



DEPARTMENT OF PHYSICS

**HONOURS LECTURE MODULE
DESCRIPTIONS**

2022

Honours Courses

There are four courses that honours students enrol in for Physics Honours. These are

PHYSICS 4010 Advanced Physics A (lecture subjects)

PHYSICS 4015 Advanced Physics B (lecture subjects)

PHYSICS 4020A Honours Physics Project part A (semester 1)

PHYSICS 4020B Honours Physics Project part B (semester 2)

and each is worth 6 units (there are similar courses if you are enrolled in the HPCP program).

Within these courses, students take seven lecture modules, six of which are counted to PHYSICS 4010 and PHYSICS 4015, and one of which is part of PHYSICS 4020A. The lecture modules (one of which is actually a practical subject) that are offered within Physics are listed below. It is also possible to replace up to two of the modules listed below with level III lecture courses (Physics, Geophysics, Maths, Computer Science etc.).

N.B. If you plan to take a level III course or a non-Physics course, please *do NOT enrol in it!* Enrol in the courses listed above, and your entry into the level III or non-Physics course will be handled informally by the honours coordinators of the relevant departments.

At the first or second honours meeting in early February, we will note your choice of lecture modules.

Lecture Module Descriptions

- H-1 Advanced Astrophysics (**Hill/Rowell**) (S2)
- H-2 Advanced Space and Atmospheric Physics (**Cervera, Neudegg, Harris**) (S2)
- H-3 Electrodynamics (**Zanotti**) (S2)
- H-4 Data Analysis and Modelling (**Rowell, White**) (S1)
- H-5 Gauge Field Theories (**Young**) (S2)
- H-6 Differential Geometry & General Relativity (**White**) (S2)
- H-7 Photonics IV (**Veitch, Perrella, Sparkes, Luiten**) (S1)
- H-8 Nuclear and Radiation Physics (**Forster/Santos**) (S1)
- H-9 Quantum Field Theory (**Young**) (S1)
- H-10 Relativistic Quantum Mechanics & Particle Physics (**Williams/Jackson**) (S1)
- H-11 Honours Electronics (**Veitch**) (S1)
- H-12 Topics in Quantum Materials (**Solomon, Tettamanzi**) (S1)

Please note that certain courses have pre-requisites.

H-6, 9 & 10 require Advanced Dynamics and Relativity (level III Physics).

H-9 & 10 require Quantum Mechanics III.

H-9 requires H-10 concurrently.

H-5 requires H-9 & 10

H – COURSE DESCRIPTIONS

H-1

ADVANCED ASTROPHYSICS

Semester II

Lecturers

A/Prof Gary Hill, Prof Gavin Rowell

Aim

This course aims to:

- ❖ Provide a detailed description of various aspects of high-energy astrophysics, both theoretical and observational.
- ❖ Provide solid fundamentals of radiative transfer in astrophysics
- ❖ Provide more detailed insight into the process of star formation, and the features of the interstellar medium.
- ❖ Describe in some detail radiation processes in high energy astrophysics, including synchrotron and inverse Compton.
- ❖ Describe special relativistic effects in astrophysical sources
- ❖ Introduce the experimental techniques and recent results in cosmic ray, gamma-ray and neutrino astrophysics, together with a theoretical background.
- ❖ Describe sources of high energy cosmic rays, gamma rays and neutrinos, e.g. supernovae and active galaxies, and discuss in detail the acceleration and production mechanisms for these messengers.
- ❖ Describe how a particle flux at the Earth can be calculated by integrating over the cosmological history of the Universe, taking into account the density and luminosity functions of the sources, and the effects of the expanding Universe.

Objectives

On completion of the course, students should:

- ❖ Have a detailed physical and mathematical understanding of a variety of astrophysical systems and processes, particularly in the area of high energy astrophysics
- ❖ Understand how high energy astrophysics experiments and observatories are addressing the open questions
- ❖ Have expertise in problem solving in the areas covered in lectures

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ To have a high order of numerical and analytical skills;
- ❖ The ability to communicate scientific information effectively;
- ❖ Scientific curiosity and the ability to continue learning independently;
- ❖ An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content (not necessarily in order below)

- Fundamentals of Radiative Transfer and scattering
- Interstellar Hydrogen, the Violent Interstellar Medium and Star Formation
- Cosmic Ray, Gamma-ray and Neutrino Observations and Techniques

- Sources of Cosmic Rays, Gamma-rays and neutrinos, and calculation of particle fluxes at Earth, including cosmological effects from the expanding Universe
- Radiation by Accelerated Charges
- Synchrotron and Inverse Compton Radiation
- Radio emission from particle showers – the Askaryan effect
- Cosmic Ray Diffusion in galactic magnetic fields
- Attenuation of cosmic rays and photons in the Universe (e.g. GZK cut off)
- Cosmic ray acceleration – the Fermi cloud theory, and diffuse shock acceleration

Structure

Two lectures per week. Tutorials arranged when needed.

Assessment

Written Examination	60-70%
Assignments	40-30%

References

Longair, M. *High Energy Astrophysics* vol 1 & 2
Rybicki, G. B. and Lightman, A. P. *Radiative Processes in Astrophysics*
Spitzer, L. *Physical Processes in the Interstellar Medium*
Shapiro, S. L. and Teukolsky, S. A. *Black Holes, White Dwarfs and Neutron Stars*
Harwit, M. *Astrophysical Concepts*

Contact information

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H-2

ADVANCED SPACE AND ATMOSPHERIC PHYSICS

Semester II

Lecturers

A/Prof Manuel Cervera, Dr David Neudegg and A/Prof T. Harris

Aim

This course aims to:

- Provide knowledge of the physical processes that govern the Earth's Atmosphere and Space environment including external influences. The regions described include, from the ground up, the troposphere, stratosphere, mesosphere, thermosphere, ionosphere, magnetosphere and geomagnetic field, solar wind and interplanetary magnetic field and the Sun
- Provide knowledge of the observation and measurement of the Atmosphere and Space Environment, for example by radar and optical means, including from the ground and Space.
- Provide knowledge of the dynamics of the Atmosphere and Space Environment, with a focus on energy transfer, particularly by waves in neutral atmosphere, partially ionised upper atmosphere (ionosphere) and fully ionised space plasmas.
- Provide knowledge of practical applications requiring knowledge the environment including radio propagation through the ionosphere for line-of-sight and sky-wave radar, terrestrial and satellite communication, satellite navigation systems (e.g. GPS), radar measurements of the atmosphere, the effect of the space environment on technology such as spacecraft.

Objectives

On completion of the course, students should:

- The basics of atmospheres, particularly those in diffusive equilibrium.
- The transfer of radiation through the atmosphere
- Measurement of the various spheres of the atmosphere, particularly by remote sensing such as radar.
- The role of atmospheric waves in transporting energy and momentum and how this affects the state of the atmosphere and ionosphere.
- The ion and electron production and loss mechanisms that lead to formation of different ionospheric regions.
- The generation of currents in the ionosphere through dynamo processes
- Transport mechanisms and variability of the ionosphere, and how it is driven from below by the neutral atmosphere and from above by solar and geomagnetic disturbances.
- The propagation of radio-waves through partially ionised plasmas (e.g. the ionosphere), how this can be used to study the ionosphere, and practical applications (e.g. radar, communications).
- The nature of more fully ionised plasma (e.g. the magnetosphere and solar wind), constraints by the geomagnetic field, waves and instabilities, and effects on spacecraft embedded within it.
- The effects of the Space Environment on technology (i.e. 'Space Weather')

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ A high order of numerical and analytical skills;
- ❖ Scientific curiosity and the ability to continue learning independently;
- ❖ An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content

Neutral Atmosphere (25%)

- Foundations
- The Middle Atmosphere
 - Radiative transfer
 - Optical Path & Heating
 - Formation of Stratosphere
 - Absorption lines & Remote sensing from Space
- The Mesosphere and lower Thermosphere
 - Observations & Constituents
 - Instruments & Phenomenology
- Waves in the Atmosphere
 - Mean circulation
 - Large-, Small- and Medium-scale wave motions

Ionospheric Physics (50%)

- Formation of ionosphere
 - Ionization production, loss mechanisms, layer formation
 - Introduction to transport mechanisms
 - Plasma frequency, gyrofrequency, Debye length
- Electromagnetic wave propagation in a weak plasma – fundamentals
 - Phase and Group path
 - Refractive index and polarization
 - Faraday rotation
- Equations of motion in a plasma
 - Air-drag, ion-drag and electron drag
 - Ionospheric conductivities, dynamo and equatorial electrojet
- Ionospheric transport and variability
 - Sq system, equatorial, mid latitude and auroral transport
 - Climatology and morphology
 - Space weather effects
- Measuring the ionosphere
 - Sounders, radar, optical, satellite
- Ionospheric representations and models
 - Climatological, data driven, empirical and physical principle models
- Tides and waves in the ionosphere
 - Ground – ionosphere coupling
- Ionospheric instabilities
 - Instability processes and mechanisms
 - Plasma bubbles and plumes, scintillation
- Electromagnetic radiowave propagation in the ionosphere with applications
 - Canonical equations, Fermat, numerical and analytical raytracing
 - Focusing, absorption, radar equation

- Applications

Space Physics (25%)

- The Sun
 - geoeffective phenomena
 - flares, coronal mass ejections, proton events, high-speed solar-wind streams
- Interplanetary Space
 - Solar Wind (SW), Interplanetary Magnetic Field (IMF), coupling ...
- Geomagnetism and the Magnetosphere -
 - Measurements, Quiet and Storm field, Effect on the Ionosphere.
- Introduction to Space Plasmas
 - Maxwells Equations to EM Force Law
 - Single Particle motion
 - orbit theory, particle gyration, L-shell/flux invariant, generalised drift, etc.
 - Particle Drift to MHD vis Kinetic Theory overview
 - Example space plasma physics spacecraft
- Space Weather
 - Effect of Space Environment on technology
 - HF systems, spacecraft, power grids, satellite navigation and comms, etc.

Structure

Two hours of lectures/tutorials per week.

Assessment

- Four equally weighted assignments 100%

References

Neutral Atmosphere

- Andrews, D. G. (2000), “An Introduction to Atmospheric Physics”, CUP
- Andrews, Holton and Leovy (1987), “Middle Atmosphere Dynamics”, AP
- Holton, J.R (2004), “An Introduction to Dynamic Meteorology”, AP
- Vallis, G.K. (2006), “Atmospheric and oceanic fluid dynamics”, CUP
- Volland, H. (1988), “Atmospheric tidal and planetary waves”, Kluwer

Ionosphere

- Davies (1990), “Ionospheric Radio”, IET
- Kelley (2009), “The Earth’s Ionosphere 2nd ed.”, AP
- Budden (1961), “Radio Waves in the Ionosphere”, CUP
- Schunk and Nagy (2009), “Ionospheres”, CUP
- Ratcliffe (1972), “An Introduction to the Ionosphere and Magnetosphere”, CUP

Space physics

- Russell, Luhmann and Strangeway (2016), “Space Physics: An Introduction,” CUP
- Prölss (2004), “Physics of The Earth's Space Environment”, Springer

Contact information

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General enquiries to the Honours coordinator, Prof. Bruce Dawson

H-3

ELECTRODYNAMICS

Semester II

Lecturer

A/Prof James Zanotti

Aim

This course aims to:

- ❖ Provide a more detailed insight into the solution of electrostatic problems through the use of Green's functions, and the Maxwell Stress tensor.
- ❖ Introduce the Inhomogeneous Wave Equations and retarded potentials.
- ❖ Introduce the calculation of radiation patterns from first principles, including both near field and radiation field components.
- ❖ Extend the treatment of wave propagation to conducting media, in particular metals, and thence to surface-plasmon-polariton solutions of Maxwell's equations.
- ❖ Introduce the implications of causality in electrodynamics, leading to a derivation of the Kramers-Kronig relations.
- ❖ Introduce metamaterials and negative refractive index.
- ❖ Review special relativity in electromagnetism, making the unification of electricity and magnetism explicit and deriving the electromagnetic field tensor.
- ❖ Introduce the Lienard-Wiechert potentials and use them to derive the radiation patterns from bremsstrahlung and synchrotron radiation.

Objectives

On completion of the course, students should:

- ❖ Have a detailed physical and mathematical understanding of a variety of electromagnetic phenomena.
- ❖ Have expertise in problem solving in the areas covered in lectures

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ To have a high order of numerical and analytical skills;
- ❖ The ability to communicate scientific information effectively;
- ❖ Scientific curiosity and the ability to continue learning independently;
- ❖ An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content (not necessarily in order below)

Electrostatics

Green's function solution of Poisson's Eq'n

Green's reciprocity theorem

Maxwell Stress Tensor

Inhomogeneous wave equations

Lorentz gauge

Green's function solution

Retarded potentials

Radiation

- Radiation from ideal dipole
- Near field and radiation fields
- Radiation from dipole antennae
- Multipole expansion and multipole radiation
- Reciprocity theorem

Propagation issues

- Drude model of metals
- Surface Plasmons
- Causality
- Kramers-Kronig relations
- Superluminal group & phase velocity
- Negative Index materials
- Metamaterials
- Negative refraction in periodic media

Relativity

- Review, four-vectors, Lorentz transform of fields
- Field Tensor
- Lienard-Wiechert potentials
- Bremsstrahlung
- Synchrotron radiation

If time permits, we will look at scattering and radiation reaction

Structure

Two lectures per week. Tutorials arranged when needed.

Assessment

Written Examination	70%
Assignments	30%

References

Intro to Electrodynamics DJ Griffiths; this is an excellent book that is well worth having. The course will go beyond its level of difficulty somewhat. The notation in the notes follows Griffiths.

Classical Electrodynamics JD Jackson; a very comprehensive text, at a fairly difficult level, but very well written. Eight copies of the second ed'n are available for borrowing from the Advanced Laboratory. N.B. this ed'n uses the Gaussian system of units, not SI.

Classical Electricity and Magnetism W Panofsky and M Philips. This is a classic text, perhaps slightly easier than Jackson, but also not as comprehensive. Very well written. Three copies of the second ed'n are available for borrowing from the Advanced Laboratory – see Adrian Giffen.

The Electromagnetic Field A Shadowitz; There should be a copy in the BSL. This has a good introduction to relativistic aspects of Electrodynamics.

Electromagnetic Fields and Waves P Lorrain and D Corson; A classic text that is in the BSL. Intermediate in level between Griffiths and Panofsky.

Contact information

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H-4

DATA ANALYSIS AND MODELLING
(formerly Fourier techniques and applications)

Semester I

Lecturers

Prof Gavin Rowell and Prof Martin White

Aim

This course aims to:

- ❖ Provide an understanding of how Fourier techniques can be used to solve problems in physics.
- ❖ Demonstrate how the Fourier transform and the related Wavelet transform provides an understanding of physical phenomena and links together many different fields
- ❖ Develop an understanding of frequentist and Bayesian statistical inference, and how to apply them to both parameter inference and model selection as they arise in the physical sciences

Objectives

On completion of the course, students should:

- ❖ Understand how and when to apply statistical inference techniques, including parameter inference and model selection
- ❖ Develop confidence in solving problems in the spectral domain, including numerical solutions FT of data and applications to power spectra.
- ❖ Understand the relationship between how the instrument response function limits resolution and its relationship to convolution.
- ❖ Understand the relationship between the FTs and wave phenomena such as diffraction and scattering from three-dimensional objects.

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ Ability to apply Fourier and statistical inference techniques to the analysis of physical problems;
- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ A high order of analytical skills;
- ❖ Scientific curiosity and the ability to continue learning independently;

Content

One-dimensional FT and applications, including convolution and wavelets (50%)

- ❖ Introduction to Fourier transforms of real variables, symmetry relations Application of Fourier Transforms to linear systems with emphasis on circuits, including transfer function and the impulse response
- ❖ Convolution in physical systems, including the Instrument Response
- ❖ Application of Modulation Rule and Shift Theorem in physical systems
- ❖ The Sampling Theorem and Aliasing
- ❖ Discrete Fourier transforms and the FFT
- ❖ Power spectra
- ❖ Wavelets transforms and their use.
- ❖ Auto and Cross- correlation functions with discrete and continuous variables

- ❖ The Wiener-Khintchine Theorem
- ❖ The Hilbert Transform and applications.

Statistical inference in Python (50%)

- ❖ Introduction to Python
- ❖ Probability (frequentist vs Bayesian definition)
- ❖ Theory of statistical estimators
- ❖ Bayesian inference, including sampling techniques such as Markov Chain Monte Carlo and nested sampling
- ❖ Frequentist inference
- ❖ Hypothesis testing

Structure

Two hours of lectures per week plus tutorials as required

Assessment

Written Examination	70%
Assignments	30%

Texts

James, J. F., "*A Students Guide to Fourier Transforms*", CUP

References

Bracewell, R. N., *The Fourier Transform and its Applications*, McGraw-Hill
 Champeny, D. C. *Fourier Transforms and their Physical Applications*, AP

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H-5

GAUGE FIELD THEORIES

Semester II

Lecturer

A/Prof Ross Young

Aim

This course aims to:

- Provide a working knowledge and understanding of the theory of particles and fields
- To derive and understand particles and their interactions based on the concept of gauge invariance
- Describe and understand the electromagnetic, electroweak and strong forces as gauge theories

Objectives

On completion of the course, students should:

- Have an understanding of these fundamental interactions, their behaviours, features and dynamics as gauge theories
- Have a good working knowledge of the elements of the Standard Model and perform calculations with them.
- Understand the concepts and problems in current particle and nuclear physics
- Gain specialised analytical skills and techniques necessary for gauge field theory calculations.

Attributes

This course is intended to develop in students the following generic attributes:

- Ability to apply an understanding of the physical principles to the other areas;
- Skills of inquiry, objective criticism, logical thought and problem solving;
- A high order of analytical skills;
- Scientific curiosity and the ability to continue learning independently;
- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content

- ❖ Principles of Gauge Invariance
- ❖ Gauge invariance in Abelian gauge field theories
- ❖ Group theory in particle physics
- ❖ U(1) gauge group
- ❖ Internal symmetries
- ❖ Special unitary groups SU(n), SU(2)
- ❖ Gauge invariance in non-Abelian gauge field theories
- ❖ Gauge invariance and geometry
- ❖ Functional methods
- ❖ Path integral quantization and gauge theories
- ❖ Generating functional methods
- ❖ Non-Abelian gauge fields and the Fadeev-Popov method
- ❖ Massive gauge bosons: Spontaneous breaking of gauge symmetry
- ❖ Higgs mechanism

- ❖ Electroweak unification and the Standard Model
- ❖ Electroweak interactions
- ❖ CKM matrix
- ❖ Perturbation theory
- ❖ Regularization and renormalization procedure

Structure

Two hours of lectures per week.

Assessment

Assignments

100%

References

- Mandl, F. and G. Shaw, Quantum Field Theory, (Revised edn, Wiley, 1993)
- Aitchison, I. J. R. and A. J. G. Hey Gauge Theories in Particle Physics, (2nd edn, IoP, 1989)
- Ryder, L. H. Quantum Field Theory, (2nd edn, CUP 1996)
- Peskin, M E. and D. V. Schroeder Introduction to Quantum Field Theory, (Addison-Wesley 1995)
- Itzykson and Zuber, Quantum Field Theory, (McGraw-Hill 1980)
- Kaku, M. Quantum Field Theory: A Modern Introduction, (Oxford Univ. Press, 1993)
- Muta, Quantum Chromodynamics,
- Halzen, F. and A.D. Martin Quarks and Leptons, (Wiley and Sons,1984)
- Bailin and Love, Introduction to Gauge Field Theory (IOP Publishing Ltd, Rev. Ed. 1993)
- Ramond, P. Field Theory: a Modern Primer, (Addison-Wesley, 1990)
- Huang, K. Quarks, Leptons and Gauge Theories, (World Scientific, 1992)

Contact information

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H-6

GENERAL RELATIVITY

Semester II

Lecturer

Prof Martin White

Aim

This course aims to:

- ❖ Explain the mathematical, physical and philosophical aspects of Einstein's theory of general relativity as the relativistic theory of gravity.

Objectives

On completion of the course, students should:

- ❖ Be able to do tensor calculus in curved Riemannian spacetimes.
- ❖ Understand that general relativity is a physical theory, in which gravitational effects are incorporated by making the four dimensional space-time of special relativity curved.
- ❖ Comprehend the motion of particles in a gravitational field as straight lines in a curved space and from that derive the geodesic equation of motion for particles in a gravitational field.
- ❖ Be able to calculate observable general relativistic effects such as the gravitational time dilation effects on the global positioning system (GPS), the bending of light by stars and the existence of black holes. Have an understanding of the standard model of cosmology with particular reference to the "Big Bang".

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ Ability to apply an understanding of the physical principles and mathematics that underpins the relativistic theory of gravity.
- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ A comprehensive understanding of tensor calculus and Riemannian geometry.
- ❖ Scientific curiosity and the ability to continue learning independently;
- ❖ An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content

Special Relativity - Review

- Minkowski space, Lorentz transformations
- Four-vectors and tensors
- Curvilinear coordinates
- World line, four-velocity and four momentum

Principle of Equivalence

- Inertial mass, active and passive gravitational mass
- Weak and strong equivalence principles
- Eotvos and Pound-Rebka experiments
- Gravity as a pseudoforce
- General covariance

Classical Field Theory

- Relativistic electrodynamics, four-current
- Lagrangian field theory
- Covariant derivative and Bianchi identity

Stress-Energy Tensor

- Relation to four-momentum and stress
- Perfect fluids and dust
- Canonical method, symmetry, result for electromagnetism
- Response of action to variation of metric tensor

Differential Geometry

- Manifolds, maps
- Tangent and co-tangent vectors
- Type (p,q) tensors

Curved Space-Time

- Covariant derivative on (p,q) tensors
- Normal coordinates for a local inertial frame
- Christoffel connection, torsion
- Parallel transport and geodesics
- Riemann curvature tensor

Einstein's Theory of Gravitation

- Bianchi identities, Ricci and Einstein tensors
- Einstein's equations
- Newtonian limit
- Cosmological constant

Schwarzschild Metric

- Birkhoff's theorem
- Schwarzschild solution

Gravitational waves

- derivation of wave equation in linearised GR

Structure

Two hours of lectures/tutorials per week.

Assessment

Assignments

100%

Texts

Carroll, S., *Spacetime and Geometry – an Introduction to General Relativity*, Addison-Wesley, 2004.

References

Misner, C W, Thorne, K S, Wheeler, J A, *Gravitation*, Freeman, J A 1973.

Weinberg, S., *Gravitation and Cosmology*, John Wiley & Sons, 1972.

d'Inverno, R., *Introducing Einstein's Relativity*, OUP, 1992.

Hobson, MP, Efstathiou, G, Lasenby, A N, *General Relativity – an Introduction for Physicists*, CUP 2006.

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H-7

PHOTONICS IV

Semester I

Lecturer

Dr Chris Perrella, Dr Rachel Offer, Dr Ben Sparkes

Aim

This course gives students:

- ❖ An introduction to laser physics.
- ❖ An introduction to elastic and inelastic nonlinear optics.
- ❖ An introduction to non-linear atom-light interaction.

Objectives

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

- ❖ Describe the operation of continuous-wave and pulsed lasers and solve simple problems.
- ❖ Discuss spatial hole burning in laser gain media and techniques for spectral control.
- ❖ Describe nonlinear optical phenomena.
- ❖ Describe and solve problems in second-harmonic generation in uniaxial crystals.
- ❖ Describe three-wave mixing processes.
- ❖ Describe the electro-optic effect and applications.
- ❖ Describe the four-wave mixing process.
- ❖ Discuss third-harmonic generation.
- ❖ Describe spontaneous and stimulated inelastic scattering processes and solve simple problems.
- ❖ Discuss the physics of nonlinear processes in the interaction of light and isolated atoms and solve simple problems.

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge and technology.
- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ Higher order numerical and analytical skills.
- ❖ Scientific curiosity and the ability to continue learning independently.
- ❖ Experience in solving original problems using their acquired skills.

Content

- ❖ Optical gain, gain saturation, effective cross-sections,
- ❖ 3 and 4-level laser characteristics
- ❖ Lasing threshold
- ❖ Laser resonators, eigenmodes, spatial mode control
- ❖ Spatial hole burning and spectral control
- ❖ Pulsed lasers: Q-switching, cavity-dumping, mode-locking, injection mode-locking
- ❖ Nonlinear electron oscillator model
- ❖ Second Harmonic Generation (SHG)
- ❖ Phase matching for SHG: critical, non-critical and quasi
- ❖ Manly-Rowe equations and general three-wave mixing
- ❖ Sum and difference frequency generation
- ❖ Optical parametric amplification and oscillators

- ❖ Nonlinear susceptibilities and condensed notation
- ❖ Pockels electro-optic (EO) effect
- ❖ Pockels cells and Q-switches
- ❖ EO phase modulators
- ❖ EO amplitude modulators
- ❖ Third-order nonlinear susceptibility and four-wave mixing
- ❖ Third-harmonic generation: $\chi^{(3)}$ and cascaded $\chi^{(2)}$
- ❖ Optical Kerr effect
- ❖ Inelastic scattering of light by matter
- ❖ Stimulated Raman and Brillouin scattering
- ❖ Linear spectroscopy
- ❖ Density matrix description of atom-light interaction.
- ❖ Bloch sphere description of light interacting with an ensemble of atoms

Structure

Two-hour lecture/workshop per week. Tutorials as required.

Assessment

Laser physics and nonlinear optics assignments	20%
Laser physics and nonlinear optics final exam	50%
Atom-light assignments	30%

Texts

Lecture notes uploaded to MyUni.

References

Milonni, P. and J. Eberly: *Lasers*
 Yariv, A.: *Optical Electronics*
 Boyd, R.: *Nonlinear Optics*
 Saleh & Teich: *Photonics*

Contact information

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H-8

Nuclear and Radiation Physics

Semester I

Lecturer

Dr Alex Santos and Dr Jake Forster

Aim

This course aims to:

- ❖ Introduce radiation and nuclear physics from an experimental viewpoint, applied to environmental, medical and solid state physics.
- ❖ Show how nuclear and radiation physics are related to other physics disciplines – solid state, elementary particle physics, radiochemistry, astronomy.
- ❖ Demonstrate the influence of experimental techniques used (or developed) for nuclear physics purposes (logic circuits, gamma cameras, semiconductor detectors) on development of new technologies.

Objectives

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

- ❖ Identify the components of the nucleus and describe the systematic behaviour of stable nuclides;
- ❖ Describe the main features of the liquid drop and shell models of the nucleus, and discuss their achievements and deficiencies.
- ❖ Discuss radioactive decay and the models used to understand it;
- ❖ Describe and explain the parameters used to describe nuclear reactions;
- ❖ Describe and apply the concepts and theories which relate to the interactions of various forms of ionizing radiation, including X-rays, gamma rays, charged particles and neutrons with matter.
- ❖ Describe the principles involved in the detection and accurate measurement of radiation.
- ❖ Discuss some of the applications of radiation and nuclear physics to medical and environmental and material physics.

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ Ability to apply an understanding of the physical principles that govern the interaction of photons and particles with matter
- ❖ Basic understanding of radiation safety issues and problems of radioactive waste disposal
- ❖ Ability to think from the experimental, technical and practical point of view
- ❖ Scientific curiosity and the ability to continue learning independently
- ❖ An appreciation of the central role of science in society and the close relationship between scientific research and many practical applications in our everyday lives that have resulted from this research.

Content

Nuclear Physics (30%)

- General properties of nuclei
- Stability, systematics, trans-uranic elements.
- Nuclear models, magic numbers
- Decay processes and half lives: fission, α and β -decay, electron capture
- Radioactive growth and decay, Bateman equations, laboratory generators

- Radioactive series
- Natural and artificial radioactivity, environmental problems, eg, radon, mining and waste disposal
- Radioisotope production
- Carbon dating, Accelerator Mass Spectrometry
- Theory of α , β and γ -decay, selection rules

Nuclear Reactions (20%)

- Interactions of neutrons with matter, neutron activation
- Applications of nuclear techniques (medical and solid state physics).

Radiation Physics (50%)

- General Properties of X-rays
- Generation of high energy Photons: X-ray apparatus, accelerators
- Tubes for imaging and therapy
- Fluorescent radiation, PIXE, monitoring bone lead levels
- Radiation measurements and units
- Interaction of Photons with Matter: photoelectric effect, Compton effect and pair production, Auger effect, Coherent (Rayleigh) scattering
- Energy transfer and deposition (absorption), build-up and KERMA
- Charged Particle Energy Losses
- Linear energy transfer (LET), stopping cross section, Bethe-Bloch formula
- Electron collision and radiation losses
- High-energy electron-photon showers, cosmic rays.

Structure

Two hours of lectures per week.

Assessment (to be Confirmed)

Written Examination (2 hours)	60%
Assignments	30%
Presentation	10%

Minimum requirements: Students must submit at least one assignment, take the examination and achieve an overall result of 50%.

Texts

Williams, W.S.C., *Nuclear and Particle Physics*, Oxford University Press, 1991.

Johns, H. E. and J. R. Cunningham, *The Physics of Radiology*, 4th Edition, CC Thomas: Springfield, 1983.

Evans, R. D., *The Atomic Nucleus*, McGraw Hill, 1955.

References

Lederer CM and V. S. Shirley, *Table of Isotopes*, 7th Edition, Wiley, 1978.

Burcham WE, and M. Jobes, *Nuclear and Particle Physics*, Longman, 1995.

Leo W. R., *Techniques for Nuclear and Particle Physics Experiments*”, Springer-Verlag, 1994.

Khan F. M. and A. R. Potish., *The Physics of Radiation Therapy*, 3rd Edition, Williams and Wilkins, 2003.

Contact information

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H-9

QUANTUM FIELD THEORY

Semester I

Lecturer

A/Prof. Ross Young

Aims

This course aims to:

- ❖ Introduce students to field quantisation, scalar field theory and quantum electrodynamics.
- ❖ Develop calculational techniques in perturbation theory.
- ❖ Prepare students for Gauge Field Theory in semester II.

Objectives

On completion of the course, students should:

- ❖ understand field quantisation and the expansion of the scattering matrix;
- ❖ be able to carry out practical calculations based on Feynman diagrams.

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ The capabilities of a professional theoretical physicist.
- ❖ An understanding of quantum theory at its most fundamental level; this is the basis of modern physics and therefore underlies most of the benefits to society from advanced technology.
- ❖ The ability to carry out advanced field-theoretic calculations, which involves the highest order of numerical and analytical skills and develops the ability to continue independent research.
- ❖ Enhanced scientific curiosity, objective criticism and an understanding of the close relationship between scientific research and the development of new knowledge.

Content

Introduction

- Review of four-vector notation.
- Why quantise fields? (a) $t \square$ operator, so neither is \mathbf{x} ; (b) causality; (c) photon field.
- Review point mechanics: Noether's theorem, Jacobi first integral, Hamiltonian.

Classical Field Theory

- Lagrangian (density), action, field equations of motion, equivalent Lagrangian.
- Real and complex scalar fields, 4-potential and Maxwell's equations, Schrödinger field.
- Stress-energy-momentum tensor and four-momentum, Hamiltonian (density).

Field Quantisation

- Dirac's quantum electrodynamics (1927).
- Free scalar field (real), 3-Fourier coefficients as ladder operators, particle number operators, Hamiltonian, zero-point energy and normal ordering, equal-time field commutators, complex scalar field.
- Heisenberg picture, space-time translations, ground state, invariantly normalized one-particle states, Fock space.

Invariant Functions

- Lorentz invariance and causality, Pauli-Jordan function, unordered free two-point function, boundary value of complex function, time-ordered functions, contour integrals and $i\epsilon$ prescriptions in momentum space.
- Feynman propagator, Green's function property and relation to canonical commutators.

Fermion Fields

- Replace commutators with anti-commutators; (Dirac equation, traces, polarization sums, etc., done concurrently in Relativistic Quantum Mechanics and Particle Physics); free fermion field and propagator, Lorentz properties.

Interacting Theories

- Local interactions: Yukawa, electromagnetic, ϕ^4 , Mexican hat.
- Interaction picture, time-evolution operator, S-matrix, Green's functions.
- Contractions, Wick's theorem, Dyson-Wick expansion.
- Feynman diagrams and rules for ϕ^4 theory, position and momentum space, Green's functions and S-matrix.
- Feynman rules for complex scalar and Yukawa theories.

Introductory Quantum Electrodynamics

- Free photon field, gauge fixing (elementary), covariant gauges.
- Feynman rules.
- Polarisation sums.

Cross Sections and Decay Rates

- Wave packets for initial and final particles, mutual beam flux, sums over final states, identical particles, examples such as Compton scattering.

Structure

Two hours of lectures per week.

Assessment

Written Examination:	50%
Assignments:	50%

Texts

Peskin, M.E. and D.V. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley 1995, Ch. 1-5.

References

Mandl, F. and G. Shaw, *Quantum Field Theory*, Wiley 1984.

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H-10

RELATIVISTIC QUANTUM MECHANICS & PARTICLE PHYSICS

Semester I

Lecturer

Prof. Anthony Williams and Prof. Paul Jackson

Aim

This course aims to:

- ❖ Review the concepts that lead to the formulation of the Klein-Gordon and Dirac Equations.
- ❖ Highlight the deep connection between the Lorentz transformations of special relativity and the transformation properties of Dirac spinors and the adjoint spinor.
- ❖ Examine plane wave solutions, completeness relations and projection operators.
- ❖ Solve the relativistic Hydrogen atom and explore its fine structure.
- ❖ Introduce the Standard Model Interactions of Particle Physics, conservation laws and associated Feynman graphs for physical processes.

Objectives

On completion of the course, students should:

- ❖ Understand the founding principles of relativistic quantum mechanics.
- ❖ Have a working knowledge of Dirac gamma matrices and their role in the Lorentz transformations of Dirac Spinors.
- ❖ Be able to use projection operators to filter spin and positive/negative energy solutions.
- ❖ Appreciate the modern field-theoretic description of negative energy states.
- ❖ Be able to solve relativistic one-body problems for spin-0 and $\frac{1}{2}$ particles.
- ❖ Identify particle interactions allowed by the Standard Model and describe the physical process by which they occur.

Attributes

This course is intended to develop in students the following generic attributes:

- ❖ To value the close relationship between scientific research and the development of new knowledge.
- ❖ An enthusiasm for, and enjoyment of, the ethos of science and the process of scientific investigation.
- ❖ Skills of inquiry, objective criticism, logical thought and problem solving;
- ❖ To have a high order of numerical and analytical skills;
- ❖ To possess scientific curiosity and the attitudes, knowledge and skills necessary for a commitment to life long learning;

Content

Relativistic Quantum Mechanics (60%)

- Klein Gordon Equation
- Problems with the Klein Gordon Equation
- Dirac Equation
- Probability Current
- Two-Spinor Decomposition
- Hole Theory and the Anti-Particle Wave Function

- Rotation Group $O(3)$ and the Lorentz Group $O(3;1)$
- Review of Tensors
- Manipulating Exponentials of Operators
- Transforming Spinors: Vector and Spinor Lorentz Generators
- Lorentz Covariance of the Dirac Equation
- Adjoint Spinor
- Four-Current Density
- Parity
- Sixteen Gamma Matrices and associated Theorems for Gamma Matrices
- Natural Units
- Plane-Wave Solutions and their Lorentz Properties
- Completeness and Projectors
- Four-Spin
- Electromagnetic Coupling, Magnetic Moment and the Gyromagnetic ratio
- Charge Conjugation
- Klein-Gordon Atom
- Relativistic H Atom
- Corrections to Dirac Spectrum

Particle Physics (40%)

- Introduction to Standard Model Interactions
- Conservation of Charge, Baryon Number.
- Conservation of Lepton and Lepton Family Number.
- Quark Structure in Reactions.
- Strangeness, Parity, Charge Conjugation and G-Parity.
- Parity of the Pion.
- Quarks and Isospin.
- Constituent versus Current Quarks.
- Feynman Diagrams for Physical Processes

Structure

Two one-hour lectures per week.

Assessment

Written Examination	75%
Two Assignments	25%

Texts

Crewther, R., *Lecture Notes: Relativistic Quantum Mechanics* (2003)

References

Bjorken, J. D. and S. D. Drell, *Relativistic Quantum Mechanics*, Vol. I (1964)
 Itzykson, C. and J.-B. Zuber, *Quantum Field Theory* (1980)

Contact information

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Prof Anthony Williams	anthony.williams@adelaide.edu.au	8313 3546

H-11

HONOURS ELECTRONICS

Semester I

Lecturer

Professor Peter Veitch

Aim

This course provides an introduction to analogue and digital electronics used for signal conditioning, data acquisition and experiment control in experimental and applied physics. It includes applications of operational amplifiers, comparators, digital gates and flip-flops, astable and monostable multivibrators, digital to analog converters, analog to digital converters, and PIC (peripheral interface controller) chips.

Structure

One three-hour practical session per week.

Assessment

Open-book practical exam	70%
Laboratory workbook assessment	30%

Texts

References

Horowitz and Hill: *The Art of Electronics*

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TOPICS IN QUANTUM MATERIALS

Semester I

Lecturers and Contact Information

Prof Glenn Solomon

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Dr Giuseppe Carlo Tettamanzi

giuseppe.tettamanzi@adelaide.edu.au

Aim

This course provides a survey of current concepts and functionality associated with quantum materials. Within this broad topic, we will choose a select subset to illustrate a variety of the basic concepts in quantum mechanics and condensed matter that underpin solid-state materials, and then show how these materials can be applied.

Objectives

On completion of the course, students should:

Have a general understanding of the field of quantum materials;

Have developed the concepts to conceptually understand and model select material classes;

Understand how these materials have been used in past and maybe used in the future in areas ranging from fundamental physics to applications in engineering and society.

Content

Introduction to Quantum Materials: Physical fabrication; Crystal structure; Bands structure and Fermi surfaces, Strain, and Spin.

Compound semiconductors: Heterostructures; Quantum well physics; Transport and Optical Processes; Optical and High-electron mobility structures and devices.

Nanostructures: (1: Concepts) Reduced dimensionality; Photon indistinguishability and Photon number; Introduction to entanglement; Topological states (2 Materials) Quantum dots; 2D graphene-like materials. Quantum point contact, Coulomb blockade and Single electron transistors.

Superconductors: (1: Concepts) Critical Phenomena and Symmetries in quantum materials; Order parameters in 2nd order phase transitions, Superconductivity. (2: Materials) Josephson junctions, Superconducting quantum interference devices (SQUIDS) and applications.

Quantum Metrology and the re-definition of the International System (SI) of units.

Structure

Two lectures per week. Optional problem sessions, tutorials, and special events.

Assessment-Tentative

Testing--One short, individual oral	25%
Final Presentation (oral or written)	40%
Assignments & Participation	35%

Texts

Class notes and occasional journal articles

References-Tentative

Physics of Optoelectronic Devices, S. L. Chuang, Wiley Series in Pure and Applied Optics.
Advanced Solid-State Physics, Philip Philips, Cambridge University Press.