic models of electrophysiology and describe how they relate to the study of brains and the senses based on the underlying physical principles.

Syllabus

5. Building blocks (2 lectures)

Molecules

Cells

2. Soft-condensed matter in biology (10 lectures)

Mesoscopic forces

Phase transitions

Motility

Aggregating self-assembly

Surface phenomena

Biomacromolecules

Charged ions and polymers

Membranes

Rheology

Motors

3. Experimental techniques (2 lectures)

Photonics techniques, mass spectroscopy, thermodynamics, hydrodynamics, single molecule methods, electron microscopy, NMR, osmotic pressure, chromatography, electrophoresis, sedimentation, rheology, tribology.

4. Systems biology (4 lectures)

Chemical kinetics

Enzyme kinetics

Introduction to systems biology

5. Spikes, brains and the senses (4 lectures)

Spikes

Physiology of cells and organisms

The senses

Brains

PHYS30762 | Physics Option Unit
Prof. N. Walet | Credit Rating: 10

PHYS30762 Object-Oriented Programming in C++ (Option) SEM2

Prerequisites A working knowledge of programming at the level of PHYS20161 and an interest in programming

Classes 10 lectures and 10 half-day practicals in S6

Assessment Continuous assessment by programming assignments

Recommended texts

A. Koenig and B. E. Moo. *Accelerated C++* (Addison Wesley, 2000)

Or any of the many C++ textbooks listed in the library reading list

Feedback

Feedback will be offered orally by demonstrators in lab-based sessions when they mark lab-based projects. Written feedback will be provided with final project marks.

Aims

1. To learn the fundamentals of Object Oriented Analysis and Design.
2. To become fluent in the C++ programming language.
3. To develop good programming style.
4. To be able to apply coding quickly and efficiently to realistic (physics) applications.

Learning outcomes

On completion successful students will be able to:-

1. Write C++ code that is compact and intelligible
2. Design and write programs in C++ using a wide range of ANSI standard features
3. Locate data structures and algorithms in the standard library to simplify coding
4. Select and use appropriate object-orientation techniques to solve new problems

Syllabus

1. The basic properties of C++: constants; boolean data-types; pointers and references; dynamic memory allocation; function overloading.
2. Data streams: standard input/output; managing files.
3. Classes and objects: encapsulation; access functions; constructors and destructors; arrays of objects; friends; operator overloading; assignment operator; shallow and deep copying; this pointer.

4. Inheritance: base and derived classes; access specifiers; overriding functions; multiple inheritance.
5. Polymorphism: base class pointers; abstract base classes; virtual and pure virtual functions; interface classes.
6. Structuring programs: header files; multiple source files; namespaces.
7. Advanced C++ features: static data; templates; runtime type checking; error handling and exceptions.
8. The C++ Standard Library; the boost library; other libraries.

PHYS30811 Physics Core Unit
Dr. Y. Xian Credit Rating: 0

PHYS30811 Second Vacation Essay (Core) SEM1

Assessment

This module has a credit weighting of zero, but the mark will count in the 3rd year average mark with a weight equivalent to a 3 credit unit corresponding to about 30 hours of work. The essay will contribute 80% of the total mark, while the presentation will contribute 20%.

Feedback

Feedback will be provided when the essay marks are returned. There will also be peer feedback on the presentations.

Aims

To develop the skills of written and oral communication.

Learning outcomes

On completion of the course, successful students will:

1. Be able to present scientific information to a scientific audience both in writing and oral presentation.

Syllabus

Submission of an essay of between 2300 and 2700 words on a physics-related subject selected from a list or otherwise approved by the Year Tutor for 2nd Year. The essay must convey knowledge and understanding of a physics-related topic in a measured but informal way at a level to educate and interest a fellow 3rd year physics student.

The deadline for submission is during Week 1 of Semester 5. The exact deadline will be announced at the end of Semester 4.

Each student will also give a 10 minute presentation on the subject of their essay to a small group of students who will provide feedback and a mark following a marking and feedback scheme. The presentation marks will be moderated by the unit coordinator. Details will be announced at the start of Semester 5.

PHYS30880 BSc Physics Core Unit
Dr. Y. Xian Credit Rating: 10

PHYS30880 BSc Dissertation (Core) ALL YEAR

Prerequisites PHYS20101, PHYS20141, PHYS20252, PHYS20312, PHYS20352

Assessment

Assessment is based on a written report and an interview with relative weights 50 and 30 respectively. The marking is carried out by the supervisor and an independent assessor. A mark of 40% or more in this module is required in order to obtain an honours BSc degree.

Penalty for Late Submission

The standard penalties as detailed in the Undergraduate Handbook will apply.

Feedback

Feedback will be offered by supervisors at each stage of the work, but especially about two weeks prior to submission, when you should discuss the structure and broad content of your dissertation with your supervisor, who will offer oral feedback.

Aims

The educational aims of the BSc dissertation are to:

1. enable students to explore in depth a topic of personal interest in the physical sciences.
2. enhance information search and selection skills specific to a particular project.
3. develop such transferable skills as scientific report writing and oral presentation.
4. facilitate self-reliance and the application of project management skills (i.e. time management, use of resources) to the successful completion of the project.

Intended learning outcomes

On completion successful students will be able to:

1. apply knowledge of physical science to the planning and development of a research/technical project.
2. use a range of primary source material including library and on-line resources.
3. critically evaluate information and techniques when deciding upon research methodologies and analysis, using criteria that can be defended.
4. manage time and resources to optimal effect to produce a dissertation to a given deadline.

Format

The project takes place during the first 10 weeks of S5, or the first 10 weeks of S6. It is expected that students will spend 1.2 days per week working on the project. It must be completed and handed in at the end of this ten week period. Students are assigned at the start of S5 a project selected from their list of choices which is timed to take place when they are free from their experimental programme (PHYS30181/2). The supervisor will outline possible approaches and offer guidance and advice during the course of the project.

The student will carry out an individual study of a current topic in physics, which should show evidence of original thinking and may take the form of a design element. **The focus of the project should be clearly on the physics, broadly construed;** students unsure whether their planned approach meets this criterion should discuss the issue with their supervisor. The student will write a report or essay along the lines of a scientific article. The length of the report should be between 4000 and 6000 words. At the end of the project you give a 5 minute presentation followed by a 25 minute question and answer session.

Example project titles

Power for the 21st century – alternative concepts in magnetically confined fusion
Measuring the Temperature of the Troposphere by Radio-Acoustic Sounding
A Tuning Device for a Musical Instrument
The Physics of traffic jams
The carbon crunch: living for the future
A sunlight health policy
Airships: History and Future Potential
The potential impact of LED based solid state lighting
Ultra-fast dynamics of biological molecules
SETI: the search for extra-terrestrial intelligence
Quantum Computers
Accelerator Driven Sub-Critical Reactors
Deceleration and trapping of polar molecules
Negative index of refraction
Helioseismology: a look inside the Sun
Why is water essential for life?
Recent neutron scattering technology development and its application in bio-research

Ethical Approval and Risk Assessments – Students undertaking independent research work with human subjects

This process applies to any student undertaking independent* research work with human subjects as part of their taught programme require ethical approval. This is a two-stage process 1) Risk Assessment 2) Ethics approval.

*Independent means outside of a laboratory, lecture or seminar and that is not directly supervised in person by a member of staff.

If this applies to your MPhys project, please contact Dr. P. Weltevrede for further details.

PHYS31692 Physics Option Unit
Dr. E. Kerins Credit Rating: 10

PHYS31692 Exoplanets (Option) SEM2

Prerequisites PHYS10191

Classes 24 lectures in S6

Assessment 1 hour 30 minutes examination in May/June.

Recommended texts

Cassan, P., Guillot, T., Quirrenbach, A. *Extrasolar Planets (Saas-Fee Advanced Course 31)* (Springer 2006), ISBN: 978-3-540-31470-7

Perryman, M. *The Exoplanet Handbook* (CUP 2011), ISBN-10: 0521765595

Feedback

Feedback will be available on students' individual written solutions to example sheets, which will be marked, and model answers will be issued.

Aims

To gain an understanding of exoplanetary systems, including how they are detected and ideas on their formation and habitability.

Learning outcomes

On completion of the course students will be able to:

1. Outline the variety of methods used to detect exoplanets
2. Evaluate exoplanet detection probabilities for different methods and compare the efficacy of different detection techniques
3. Explain the properties of known exoplanetary systems in the context of detection biases
4. Summarize leading planet formation theories and explain dynamical effects such as planet migration
5. Explain how observations constrain exoplanetary interior and atmosphere models
6. Discuss current ideas about planetary habitability.

Syllabus

1. **Introduction**

   Course overview. The brief history of exoplanet research. Definition of a planet and its orbital elements.

2. **Our Solar System in context**

   The architecture of our Solar System. Gas giant, ice giant and rocky planets. Planet equilibrium temperature. Surface temperature of a rocky planet with a simple greenhouse model.

3. **Exoplanet detection methods**

   Radial velocity and astrometry; transits and TTV (exomoon detection); gravitational microlensing (bound and isolated exoplanets); direct imaging. The relative sensitivity of the different methods and their dependency on planet and host star properties.

2. **Properties of detected exoplanets**

   Planet frequency distribution versus planet mass, radius, host separation and host properties. Detection bias. Multiple planet systems and circum-binary planets.

3. **Planetary structure**

   Planet interior models for gas giant, ice giant and rocky planets. Constraints from observations. Observations of planetary atmospheres through transmission photometry and transmission spectroscopy. Comparison with simple theoretical models.

4. **Planet formation theory**

   Key phases of planet formation. Magneto-rotational instability. Core accretion and gravitational instability scenarios. The snow line. Planet migration.

5. **Planet habitability and the prospects for extra-terrestrial life**

   The stellar habitable zone and Galactic habitable zone. Current statistics of potentially habitable planets. Impact of current knowledge on speculative ideas of the abundance and spread of extra-terrestrial life and intelligent life: the Drake equation; the Fermi Paradox.

PHYS40181
PHYS40182
Dr. P. Weltevrede

MPhys Core Unit
Credit Rating: 20

PHYS40181 [SEM1]/ PHYS40182 [SEM2] MPhys Projects

Format

Students are assigned (in pairs or individually) each semester to a project drawn from a list of their choices. Each project takes 24 days (two days per week) in the appropriate teaching or research laboratory, which will be open from 9am to 5pm on those days. Further attendance outside these times may be possible by arrangement. Although suitable instrumentation and demonstrator guidance will be available from the start, such projects are open-ended, and students will be expected to formulate and agree a plan of action with the project supervisor and to carry it through by whatever means of design, construction, interfacing and analysis prove necessary.

Full-year projects will also be offered. These take 48 days to complete and have a credit rating of 40. Full year projects only continue after the first semester if both supervisor and the students agree.

Feedback

Will be offered by supervisors at each stage of the work, but especially about two weeks prior to submission, when you should discuss the structure and broad content of your report with your supervisor, who will offer oral feedback. In addition detailed feedback on the assessment will be provided.

Philosophy

The main purpose of these projects, in addition to illustrating particular aspects of physics, is to represent tasks that might well be expected of physics graduates in the real world of research, technology and commerce. You will seek to attain a goal agreed with the project supervisor (your 'line manager') by deploying all the skills and physical background you have accumulated during the past three years.

Project types

Three types of project are available: experimental (E), involving some or all of design, construction and use of apparatus, and analysis of experimental data; computing with experimental input (CE) involving data analysis, programming or running simulations to compare with data; and computing with theoretical input (CT), involving mathematical modelling, programming and running simulations to model the behaviour of complex physical systems.

Assessment

At the end of the semester students are required to submit an individual report. The report must be detailed, well laid out and word-processed. It should summarise the tasks agreed, the steps taken to achieve them, the failures and successes en route, the extent to which goals have been achieved, and which makes recommendations for future action. The total length of the report, including figures and references, should not exceed 20 A4 pages.

At a subsequent interview (15 minute presentation followed by a 30-45 minute question and answer session) with the project supervisor and a further staff member, you will be expected to explain and justify the steps you took, to supply any missing items of detail, to show familiarity with related work published in the scientific literature, and to account for any discrepancy between this and your own results.

It is required to pass the projects in order to be awarded an MPhys degree. The final mark is a sum of the marks for:

- Implementation of project (25% of the mark), awarded for the quality of the lab book, effort, initiative, critical thinking, originality, extend and quality of the work
- Report (50% of the mark), awarded for structure & presentation, style & grammar, clarity & conciseness, figures & tables, references, physics & technical content and critical evaluation
- Interview (25% of the mark), awarded for the presentation and the understanding of the results and background physics

Detailed grade descriptors are available via blackboard. To obtain good grades you are expected to show logical thinking, a broad ranging grasp of physics, good organization, application and ingenuity, and to present a critical analysis of the conduct of the project and its results.

Full year projects

Those on full-year projects write reports and have presentations/interviews at the end of both semesters. The first (interim) report might focus on an introduction into the subject, the methods that will be used and possibly some initial results, while the second (final) report covers the overall results and conclusions obtained. The final report may refer to the first report (e.g. a detailed description of a method), but no material can be repeated from the first report (which would be self-plagiarism, see section 10.2 of the Undergraduate Handbook).

Penalty for late submission

The standard penalties as detailed in Section 10.1 of the Blue Book will apply.

Penalty for not attending the mandatory safety induction

A mandatory safety induction will be organised 3 times per year: once during registration week, and once in the first few weeks of each semester. All students who do project work are expected to either attend the induction during registration week or the induction during the relevant semester. Failure to attend the safety induction implies that the student cannot start their project work. The resulting delay, and the resulting negative impact on the work, will be considered in the assessment of the project work. Depending on the nature of the project, it can be decided to not offer a further opportunity for a safety induction, while allowing the project work to start. In those cases a penalty equivalent to a report handed in 1 day late (see above) will be applied.

Projects are designed and proposed by potential supervisors and the list will be made available on blackboard before the start of the session.

Ethical Approval and Risk Assessments – Students undertaking independent research work with human subjects

This process applies to any student undertaking independent* research work with human subjects as part of their taught programme requires ethical approval. This is a two-stage process 1) Risk Assessment 2) Ethics approval.

*Independent means outside of a laboratory, lecture or seminar and that is not directly supervised in person by a member of staff.

If this applies to your MPhys project, please contact Dr. P. Weltevrede for further details.

PHYS40202 | Physics Option Unit
Prof. A. Pilaftsis | Credit Rating: 10

PHYS40202 Advanced Quantum Mechanics (M) (Option) SEM2

Prerequisites PHYS10672, PHYS20401, PHYS30201 and PHYS30441

Follow up units PHYS40481, PHYS40682, PHYS40771 and PHYS40772

Classes 24 lectures and problem classes in S6

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

There is no single book that covers all the material in the course. The following books represent a basic choice:

Shankar R., *Principles of Quantum Mechanics* 2nd ed, 3rd printing (Springer, 2008)

Atkinson I.J.R. and Hey, A.J.G. *Gauge Theories in Particle Physics, Vol 1* (IoP, 2003)

Feedback

Feedback will be provided via solutions to the problem sheets, which will be made available electronically on Blackboard. More detailed feedback will be provided in example classes which are integrated within the 24 lectures.

Aims

1. To enhance knowledge and understanding of Quantum Mechanics.
2. To prepare students for Quantum Field Theory, Gauge Theories and other related courses.

Learning Outcomes

On completion successful students will be able to:

1. Find the unitary transformations linked to symmetry operations.
2. Apply time-dependent perturbation theory to variety of problems.
3. Derive a mathematical description of quantum motion in electromagnetic fields.
3. Apply the relativistic wave equations to simple single-particle problems.

Syllabus

1. **Symmetries in quantum mechanics** (4 lectures)

   Rotations, space-time reflections and parity

   Unitary operators for space and time translations

   Conversation laws

   Schrödinger vs Heisenberg picture

2. **Time-dependent perturbation theory** (6 lectures)

   Fermi's Golden Rule

   Selection rules for atomic transitions

   Emission and absorption of radiation

   Finite width of excited state

   Selection rules for hydrogen

3. **Coupling to E&M fields** (6 lectures)

   Minimal coupling

   Landau levels

   The Gauge Principle in Quantum Mechanics

   The Pauli-Schrödinger equation

4. **Relativistic wave equations** (8 lectures)

   The Klein-Gordon equation

   The Dirac equations

   Chirality and helicity

   Lorentz invariance and the non-relativistic limit

   The hydrogen atom and fine structure

   Graphene

PHYS40222 Physics Option Unit
Dr. A. Oh & Prof. Y. Peters Credit Rating: 10

PHYS40222 Particle Physics (Option) SEM2

Prerequisites PHYS30121

Follow-up units PHYS40521, PHYS40722

Classes 23 lectures in S6

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Martin, B.R. & Shaw, G. *Particle Physics* (Wiley) (Main text)

Perkins, D.H. *Introduction to High Energy Physics* (CUP)

Feedback

Feedback will be offered by examples class tutors based on examples sheets, and model answers will be issued.

Aims

To study the basic constituents of matter and the nature of interactions between them.

Learning outcomes

On completion successful students will be able to:

1. understand the principles of the quark model.
2. understand all interactions in terms of a common framework of exchange quanta.
3. represent interactions and decays in terms of Feynman diagrams.
4. apply relativistic kinematics to reaction and decay processes.
5. appreciate the likely direction of new research over the next 10 years.

Syllabus

1. **Ingredients of the Standard Model**

   Quarks and leptons. Mesons and baryons.

   Exchange of virtual particles. Strong, electromagnetic and weak interactions.

2. **Relativistic kinematics**

   Invariant mass, thresholds and decays.

3. **Conservation laws**

   Angular momentum. Baryon number, lepton number. Strangeness. Isospin.

   Parity, charge conjugation and CP.

4. **The quark model**

   Supermultiplets.

   Resonances; formation, production and decay.

   Heavy quarks, charm, bottom and top.

   Experimental evidence for quarks.

   Colour; confinement and experimental value.

5. **Weak interactions**

   Parity violation. Helicity.

   CP violation, K^0 and B^0 systems.

6. **The Standard Model and beyond**

   Quark-lepton generations.

   Neutrino oscillations.

   The Higgs boson.

   Grand Unified Theories

   Supersymmetry.

PHYS40322 Physics Option Unit
Dr. D. Cullen Credit Rating: 10

PHYS40322 Nuclear Physics (Option) SEM2

Prerequisites PHYS30101 or PHYS30201, PHYS30121, PHYS30151

Follow-up units PHYS40421

Classes 24 lectures in S6

Assessment 1 hour 30 minutes examination in May/June

Recommended text

Krane, K.S. *Introductory Nuclear Physics* (Wiley)

Supplementary reading

Hodgson, P.E., Gadioli, E. & Gadioli Erba, E. *Introductory Nuclear Physics,* (OUP)

Martin, B.R. *Nuclear and Particle Physics; an Introduction* (Wiley)

Bertulani, C. *Nuclear Physics in a Nutshell* (Princeton University Press)

Feedback

Feedback will be offered by examples class tutors based on examples sheets, and model answers will be issued.

Aims

To provide a basic knowledge of the physics of atomic nuclei, models of the structure of the nucleus and basic mechanisms of radioactive decay and nuclear reactions.

Learning outcomes

On completion successful students should be able to:

1. Describe and explain the various methods used to determine nuclear shapes and sizes
2. Evaluate Electromagnetic moments in nuclei
3. Describe, explain and categorise the mechanisms behind nuclear decay processes
4. Evaluate the transition rates for nuclear decay processes
5. Describe, categorise and explain the basic properties of excited nuclear states using simple models.

Syllabus

1. **Basic Concepts in Nuclear Physics:**

   Brief resumé

2. **Sizes and Shapes of Nuclei:**

   Measurements of nuclear mass and charge radii: electron scattering, muonic atoms. Electromagnetic moments: hyperfine structure. Nuclear deformation.

3. **Mechanisms of Nuclear Decay:**

   α decay: Barrier penetration, Geiger-Nuttall systematics, relationship to proton/ heavy-fragment emission.

   β decay: Fermi theory, selection rules.

   γ decay of excited states: multipolarity, selection rules and decay probabilities.

4. **Excited States of Nuclei:**

   Description of the properties of excited states using the nuclear shell model. Collective behaviour: rotational and vibrational states.

5. **Nuclear Reactions:**

   Cross section. Simple features of nuclear reactions. Direct and compound-nuclear mechanisms. Fusion and fission.

PHYS40411
Dr I Vera Marun (Co-ordinator)
Dr A Mishchenko
Dr L Fumagalli

Physics Option Unit
Credit Rating: 10

PHYS40411 Frontiers of Solid State Physics (Option) SEM1

Prerequisites	PHYS10352, PHYS20252, PHYS30151
Classes	24 lectures in S7
Assessment	1 hour 30 minutes examination in January

Recommended texts

Katsnelson, M. I. *Graphene: Carbon in Two Dimensions*, (Cambridge University Press) 2012

Kittel, C. *Introduction to Solid State physics,* (Wiley) 2005

Ferry D. K., Goodnick S. M., and Bird J. *Transport in Nanostructures,* (CUP) 2009

Tsymbal E. Y. & Zutic, I. *Handbook of Spin Transport and Magnetism* (CRC Press) 2012

Feedback

Feedback will be available on students' solutions to example problems and model answers will be issued.

Aims

To achieve awareness and basic understanding of several inter-related topics of modern solid state physics.

Learning outcomes

On successful completion of this course unit, students will be able to

1. Describe main techniques for fabrication and characterisation of nanostructures.
2. Rationalise the concept of topology in solid state physics.
3. Analyse important quantum (charge and spin) electronic properties of graphene and other low dimensional systems.
4. Apply concepts of magnetism and spin-dependent transport to magnetic nanostructures and spintronic devices.
5. Describe main scanning probe techniques for characterisation of low dimensional systems.
6. Conduct elementary calculations and estimations of quantities relevant to various parts of the syllabus.

Syllabus

Mishchenko (8 Lectures)

Techniques of nanofabrication and characterisation.

Quantum confinement, low dimensional systems : 2D, 1D and 0D.

Electronic transport in graphene

Topology in solid state physics

I Vera Marun (8 Lectures)

Introduction into nanomagnetism.

Fundamentals of spin-dependent transport.

Spintronic devices and techniques.

Graphene spintronics

Fumagalli (8 Lectures)

Fundamentals of scanning probe microscopy.

Advanced scanning probe microscopy techniques.

Scanning probe microscopy applied to low dimensional systems (nanowires, quantum dots, single molecules).

Scanning probe microscopy of 2D materials.

PHYS40421 Nuclear Structure and Exotic Nuclei (Option) SEM1

Prerequisites *PHYS40322*

Follow-up units PHYS40622 and postgraduate research in Nuclear Physics

Classes 24 lectures in S7

Assessment 1 hour 30 minutes examination in January

Recommended texts

K. Heyde, *Basic Ideas and Concepts in Nuclear Physics* (IOP 2nd Edition)

Part C+D: Nuclear Structure: Recent Developments

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

1. To introduce major components of modern research in nuclear physics.
2. To provide a suitable introduction to students who will undertake research in the subject.

Learning outcomes

On completion successful students will be able to:

1. demonstrate a knowledge of physics themes characterising recent advances in nuclear physics.
2. demonstrate knowledge and be able to explain in detail the significance of results from recent and current experiments.
3. demonstrate knowledge of and explain the physics behind the facilities and techniques used by nuclear physicists.
4. demonstrate knowledge of and apply the basic models used to describe nuclear structure

Syllabus

1. **Review of nuclear models** (1 lecture)

   Liquid drop model and independent particle shell model

2. **The nuclear shell model** (5 lectures)

Fermi gas ; Residual force ; Hartree Fock ; Effective interactions ; two-particle states ; full CI ; spectra near closed shell ; pairing

3. **Collective Phenomena in nuclei** (5 lectures)

Liquid drop model. Fermi gas. Mean field. Deformation. Vibrational and rotational motion. Super and hyper deformation.

4. **Weakly-bound quantum systems and exotic nuclei** (8 lectures)

physics at the proton and neutron drip line; new decays modes – proton decay, beta-delayed proton and neutron emission; fission limit and super-heavy elements, production, detection and properties.

5. **Radioactive ion beams (RIBs)** (2 lectures)

production by in-flight and ISOL techniques; FAIR, SPIRAL-2 and HIE-ISOLDE.

6. **Experimental techniques and recent results** (2 lectures)

Coulomb excitation of RIBs; transfer reactions in inverse kinematics; fragmentation experiments.

PHYS40422 Physics Option Unit
TBC Credit Rating: 10

PHYS40422 Applied Nuclear Physics (Option) SEM2

Prerequisites	PHYS30121
Follow-up units	PHYS40421, MACE31642 and postgraduate courses
Classes	22 lectures in S6
Assessment	1 hour 30 minutes examination in May/June

Recommended texts

Lilley, J. *Nuclear Physics Principles and Applications* (Wiley)

Some of the course material is also covered by sections from

Burcham, W.E. *Elements of Nuclear Physics,* (Longman)

Krane, K.J. *Introductory Nuclear Physics,* (Wiley)

Additional reading

Bennet, D.J. & Thompson, J.R. *Elements of Nuclear Power,* (Longman)

Coggle, J.E. *Biological Effects of Radiation,* (Wykham)

Feedback

Will be available on students' solutions to example sheets. This feedback and the model answers will be available on-line.

Aims

To achieve an awareness and basic understanding of the way the principles and methods of nuclear physics are put into practice to serve the needs of a modern society.

Learning outcomes

On completion successful students will be able to:

1. Summarise the aspects of nuclear physics which are most relevant to current applications.
2. Derive the key relationships describing nuclear behaviour and properties of radiation which are exploited in areas of application from fundamental concepts and nuclear properties.
3. Demonstrate, by example, how the principles and concepts of physics and nuclear physics are exploited in areas of technology, energy, environment and health.
4. Calculate solutions to basic problems involving the application of the concepts of physics and nuclear physics in the practical situations covered in the course unit.

Syllabus

1. **Interaction of Radiation with Matter**

   Theory and general features for charged particles - the Bethe-Bloch equation

   Photon interactions - photoelectric effect, Compton scattering, pair production

   Neutron scattering and absorption

   Attenuation and shielding

2. **Radiation detection**

   Gas-filled counters - ionization chambers, proportional and Geiger counters

   Scintillators - properties of different phosphors

   Semiconductor detectors: silicon, germanium

3. **Biological effects of radiation**

   Stages of damage in tissue - response to different radiation types

   Radiation dosimetry - activity, dose, quality factor

   Radiobiological effects - molecular damage and repair, cell survival

   Human exposure and risk

   Environmental factors

4. **Nuclear fission**

   Fission and nuclear structure, energy in fission

   Fission products, prompt and delayed neutrons - chain reaction and critical mass

   Role of thermal neutrons - neutron moderation

   The thermal fission reactor: the neutron economy, criticality

   Homogeneous reactor examples - infinite and finite reactor

   Operation and control

   Accidents

5. **Nuclear fusion**

   Basic reactions and energetics

   Controlled fusion - plasma confinement, laser implosion

6. **Applications of nuclear techniques**

   Nuclear forensics and safeguards

   Radiometric dating techniques

   Radiation diagnosis and therapy

PHYS40451 Physics Option Unit
Prof. A. Golov Credit Rating: 10

PHYS40451 Superconductors and Superfluids (Option) SEM1

Prerequisites PHYS30101 or 30201, PHYS30151, PHYS40352

Classes 24 lectures in S7

Assessment 1 hour 30 minutes examination in January

Recommended texts

Tilley, D.R. & Tilley, J. *Superfluidity and Superconductivity,* (Bristol: Hilger 1990);

Annett, J.F. *Superconductivity, Superfluids and Condensates* (Oxford 2004);

Schmidt, V.V. *The Physics of Superconductors: Introduction to Fundamentals and Applications*, (Springer 1997);

Supplementary reading will be suggested throughout the course

Feedback

Model solutions to the examples sheets will be issued. Feedback will be available through an online Blackboard discussion forum covering lectures, problem sheets and other aspects of the course.

Aims

To describe and explain the unique properties of superconductors and superfluids and to show how they exhibit quantum mechanical phenomena on a macroscopic scale.

Learning outcomes

On completion successful students will be able to:

1. Describe and explain the properties of superfluids and superconductors.
2. Use the concepts of ground state, excitations and quantization of velocity circulation and magnetic flux.
3. Explain the two-fluid model and apply the equations of superfluid hydrodynamics
4. Explain the electromagnetic properties of superconductors including the Meissner effect and the distinction between type I and type II behaviour, including the vortex state.
5. Describe and explain the applications of superconductors.
6. Use Ginzburg-Landau theory and the fundamentals of BCS theory.
7. Explain the DC and RF Josephson effects and use the Josephson equations.

Syllabus

1. Weakly interacting Bose gases, Bose-Einstein condensation, ground state and excitations. (2 lectures)
2. Liquid ^{4}He and ^{3}He, properties of superfluid ^{4}He, macroscopic wave function, quantized circulation and vortices, excitations, Landau criterion for superfluidity, two-fluid hydrodynamics, first and second sound. (6 lectures)
3. Microscopic theory of superconductivity, Cooper problem, elements of BCS theory, excitations, thermodynamic properties. (6 lectures)
4. Superconductors, persistent current and Meissner effect, evidence for energy gap, London. Electrodynamics and penetration depth, thermodynamics and critical field. (4 lectures)
5. Ginzburg-Landau theory and coherence length, type I and type II behaviour, flux quantization, vortex state, flux pinning and applications. (4 lectures)
6. Weakly coupled superconductors, Josephson effect, dc SQUID and applications. (2 lectures)

PHYS40481 Physics Option Unit
Dr. M. Dasgupta Credit Rating: 10

PHYS40481 Quantum Field Theory (M) (Option) SEM1

Prerequisites	*PHYS40202, PHYS30441, PHYS20401* is strongly recommended.
Follow up units	PHYS40682
Classes	24 lectures in S7
Assessment	1 hour 30 minutes examination in January

Recommended texts

Cheng, T. P. and Li, L. F. *Gauge Theory of Elementary Particle Physics*, Oxford University Press, 1984.

Mandl, F. and Shaw, G. *Quantum Field Theory*, Wiley, 1992.

Peskin, M. E. and Schroeder, D. V. *Quantum Field Theory*, Perseus Books Group, 1995.

Pokorski, S. *Gauge Field Theories*, Cambridge University Press, 2000, Second Edition.

Feedback

Feedback will be available on students' individual written solutions to selected examples, which will be marked, and model answers will be issued.

Aims

To understand the unifying framework of quantization of fundamental forces and particles in agreement with special relativity.

Learning outcomes

On completion successful students will be able to:

1. Explain the concept of canonical quantization for scalar, vector and fermion fields.
2. Explain the concept of global and local symmetries in Quantum Field Theory and their implications
3. Derive the Feynman rules from the Lagrangian formalism, use these to calculate S-matrix elements, and explain their physical significance.
4. Calculate the lifetime of unstable particles and cross sections of reactions that occur in the lowest order of perturbation theory.
5. Explain the concept of renormalization and apply this to field theories.

Syllabus

1. **Preliminaries** (3 lectures)

   Classical Lagrangian Dynamics; Lagrangian Field Theory; Global and Local Symmetries; Noether’s Theorem.

2. **Canonical Quantization** (4 lectures)

   From Classical to Quantum Mechanics; Quantum Fields and Causality; Canonical Quantization of Scalar Field Theory; Complex Fields and Anti-Particles.

3. **The S-Matrix in Quantum Field Theory** (5 lectures)

   Time Evolution of Quantum States and the S-Matrix; Feynman Propagator and Wick's Theorem; Transition Amplitudes and Feynman Rules; Particle Decays and Cross Sections; Unitarity and the Optical Theorem.

4. **Quantum Electrodynamics** (6 lectures)

   Dirac Spinors; Quantization of the Fermion Field; Gauge Symmetry; Quantization of the Electromagnetic Field; the Photon Propagator and Gauge Fixing; Feynman Rules for Quantum Electrodynamics.

5. **Renormalization** (6 lectures)

   Renormalizability; Dimensional Regularization, Renormalization of a Scalar Theory; Anomalous magnetic moment and the Lamb shift.

PHYS40521 Physics Option Unit
Prof. Y. Peters and Dr. A. Oh Credit Rating: 10

PHYS40521 Frontiers of Particle Physics 1 (Option) SEM1

Prerequisites	PHYS30101 or PHYS30201, PHYS30121, *PHYS40222*
Follow-up units	PHYS40722
Classes	24 lectures in S7
Assessment	1 hour 30 minutes examination in January

Recommended texts

Martin, B. & Shaw, G., *Particle Physics,* (3rd ed.) (Wiley)

Leo, W. R., *Techniques for Nuclear and Particle Physics Experiments* (Springer)

Thomson, M., *Modern Particle Physics* (Cambridge University Press)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

1. To provide a review of modern-day particle physics experiments, and the physics they aim to address.
2. To provide a suitable introduction to experimental methods commonly used in particle physics for students who will undertake research in the subject.

Learning outcomes

On completion successful students will be able to:

1. Identify the three experimental particle physics frontiers, and define their objectives.
2. Describe the facilities commonly used by experimental particle physicists.
3. Explain qualitative and quantitative techniques applied to particle physics experiments.
4. Judge the significance of recent and current results in the main areas of particle physics (QCD, EWK, BSM) in the wider context of past and present particle physics experiments.
5. Describe experiments planned for the near future and explain their significance.

Syllabus

1. **Introduction to modern particle physics experiments**

   Standard Model and the three particle physics frontiers

   Particle properties and experimental methods in particle physics

   Modern-day experiments

   Data analysis, statistics, and Monte Carlo techniques

2. **Physics at the high energy frontier**

   Partons and QCD

   Electroweak gauge bosons (W and Z bosons)

   Top quark physics

   The discovery of the Higgs boson

   Standard Model: successes and limitations

   Searches for physics beyond the Standard Model

   Future Colliders

PHYS40571 Physics Option Unit
Prof. A. Grigorenko Credit Rating: 10

PHYS40571 Advanced Statistical Physics (M) (Option) SEM1

Prerequisites PHYS20101, PHYS20352

Classes 24 lectures in S7

Assessment 1 hour 30 minutes examination in January

Recommended texts

Gardiner, C. *Stochastic Methods, A Handbook for the Natural and Social Sciences* (Springer)

Jacobs, K. *Stochastic Processes for Physicists, Understanding Noisy Systems* (Cambridge University Press)

Reichl, L.E. *A Modern Course in Statistical Physics,* 2nd ed, (Wiley)

Feedback

Feedback will be available on any students' request.

Aims

To understand the nature and scope of the dynamical description of the macroscopic world based on statistical principles.

Learning outcomes

On completion successful students will:

1. Be able to explain what a Markov process is and to use analytical methods to study the dynamics of Markovian systems.
2. Understand the origin of the irreversibility seen at the macroscale including examples which illustrate the essential ideas behind the fluctuation-dissipation theorem; be familiar with modern concepts relating equilibrium and non-equilibrium statistical physics.

   Bbe able to show how different kinds of description of stochastic processes are related, especially the idea of a microscopic model and its relation to a macroscopic model.
3. Be able to perform straightforward calculations for systems which are described by stochastic dynamics, determining stationary probability distributions from master or Fokker-Planck equations and correlation functions from Langevin equations.
4. Be familiar with the basic numerical methods used to simulate stochastic dynamical systems.

Syllabus

1. **Stochastic variables and stochastic processes**

   Revision of the basic ideas of probability theory; probability distribution functions; moments and cumulants; characteristic functions; the central limit theorem and the law of large numbers.

2. **Markov processes**

   The Chapman-Kolmogorov equation; Markov chains; Applications: (random walk, birth-death process); the master equation; methods of solution of the master equation; efficient simulation methods for Markov processes with discrete states.

3. **Drift and diffusion**

   The Fokker-Planck equation: derivation and methods of solution; relation to Schrödinger's equation; applications to barrier crossing, activation and mean-first-passage times.

4. **Stochastic differential equations**

   The Langevin equation and its generalisations; analytical and numerical methods of solution; applications to Brownian motion.

5. **Modern topics in statistical physics**

   Fluctuation theorems; statistical physics of small systems; applications to complex systems modelling.

PHYS40580 Laboratory For Students Returning From A Year Abroad (Core) ALL YEAR

Note: This is a version of the third year laboratory specifically adapted to the experience and needs of MPhys and MMath&Phys students who have spent year 3 abroad, and may need additional laboratory experience before attempting an MPhys project.

Feedback

Will be offered orally by demonstrators in lab sessions, orally by demonstrators when they mark each experiment, and in writing for all lab reports and posters.

Aims and Objectives

These are presented in Section 2 of this book.

Prerequisites	PHYS20101, PHYS20141, PHYS20161, PHYS20171, PHYS20252, PHYS20312, PHYS20352
Follow-up courses	4th year projects or postgraduate research.

Classes

Laboratory work is divided into two blocks, A and B in S5. Each block spans six weeks and is worth 10 credits. Lab blocks comprise 8 full days in the lab on Tuesdays and Thursdays, 9.00am to 5.00pm, over four weeks, followed by an assessment in the fifth week and a written report completed during weeks five and six. Students take either block A or block B.

Students may express a preference as to which blocks they take. However, the final choice of blocks for each student will be made by the Laboratory Tutor for logistic reasons.

Experiments last 12 full days: 8 days of experimental work plus 4 days for preparing presentations and for assessment. Experiments will be assigned beforehand by the laboratory tutor on the basis of student requests.

Students will work in pairs on their experiment and will be given a great deal of freedom in the way they perform the experiments, but demonstrators will discuss the experiments with them at the beginning and will be available to assist and advise at all stages.

Assessment

Assessment comprises of two components. The first is through a **presentation and interview** on completion of each experiment. The presentation is made jointly by the student pair. This component will take into account the following: experimental skill and logbook notes, the oral presentation, understanding of the relevant physics, quality of the results and the analysis, originality and initiative. The second component of assessment is through **written reports** of each experiment. Independent written reports are completed individually by each student and are assessed individually. Each written account must be in word-processed form. The credit split for the interview/report is 70/30. Dates for interviews and deadlines for written reports and posters will be published well in advance and late penalties will apply.

The learning outcomes for students in year 4 are those specified in section 2.4 above for year 4, and the assessment will be done against the outcomes given there, which are more demanding than for PHYS30180/280.

Late submissions of lab. reports

The standard penalties as detailed in Section 9.1 of the Blue Book will apply.

Late interviews

20 marks will be deducted if an interview is not booked by the end of the fourth week. If an interview is not booked by the end of the fifth week, or if students fail to show up for an arranged interview they will be awarded zero.

Passing the lab is a requirement for the award of an honours degree.

Please note that you are required to pass the lab (>40%) in order to graduate with a MPhys.

Induction to the Laboratory Course

All returning year abroad students will attend at the beginning of the year, a presentation by the Laboratory Tutor and will receive from their Personal Tutors a handout describing in detail the organisation, philosophy, and methods of assessment.

PHYS40591 Radio Astronomy (Option) SEM1

Prerequisites PHYS20171, PHYS20312, PHYS30141 or 30441, PHYS30392

Classes 24 lectures in S7

Assessment 1 hour 30 minutes examination in January

Recommended texts

Rohlfs, K. and Wilson, T.L. *Tools of Radio Astronomy*, 3rd ed (Springer-Verlag 2000)

Further texts

Burke, B. and Graham-Smith, F. *Introduction to Radio Astronomy, 2nd ed* (CUP 2002)

Kraus, J. *Radio Astronomy*, (McGraw-Hill 1986)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

6. To provide an overview of phenomena which can be studied with radio techniques including a range of non-astronomical applications.

7. To introduce the techniques of radio astronomy, from antennas to radio receivers, emphasising their strengths and limitations and the applicability of these techniques to a range of non-astronomical applications.

Learning outcomes

On completion successful students will be able to:

1. Relate radio-waveband observations of astrophysical objects to the mechanism that generated the emission.
2. Explain how radio waves are affected as they travel through the interstellar medium and the Earth's stmosphere.
3. Calculate key performance indicators of a radio telescope such as its sensitivity and angular resolution.
4. Assess the optimum choice of receiver system for a desired radio astronomical measurement.
5. Describe the operation and advantages of radio interferometers in imaging applications.

Syllabus

1. **Fundamentals**

   The radio universe: “hidden” objects (pulsars, double radio sources, OH/IR stars etc) and a new light on the familiar (e.g. HII regions, supernova remnants, spiral galaxies).

   Brightness, flux density and brightness temperature, emission mechanisms, thermal and synchrotron continuum radiation, spectral lines, simple radiative transfer, antenna characteristics.

2. **Antenna concepts**

   The antenna as an aperture; Rayleigh distance; far-field Fourier transform relations and differences for the near field; effective area, aperture efficiency; beam solid angles and antenna gain; antenna temperature; Ruze formula; Wiener-Kinchine theorem, convolution and antenna smoothing; parabolic antennas and basics of quasi-optics.

3. **Receiver concepts**

   Johnson noise; Nyquist theorem and noise temperature, band-limited noise, minimum detectable signal, noise accounting in receivers; heterodyne systems and sidebands; polarization sensitive receivers; gain instabilities; Dicke-switched and correlation receivers.

   Spectral line receiver concept: detectability of spectral lines, filter bank, autocorrelation and Fourier transform receiver principles.

   Interferometric receiver concepts; spatial and temporal coherence; adding, phase switching and multiplying types; resolution; complex visibilities; aperture synthesis and imaging of various targets.

4. **Case Studies**

   Application of radio astronomy techniques to specific astrophysical targets e.g. discrete source surveys; the Cosmic Microwave Background; mm-wave imaging of Earth from space; mm-wave imaging of terrestrial targets for all-weather surveillance and security.

PHYS40611 Physics Option Unit
Dr. D. M. Graham Credit Rating: 10
Dr. D. Binks

PHYS40611 Frontiers of Photon Science (Option) SEM1

Prerequisites	Physics core courses
Classes	24 lectures in S7
Assessment	1 hour 30 minute examination in June.

Recommended texts

Dexheimer, S. L., *Terahertz Spectroscopy*, (CRC Press)

Hannaford P., *Femtosecond Laser Spectroscopy*, (Springer Science)

Feedback

Feedback will be available on students' solutions to problem sheets.

Aims

1. To gain an appreciation of the techniques of photon science.

In particular, to understand how:

- ultrafast laser pulses are produced, characterised and used
- nonlinear frequency conversion techniques can be used to change the wavelength of laser beams
- terahertz-frequency light is produced and detected

2. To illustrate the application of these techniques in scientific research
3. To provide a suitable introduction to students wishing to pursue postgraduate research in photon science.

Learning outcomes

On completion successful students will be able to:

1. Describe the equipment and techniques used by photon scientists to produce and measure ultrafast laser pulses in the UV, visible, infra-red and terahertz spectral regions.
2. Analyse the optical response of nonlinear materials and explain how it can be optimised to enable the significant wavelength conversion of laser beams.
3. Describe terahertz radiation and its effect on materials

4. Explain quantitatively how these techniques can be used in scientific research to investigate electronic processes occurring on a sub-nanosecond time-scale.

Syllabus

1. **Producing ultrafast laser pulses** (4 lectures)

   Mode-locking; dependence of pulse length and peak power on mode number; active and passive techniques. Oscillator-amplifier systems.

2. **Nonlinear frequency conversion** (8 lectures)

   Nonlinear optical materials; modification of the wave-equation; three-wave coupling; phase-matching; second harmonic and sum-frequency generation; optical parametric amplifiers and oscillators

3. **Advanced ultrafast laser diagnostics** (3 lectures)

   Single- and multiple-shot autocorrelators. Frequency-Resolved Optical Gating (FROG). Spectral Phase Interferometry for Direct Electric-field Reconstruction (SPIDER).

4. **Terahertz spectroscopy** (4 lectures)

   Pump-probe detection techniques. Methods of generating terahertz radiation (photoconductive antennas and optical rectification). Electro-optic sampling. Time-domain and frequency-domain techniques. Asynchronous optical sampling methods. Applications of terahertz spectroscopy (conductivity processes in semiconductors and biomolecules).

5. **Ultrafast Transient Absorption Spectroscopy** (5 lectures)

   White light continuum generation. Application to carrier dynamics in quantum dots: state-filling effects; carrier cooling and recombination; carrier trapping; multiexciton effects including Auger recombination and biexciton binding energy. Mulitple exciton generation as means of exceeding the Shockley-Queisser limit to solar cell efficiency.

PHYS40622 Physics Option Unit
Dr A. G. Smith & Prof. M. Birse Credit Rating: 10

PHYS40622 Nuclear Forces and Reactions (Option) SEM2

Prerequisites *PHYS40322*

Classes 24 lectures in S8

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Bertulani, C. A. *Nuclear Physics in a Nutshell* (Princeton)

Krane, K. S. *Introductory Nuclear Physics* (Wiley)

Wong, S. S. M. *Introductory Nuclear Physics* (Wiley)

Feedback

Feedback will be available on students individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To introduce the main features of the forces between nucleons and reactions between nuclei, and to link nuclear physics to other areas of physics.

Learning outcomes

On completion successful students will be able to:

1. describe the main features of the forces between protons and neutrons, and their relation to the underlying forces between quarks.

2. use cross sections and phase shifts to describe quantum mechanical scattering processes.

3. show how simple models can explain the main features of nuclear reactions.

4. explain how specific nuclear reactions are responsible for the formation of the elements.

Syllabus

1. **Nuclear forces** (8 lectures)

   Symmetries in nuclear physics

   From quarks to pions and nucleons

   The deuteron

   Scattering in quantum mechanical systems

   Partial waves

   Effective-range expansion

   Pion-exchange force

   Phases of nuclear matter

2. **Nuclear reactions** (8 lectures)

   Reaction cross sections

   Resonances

   Optical potential

   Compound nucleus

   Direct reactions

   Nuclear fission

3. **Nuclear astrophysics** (6 lectures)

   The Big Bang

   H and He burning in stars

   Formation of heavier elements

   Supernovae and neutron stars

PHYS40631 Physics Option Unit
Dr. A. Murray and Dr. M. Dickinson Credit Rating: 10

PHYS40631 Laser Photomedicine (Option) SEM1

Prerequisites PHYS20101, PHYS20141, PHYS20171, PHYS20312

Classes 12 lectures/seminars and directed learning in S7

Assessment Examination and continually assessed. The exam constitutes 65% of the marks and the continuous assessments 35%

Recommended texts

Katzir, A., *Lasers and Optical Fibers in Medicine,* (Academic 1993)

Waynant, R.W., *Lasers in Medicine,* (CRC Press 2001)

Useful references

Niemz, M.H. *Laser-Tissue Interactions,* (Springer 1996)

Welch, A.J. & van Gemert, M.J.C. *Optical-Thermal Response of Laser-Irradiated Tissue,* (Plenum 1995)

Optical Radiation Techniques in Medicine and Biology in Physics in Medicine and Biology, vol. 42, No. 5, May 1997

To be supplemented by further recommended texts.

Feedback

Feedback will be offered for the continuously assessed elements of the unit.

Aims

This course introduces students to the physics of medical lasers and light, including light tissue interactions; the properties of lasers and light, and delivery systems that are beneficial in medical applications; how light is utilised for imaging, diagnostic and therapeutic medical applications; and reviews selected medical applications.

Learning outcomes

On completion successful students will be able to:

1. Classify and describe the mechanisms associated with the interaction of light with tissue;
2. Explain the relevant properties of lasers and light delivery systems for applications in medicine;
3. Compare imaging, optical diagnostic and therapeutic applications in medicine and predict which are most appropriate for applications;
4. Discuss selected applications of lasers and optical techniques which are presently important in

medicine.

Syllabus

1. **Basic Tissue Optics and Laser Tissue Interactions**

   Photochemical

   Photothermal

   Photomechanical

   Photoablative

2. **Medical Laser and Delivery Systems**

   Technology of medical lasers and alternative light sources

   Laser radiation characteristics

   Light delivery systems

3. **Diagnostic Techniques and Applications**

   Conventional, confocal and two-photon microscopy

   Raman spectroscopy

   Optical coherence tomography, laser Doppler, photoacoustic imaging

   Optical tweezers for particle trapping

   Tissue identification by optical, spectroscopic and imaging techniques

4. **Selected Medical Application**

   Laser surgery and microsurgery

   Photomechanical applications in ophthalmology, lithotripsy

   Photodynamic therapy

   Applications in dermatology, ophthalmology, urology and dentistry.

PHYS40642 Physics Option Unit
Prof. A.J. Murray Credit Rating: 10

PHYS40642 Atomic Physics (Option) SEM2

Prerequisites: PHYS20312, PHYS20352, PHYS30101 or PHYS30201, PHYS30141 or PHYS30441

Classes: 22 lectures in S8

Assessment: 1 hour 30 minutes examination

Recommended texts:

Corney, A, *Atomic & Laser Spectroscopy*

Blum, K., *Density Matrix Theory and Applications*

Metcalf J.M. & van der Straten P, *Laser Cooling & Trapping*

Foot C.J., *Atomic Physics*

Feedback

Feedback will be available through worked examples during the lectures, with answers available through web pages, and through separate examples & solutions given throughout the course

Aims

This course will discuss the physics of atoms and their interactions with radiation, and how these processes are measured. The historical evolution of atomic physics will initially be described, by discussing key experiments and theoretical developments that have lead to our modern understanding of atoms and their structure. New methods in atomic physics will then be discussed, including how they are excited and ionized, and how they can be trapped and cooled to very low temperatures. The application of cold atoms for metrology and for possible future quantum computing will then be detailed.

Learning outcomes

On completion successful students will be able to:

1. Describe the structure of atoms, and how these are determined in experiments.
2. Detail the processes used to excite and ionize atoms using radiation.
3. Describe how atoms are cooled and trapped to very low temperatures.
4. Explain how cold atoms can be used to measure fundamental constants to high precision.
5. Discuss how cold atoms might be used in future quantum computers.

Syllabus

1. Historical overview of the evolution of atomic physics from early spectroscopy to the modern day. Key experiments and theoretical developments that have led to our present understanding of atoms and their structure. (3 lectures)

2. Interactions of atoms with radiation, and with charged particle beams. (3 lectures)

3. Excitation & ionization processes & how they are measured & described. (2 lectures)

4. The theoretical framework used to describe atom-laser interactions. (4 lectures)

5. Atomic cooling and trapping processes & techniques used for production of cold atoms. (4 lectures)

5. Applications of cold atoms to precision measurements & for future quantum computing. (6 lectures)

PHYS40682 Physics Option Unit
Prof. A. Pilaftsis Credit Rating: 10

PHYS40682 Gauge Theories (M) (Option) SEM2

Prerequisites *PHYS30441, PHYS40481*

Classes 24 lectures in S8

Assessment 1 hour 30 minutes examination in May/June.

Recommended texts

Cheng T. P. and Li L. F., *Gauge Theory of Elementary Particle Physics*, Oxford University Press, 1984.

Peskin M. E. and Schroeder D. V., *Quantum Field Theory,* Perseus Books Group, 1995.

Pokorski S., *Gauge Field Theories*, Cambridge University Press, 2000, Second Edition.

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To understand in detail the origin and nature of the fundamental interactions generated by invariance of the Lagrangian under local gauge transformations.

Learning outcomes

On completion successful students will be able to:

1. use concepts of a Lie Algebra and Lie Groups in explaining symmetry properties in physics

2. use the principle of gauge invariance and generalize it from the Abelian theory of Quantum Electrodynamics to the non-Abelian cases of Quantum Chromodynamics and the Standard Model (SM) of electroweak interactions

3. describe in detail the Higgs mechanism as a means to generate masses for the SM fermions, gauge bosons, and the observed Higgs boson, as well as the role of Yukawa interactions in explaining lepton- and quark-mixing phenomena in electroweak processes

4. explain the ideas and concepts involved in the motivation and construction of theories beyond the SM, including Grand Unified Theories

Syllabus

1. Preliminaries (2 lectures)

Abelian gauge invariance, Quantum Electrodynamics (QED);

QED Feynman rules.

2. Group Theory (4 lectures)

Lie groups; SO(N) and SU(N) Groups; Group representations

2. Quantum Chromodynamics (QCD) (6 lectures)

Non-Abelian gauge invariance; Fadeev-Popov Ghosts;

Becchi-Rouet-Stora Transformations; QCD Fenyman Rules;

Asymptotic Freedom and Confinement.

4. **The Standard Model (SM) of Electroweak Interactions** (8 lectures)

Goldstone Theorem; Higgs Mechanism; Yukawa Interactions; Quark and Lepton Mixing;

SM Feynam Rules, Unitarity and renormalizability of the SM.

5. Beyond the Standard Model (4 lectures)

Grand Unification and Supersymmetry

PHYS40712
Dr. P. Parkinson & Dr. I. J . Vera Marun

Physics Option Unit
Credit Rating: 10

PHYS40712 Semiconductor Quantum Structures (Option) SEM2

Prerequisites PHYS10121, PHYS10352, PHYS20252, PHYS30151

Classes 23 lectures in S6

Assessment 1 hour 30 minutes examination in May/June, Standard format

Recommended text

Davies, J.H. *The Physics of Low-Dimensional Semiconductors (Cambridge University Press)*

Fox, M. *Optical Properties of Solids (Oxford University Press)*

Singleton, J. *Band Theory and Electronic Properties of Solids (Oxford University Press)*

Singh, J. *Semiconductor Optoelectronics* (McGraw-Hill)

Streetman, B & Banerjee S, *Solid State Electronic Devices*

Wilson, J.F. & Hawkes, J. *Optoelectronics, an Introduction* (Prentice and Hall)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, and model answers will be issued.

Aims

To explore light absorption, emission and transport processes in bulk and low dimensional semiconductor structures. To apply these ideas to practical devices including high-efficiency LEDs and lasers, and transistors with improved characteristics.

Learning outcomes

On completion of the course students will be able to:

1. explain the processes of light emission, absorption and transport in semiconductor materials.
2. outline the materials used in optical and electronic devices and advanced semiconductor growth techniques, including methods of material doping.
3. employ mathematical and physical concepts to describe the behaviour of carriers which are confined in two, one and zero dimensional systems.
4. interpret the consequences of carrier confinement on electronic and optical properties of materials.
5. Explain and compare the physical principles governing the operation of semiconductor LEDs semiconductor lasers and diodes.

6. Explain the principles behind the realisation and application of advanced electronic structures.

Syllabus

1. Review of relevant solid state physics (2 hours)
   (Band theory, dispersion relation, density of states)

2. Doping of semiconductors (0.5 hour)
   (Donors and acceptors)

3. Carrier distribution in intrinsic and extrinsic semiconductors (1.5 hours)
   (Fermi energy, electron and hole distributions in conduction and valence bands)

4. Carrier recombination and (3 hours)
   (Diffusion, drift, conductivity, Hall Effect)

5. P/N junctions (1 hour)
   (Minority carrier injection, bias)

6. Optical properties of semiconductors (2 hours)
   (Absorption, emission, Fermi's Golden Rule, excitons, LEDs)

7. Semiconductor lasers (4 hours)
   (Condition for gain, gain spectrum, threshold current, Double Heterostructures)

8. Materials systems (2 hours)
   (III - V materials, epitaxial growth techniques, alloys, lattice matching)

9. Semiconductor quantum structures (4 hours)
   (Quantum wells, wires and dots, density of states in two, one and zero dimensions)

10. Applications of PN junctions and advanced electronic structures (3 hours)
    (Photodiodes, solar cells and high electron mobility transistors)

PHYS40722 Physics Option Unit
Dr. M. Gersabeck & Dr. A. Szelc Credit Rating: 10

PHYS40722 Frontiers of Particle Physics 2 (Option) SEM2

Prerequisites *PHYS40521*

Classes 24 lectures in S8

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Martin, B. & Shaw, G. *Particle Physics*, (Wiley)

Perkins, D.H. Introduction to High Energy Physics (CVP)

Feedback

Feedback will be available on students' individual written solutions to examples sheets and model answers will be issued.

Aims

1. To provide a thorough and in depth knowledge of modern experimental particle physics including recent results.
2. To provide an essential basis for students who will undertake research in this subject.

Learning outcomes

On completion successful students will be able to:

1. judge the significance of specific experimental observations in the broader context of fundamental particle physics questions
2. identify the key unanswered questions in quark flavour, neutrino and dark matter physics, and propose how physicists can answer these questions experimentally
3. explain the main theoretical concepts underpinning quark flavour, neutrino and dark matter physics, and apply them to calculations
4. describe the experimental techniques used in the field, in particular the particle detection mechanisms and the methods of suppressing background
5. analyse data (e.g. in the form of oscillation or CP violation measurements) to derive key results in particle physics

Syllabus

2. Quark flavour physics

CKM matrix

CP violation

LHCb experiment and recent results

2. Neutrino physics and other rare processes

Neutrino masses and oscillations

PMNS matrix

Majorana and Dirac neutrinos

Charged lepton flavour violation

Dark matter

PHYS40732 Physics Option Unit
Prof. J. Lu Credit Rating: 10

PHYS40732 Biomaterials Physics (Option) SEM2

Prerequisites	S5 and S6 Physics cores and PHYS30352
Classes	20 Lectures + 2 problem classes in S8
Assessment	1 hour 30 minute examination in May/June

Recommended Texts

Kittel C., *Introduction to Solid State physics,* latest edition (J Wiley)

Mohammad Farrukh A., *Functionalized Nanomaterials* Publisher: In Tech, ISBN 978-953-51-2856-4.

Haider S. and Haider A., *Electrospinning-Material*, *Techniques, and Biomedical Applications,* ISBN 978-953-51-2822-9.

Stefan G Stanciu S.G., *Micro and Nanotechnologies for Biotechnology,* ISBN 978-953-51-2531-0.

Supplementary Reading

Graphene - New Trends and Developments, edited by Farzad Ebrahimi, ISBN 978-953-51-2220-3.

Biosensors - Micro and Nanoscale Applications, edited by Toonika Rinken, ISBN 978-953-51-2173-2.

Application of Nanotechnology in Drug Delivery, edited by Ali Demir Sezer, ISBN 978-953-51-1628-8.

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

Through discussion of suitably selected topics, to develop an awareness of contributions of nanomaterials, nanotechnology to medical diagnostics and therapies, which encompasses the use of nanoscale sensors to detect internal signals and to the targeted drug deliver.

Learning outcomes

On completion successful students should be able to:

1. describe the range of structures of biomolecules and their functionality in living systems.
2. explain the key relationships between the structures and properties of nanomaterials.
3. describe a few typical methods of production of nanomaterials.
4. describe quantum effects on the physical and chemical properties of materials at nanoscales; their potential applications in daily life; and their potential risks.

5. discuss the medical requirements for these advanced materials.
6. describe selected applications of nanomaterials and nanotechnology in the area of diagnostics, therapies and drug delivery.
7. explain the principles of a range of advanced experimental techniques used in determination of the structure and dynamical properties of biomaterials.

Syllabus

1. Structures and properties of nanomaterials (12 lectures)

Introduction of nanomaterials, nanotechnology and nanomedicine.

Introduce the structures of solids: crystalline, polycrystalline, amorphous (glass) materials and their connection to physical, chemical and mechanical properties.

Introduce structures of water, amino acids, DNA, proteins and their functions in living cell.

Structure and properties of low dimensions, e.g. fullerenes, graphene and carbon nanotubes.

Quantum confinement effect to the properties of nanoclusaters, nanoparticles, Quantum dots and their applications in nanomedicine.

2. Nanotechnology and Nanomedicine (8 lectures)

The introduce material's biocompatibility and medical requirements.

Introduce nanotechnology to medical diagnostics and therapies.

Introduce nanoscale sensors and advanced drug delivery methods.

Introduce experimental techniques such as synchrotron radiation and neutron scattering for determination of the structures of nanomaterials and biomolecules, STM, AFM and vibrational spectroscopic techniques for probing surfaces of biomolecules.

PHYS40752
Dr. I. Dierking

Physics Option Unit
Credit Rating: 10

PHYS40752 Soft Matter Physics (Option) SEM2

Prerequisites PHYS30101 or 30201, PHYS30151, PHYS30141 or 30441

Classes 24 lectures in S8

Assessment 1 hour 30 minutes, examination in May/June

Recommended texts

Collings, P.J. & Hird, M. *Introduction to Liquid Crystals*

Hamley, I.W. *Introduction to Soft Matter* (Wiley) Chichester, 2000

Jones, R.A.L. *Soft Condensed Matter* (OUP) Oxford, 2002

Kleman, M., Laverentovich O. *Soft Matter Physics* (Springer), 2003

Rubinstein, M., Colby, R. H., *Polymer Physics* (OUP), 2003

Tabor, D., *Gases liquids & solids* CUP, 1991

Feedback

There will be questions given out with the lecture summaries every week. Solutions will be discussed in three Q&A sessions which will provide feedback to students on their present understanding of course material covered.

Aims

1. to provide a broad overview of different states, and properties of soft matter.
2. to introduce the physics of soft materials including liquid crystals, polymers and colloids.
3. to point out the connections between different soft matter materials, in particular liquid crystals, polymers and colloids.

Learning outcomes

On completion successful students will be able to:

1. Explain the general concepts of soft matter physics
2. Describe concepts of the physics of liquid crystals, polymers and colloids
3. Give examples and explanations of phase transitions in soft matter
4. Describe the connections between liquid crystals, polymers and colloids
5. Explain key experimental techniques in relation to soft condensed matter

Syllabus

1 **Introduction to Soft Materials**

Classification in terms of their thermal, mechanical and often unusual physical properties.

2 **Liquid Crystals**

General structure of liquid crystalline molecules, structure of phases.

3 **The liquid crystalline state**

Order parameter and Maier-Saupe theory.

4 Chirality, optical properties, ferroelectricity and Landau theory

5 Experimental techniques in the study of liquid crystal properties

6 **Introduction to polymers**

Terminology and nomenclature molar masses and distributions, chain – dimensions and structures.

7 **Polymers in solution**

Ideal solutions, Flory–Huggins theory

8 Mechanical properties of polymers and visco-elastic behaviour.

9 **The glass transition**

General phenomenon and theoretical models, experimental determination.

10 **Liquid crystal polymers, elastomers**

11 **Colloids**

Stability, DLVO theory and gels

12 Association colloids, Lyotropic Liquid Crystals and Langmuir-Blogett films

PHYS40771 | Physics Option Unit
Prof. M. Seymour | Credit Rating: 10

PHYS40771 Gravitation (M) (Option) SEM1

Prerequisites No prerequisite courses, but see below

Related courses *PHYS10672, PHYS20401, PHYS30201, PHYS30441, PHYS30392*

Follow Up Units PHYS40772

Classes 24 lectures and 12 example classes in S7

Assessment 1 hour 30 minutes examination in January

Prerequisite Material Even though there are no prerequisite courses for this unit, we shall make use of vector algebra as taught, e.g., in PHYS30201, variational calculus as taught in PHYS20401 and PHYS30672, index notation and tensor calculus (e.g., PHYS10672 and PHYS30441). Some of this material will be reviewed in the first lectures, and additional self-teaching material is available for students who are prepared to make an effort to self-teach this material.

Recommended texts

The following texts are useful for revising the material for the course

Cheng, T. P., R*elativity, Gravitation and Cosmology: A Basic Introduction* (second edition, Cambridge University Press, 2010)

D'Inverno, R. *Introducing Einstein's Relativity,* (Oxford University Press, 1992)

Hartle, J. B. *An Introduction to Einstein's General Relativity,* (Addison Wesley, 2004)

Hobson, M. P., Efstathiou, G. & Lasenby, A. N. *General Relativity: An Introduction for Physicists* (Cambridge University Press, 2006)

Lambourne, R. J. A., *Relativity, Gravitation and Cosmology* (Cambridge University Press, 2010)

More advanced texts

Misner, C.W. Thorne, K.S & Wheeler, J.A. *Gravitation,* (Freeman)

Wald, R.M. *General Relativity* (University of Chicago Press)

Weinberg, S. *Gravitation and Cosmology,* (Wiley)

Feedback

Feedback will be available on students’ individual written solutions to selected examples, which will be marked when handed in, and model answers will be issued.

Aims

Development of the ideas of General Relativity within the framework of differential geometry on a curved manifold.

Learning outcomes

On completion successful students will be able to:

1. apply the basic concepts of differential geometry on a curved manifold, specifically the concepts of metric, connection and curvature.
2. use the Einstein equations to describe the relation between mass-energy and curvature.
3. understand the relation of General Relativity to Newtonian theory and post-Newtonian corrections.
4. describe spherical Black Holes.
5. derive the basic properties of the FRW Universe.

Syllabus

The weakest of all the fundamental forces, gravity has fascinated scientists throughout the ages. The great conceptual leap of Einstein in his 'General Theory of Relativity' was to realize that mass and energy curve the space in which they exist. In the first part of the course we will develop the necessary mathematics to study a curved manifold and relate the geometrical concept of curvature to the energy momentum tensor. In the second part of the course we solve the Einstein equations in a number of simple situations relevant to the solar system, black holes, and a homogeneous and isotropic universe.

1. **Preliminaries** (4 lectures)

   Cartesian Tensors; Variational Calculus; Newtonian mechanics and gravity; Review of Special Relativity; Einstein's lift experiment; Einstein's vision of General Relativity, Rindler space.

2. **Manifolds and differentation** (4 lectures)

   Manifolds, curves, surfaces; Tangent vectors; Coordinate transformations; Metric and line element; Vectors, co-vectors and tensors; Conformal metrics.

3. **Connection and tensor calculus** (4 lectures)

   Covariant differentiation and Torsion; Affine Geodesics; Metric Geodesics and the Metric Connection; Locally Inertial Coordinates; Isometries and Killing's Equation; Computing Christoffel symbols and Geodesics.

4. **Curvature** (2 lectures)

Riemann Tensor; Ricci Tensor and Scalar; Symmetries of the Riemann tensor and the Bianchi identities; Round trips by parallel transport; Geodesic deviation.

5. **Einstein equations** (2 lectures)

Energy-momentum tensor; Einstein tensor and the Einstein Equations; Newtonian limit; Gravitational radiation.

6. **Schwarzschild Solution** (6 lectures)

Spherically symmetric vacuum solution; Birkhoff's theorem; Dynamics in the Schwarzschild solution; Gravitational Redshift; Light deflection; Perihelion precession; Black holes.

7. **FRW universe** (4 lectures)

Expansion, isotropy and homogeneity; FRW metric; Friedmann and Raychauduri equations; Solutions in radiation and matter eras; Cosmological constant; Cosmological redshift; Cosmological distance measures; Flatness and horizon puzzles.

PHYS40772 Physics Option Unit
Prof. F. Bezrukov Credit Rating: 10

PHYS40772 Early Universe (M) (Option) SEM2

Prerequisites *PHYS30392, PHYS40771*

Classes 23 lectures in S8

Assessment 1 hour 30 minutes examination in May/June

Recommended texts

Gorbunov D.S. & Rubakov V.A. *Introduction to the Theory of the Early Universe: Cosmological Perturbations and Inflationary Theory*, (World Scientific, 2011)

Mukhanov, V.F. *Physical Foundations of Cosmology,* (CUP, 2005)

Weinberg, S. *Cosmology* (OUP)

Feedback

Will be available on students' individual written solutions to examples sheets, model answers will be issued. Several review sessions will be suggested during the semester.

Aims

Development of the cosmological model, its problems and their possible resolution within the framework of relativistic gravity and modern particle physics.

Learning outcomes

On completion successful students will be able to:

1. formulate the linear theory of structure formation in the CDM model, obtain solutions in simple model cases of one component universe.
2. explain the problems of the big bang cosmology and the way to solve them in inflationary theory.
3. calculate basic cosmological parameters in inflationary slow roll models.
4. indicate the relations of the Cosmic Microwave Background Radiation and cosmological parameters.
5. discuss the evidence for an accelerating universe and the possible role of dark energy.

Syllabus

1. **Standard model of cosmology: Review**

   Review of FRW universe; Natural units; Distance measures in FRW and conformal time; Basic observational facts; Neutrino decoupling and the radiation density; A brief history of time.

2. **Structure formation**

   Overview of structure formation; Relativistic perturbation theory; Conformal Newtonian gauge; Evolution of vector and tensor perturbations; Scalar perturbations in one component universe; Adiabatic and isocurvature perturbations; Power spectra; Suppression of power on small scales due to baryons and neutrinos.

3. **Cosmic microwave background**

   Basic features of the angular power spectrum; Recombination and photon decoupling; Density and velocity fluctuations; Sachs-Wolfe effects.

4. **Inflation**

   Horizon and Flatness puzzles, primordial perturbations; Definition of inflation and its solution of the horizon and flatness puzzles; Potential formulation and slow roll dynamics; reheating and the transition to radiation domination; Klein-Gordon field as a simple worked example; Fluctuations generated during inflation; Model zoo: large field, small field and hybrid models; Connecting observations with theory; Preheating and the transition to radiation domination..

5. **Dark energy**

   Vacuum energy and timescale problems; Cosmological constant; Quintessence.

PHYS40811 Physics Option Unit
Dr. S. Kay Credit Rating: 60

PHYS40811 Physics Professional Placement (Option) SEM1

Prerequisites: PHYS30180 or PHYS30280, plus 3 from *PHYS40222, PHYS40322, PHYS40352, PHYS30392*

Follow-up units: None

Classes: None

Aims

To provide work experience within a professional environment that will be valuable in preparation for graduate employment. To provide the opportunity to apply skills attained from studying physics to degree level, to make a meaningful contribution to a project of current importance to a host company or research institution. To foster the development of professional skills, including the ability to communicate clearly, think independently, make informed judgments and work effectively as part of a team.

Overview

Students taking this course unit undertake a full-time, physics-based project located within a company or external research institution. It provides an opportunity to gain valuable experience working within a professional environment. It also requires further development of professional skills in preparation for graduate employment.

Eligibility and application details

This course unit is only available to MPhys students registered on the *Physics* degree programme and who have not studied abroad during their degree. The duration of the placement is 12 weeks in S7, followed by the submission of a written dissertation. No other course units are taken in S7, while S8 option choices may not include PHYS40182 (MPhys Project).

The number of available placements will be strictly limited and are therefore offered via competition, details of which are advertised throughout the year. Students wishing to take this course unit are required to gain approval from the course organiser in the third year before proceeding with their applications.

Format

Students are assigned both an academic mentor and a placement supervisor. It is expected that students will contact both people in advance of the start-date of the placement to make any necessary arrangements. In the early stages of the placement, students are required to produce a brief summary of their project and a work-plan, completed in consultation with their placement supervisor. Around the mid-point of the project, students are visited on their placement by their academic mentor to discuss progress. It is also expected that frequent (i.e. at least fortnightly) contact will be made by phone or email with the academic mentor throughout the placement. The final stages of the semester should be devoted to writing up the dissertation.

Assessment

This course unit is continually assessed. At the beginning of the placement, an initial work-plan is submitted. An interim report is then required around the mid-point of the placement, followed by a 30-minute progress interview during the site visit. The length of this report should be in the region of 15 A4 pages and its focus should be a review of background material that is relevant to the project. Following completion of the placement, a written dissertation is submitted with a deadline towards the end of the semester. The length of the dissertation (including figures, tables and bibliography) should be in the region of 40 A4 pages and may include the background material contained within the interim report. The dissertation should also present and discuss the methods or techniques used in the work, the results obtained and conclusions drawn. An hour-long interview will follow, comprising a 15-minute presentation followed by a discussion. A final report on the student's performance is also provided from the placement supervisor. The final mark (ex 100) is the sum of the following components: *initial work-plan* (ex 5); *interim report* (ex 15) *and interview* (ex 10); *dissertation* (ex 35) *and interview* (ex 15); *supervisor's final report* (ex 20).

Feedback

Feedback will be given on both the initial work-plan and interim report. Students will also be given the opportunity to submit a draft chapter on background material/theory from their dissertation for comments from their academic mentor. Feedback will be given on the final report by the assessors and from the placement supervisor on their general performance during the placement.

Learning outcomes

On completion successful students will have:

1. Described their experience working on a physics (or physics-related) problem of current importance in research or industrial application, within a professional environment.

2. Demonstrated a work ethic that is suitable for graduate employment.
3. Produced a scientific dissertation that is of professional quality, detailing their contribution to the project.
4. Demonstrated a high level of oral and written communication skills, and the ability to work within a team.

PHYS40992 Galaxy Formation (Option) SEM2

Prerequisites	*PHYS30392*
Follow up units	None
Classes	24 lectures in S8
Assessment	1 hour 30 minutes examination in May/June

Recommended text

Binney, J. & Tremaine, S. *Galactic Dynamics* (Princeton) (2nd edition)

Coles, P. & Lucchin F., *Cosmology: The Origin and Evolution of Cosmic Structure* (Wiley)

Peacock, J. *Cosmological Physics* (CUP)

Feedback

Feedback will be available on students' individual written solutions to examples sheets, which will be marked, and model answers will be issued.

Aims

To provide an introduction to the modern theory of galaxy formation and large-scale structure of the Universe.

Learning outcomes

On completion of the course, students should be able to:

1. Discuss key observable properties of the low and high redshift galaxy population within a cosmological context.
2. Explain the basic ideas of how large-scale structures grow and lead to the formation of dark matter haloes.
3. Discuss the important physical processes that set the conditions for galaxy formation.
4. Describe and explain the properties of galaxy clusters and their application to cosmology.
5. Outline modern research methods used to model galaxy formation and discuss key outstanding problems.

Syllabus

1. **Overview**

   Observations of galaxies and their environments at low and high redshifts; key observational tests for galaxy formation models; galaxies in a cosmological context.

2. **Growth of large-scale structures:**

   Linear growth of structures; Zel'dovich approximation; characteristic halo mass and hierarchical growth; power spectrum.

3. **Dark matter haloes:**

   Spherical top-hat collapse model; Press Schechter formalism and the halo mass function; mergers and accretion; internal structure; halo shapes and spin; substructure.

1. **Gas processes:**

   Hydrostatic equilibrium; Jeans mass; accretion shocks; radiative cooling; angular momentum and disk formation; star formation and feedback processes.

2. **Galaxy clusters:**

   Galaxies in clusters; intracluster medium; dark matter and mass measurements; cluster scaling relations; cosmology with clusters.

3. **Frontiers of galaxy formation:**

   N-body simulations; semi-analytic models; hydrodynamic simulations; outstanding problems.

PHYS41702 | Physics with Philosophy Core Unit
TBC | Physics Option Unit
Credit Rating: 10

PHYS41702 Physics and Reality (C/O) SEM2

Prerequisites	PHYS10121, PHYS20352, PHYS30101 or PHYS30201
Follow up units	None
Classes	12 lectures and 12 two hour seminars in S6
Assessment	1 Talk (15%); 1 Essay (45%) 1 hour 30 minutes examination in May/June (40%)

Recommended text

There is no single text for this course, nevertheless it is essential that students read *extensively*. During the course students will be issued with study packs containing a number of key passages (e.g. chapters of books) for each topic. The lectures will develop the ideas discussed in these texts, which students are expected to read *before* the lectures and seminars. Students who extend their reading around the essential passages will improve their chances of doing well in the assessment.

Attendance and participation

We expect students to attend and participate in at least 11 of the 12 seminars; a 4% deduction of the final mark will be applied each time a student fails to attend or participate in a seminar, apart from the first occurrence.

Capacity

This class will take a maximum of 33 students.

Feedback

Feedback will be provided through the seminars, and on the essay or talk.

Aims

Physics was originally an attempt to understand the "nature of things", but nowadays this tends to be overshadowed by our ability to make accurate predictions, often with theories whose implications about "the real world" are obscure. Quantum mechanics, as pointed out by Schrödinger, may not even be consistent with our everyday world in which things are either here or there, and cats are either dead or alive (but not both at once). In this course we will explore a number of issues in the interpretation of physical theories that do not seem resolvable by experiment (even in principle), and so can be labelled as metaphysics.

Learning outcomes

On completion of the course, successful students will be able to:

1. Evaluate the strengths and weaknesses of different interpretations of quantum mechanics;
2. Identify the philosophical tensions between quantum mechanics and relativity associated with the concepts of entanglement and non-locality;
3. Compare and contrast the philosophies of time of Augustine, Newton, Leibniz, Einstein, and modern quantum gravity;
4. Distinguish between different "arrows of time" and relate them to each other;
5. Relate different areas of physics to the common mathematical paradigm of the gauge transformation;

Syllabus

Delivery method

The course consists of three topics, each taught over a four week period, where each week consists of a lecture followed by a seminar.

There will be three short student talks in each seminar, apart from in the first week. Students will be assigned a topic to speak on, and will be expected to answer questions from the audience.

The topics discussed will be chosen by the lecturers. They will always include some subjects from the foundations of quantum mechanics and cosmology.

Students will be asked to write an essay. The essay will be set a deadline early in week 11, and will be assigned based on preferences from a set of titles covering the first three topics taught.

Students will be asked to answer questions in the exam on a topic where they neither gave a talk nor wrote an essay on.

In 2017 the topics will be:

- Interpretations of quantum mechanics: the reality of the wavefunction, role of the observer, hidden variables, many worlds.
- Time in physics: absolute versus relative time, the arrow of time, entropy and cosmology.
- Theories of everything: from Newton, Maxwell and Boltzmann to string theory, the anthropic principle, and the nature of reality.