THE UNIVERSITY
of ADELAIDE

SUB CRUCE LUMEN

DEPARTMENT OF PHYSICS

HONOURS LECTURE MODULE DESCRIPTIONS

2020

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. 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).

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 Atmospheric Physics **(TBD)** (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   Non-Linear Optics/ Photonics IV **(Veitch, Perrella, Sparkes, Luiten)** (S1)
H-8   Nuclear and Radiation Physics **(Santos/Bezak)** (S1)
H-9   Quantum Field Theory **(Young)** (S1)
H-10   Relativistic Quantum Mechanics & Particle Physics **(Williams/Leinweber)** (S1)
H-11   Honours Electronics **(Veitch)** (S1)
H-12   Applications of Relativity **(Drake)** (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 Tuekolsky, S. A. *Black Holes, White Dwarfs and Neutron Stars*
Harwit, M. *Astrophysical Concepts*

Contact information

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ADVANCED ATMOSPHERIC PHYSICS

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Semester II

Lecturer

TBD

Aim

This course aims to:

- ❖ Introduce the physics of planetary atmospheres and ionospheres, with special emphasis on the atmosphere and ionosphere of the Earth.
- ❖ To provide students with knowledge of the physical processes that govern the atmosphere.
- ❖ To provide students with knowledge of the processes that govern the formation of planetary ionospheres and radiowave propagation through weak plasmas.

Objectives

On completion of the course, students should:

- ❖ Have an understanding of the basics of atmospheres, including atmospheres in diffusive equilibrium.
- ❖ Understand the transfer of radiation through the atmosphere, including general solutions of the Radiative Transfer (Schwartzschild) equation.
- ❖ Understand the production and loss mechanisms that lead to formation of different atmospheric regions.
- ❖ Understand radiative properties of single lines and use for remote sensing from space.
- ❖ Understand the role of atmospheric waves in transporting momentum and how this affects the state of the atmosphere.
- ❖ Understand ionisation processes in planetary atmosphere and the production and loss mechanisms that influence the formation of different regions of the ionosphere
- ❖ Understand the propagation of radiowaves through weak plasmas and how this can be used to study the ionosphere.

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

Introduction to Planetary Atmospheres (10%)
- Atmospheric composition, density and temperature
- Atmospheric thermodynamics and stability

Radiation and Radiative Transfer (25%)
- radiative transfer equation and solution
- heating rates
- radiative cooling to space approximation
- formation of the stratosphere
- heat conduction and the energy budget above 100 km
- remote sensing of atmospheres from space

Atmospheric Dynamics and the Role of Waves (45%)
- primitive equations for an atmosphere on a rotating planet
- Large scale motions for an atmosphere in radiative equilibrium
- vorticity and circulation
- the vorticity equation and potential vorticity
- Periodic motions and linear wave theory and solutions in a spherical atmosphere
- vertical propagation of planetary waves and their role in the energy budget of the middle atmosphere and the formation of the ozone hole
- vertical oscillations in a stratified fluid
- solutions of the primitive equations in a non-rotating, stratified fluid
- properties of atmospheric gravity waves
- Reynolds stresses and the transport of momentum by waves
- Wave-driven circulations of the atmosphere

Ionospheric Physics (20%)
- The ionosphere, formation and dissipation
- Propagation of radiowaves in a weak plasma with and without an external magnetic field
- Characteristic modes and ionospheric sounding

Structure

Two hours of lectures/tutorials per week.

Assessment

Written Examination	70%
Assignments	30%

References

Andrews, D. G. (2000): *An Introduction to Atmospheric Physics*, CUP.
Andrews, D. G. J. R. Holton and C. B. Leovy (1987): *Middle Atmosphere Dynamics*, Academic Press.
Houghton, J. (1977): *The Physics of Atmospheres*, CUP.
Holton, J. R. (1980): *An Introduction to Dynamic Meteorology*, Academic Press.

Contact information

General enquiries to the Honours coordinator, Bruce Dawson

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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DATA ANALYSIS AND MODELLING
(formerly Fourier techniques and applications)

Semester I

Lecturer

Prof Gavin Rowell and A/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 provides an understanding of physical phenomena and links together many different fields
- Develop an understanding of how to use Monte-Carlo simulation techniques

Objectives

On completion of the course, students should:
- Understand how and when to apply Monte-Carlo techniques
- Develop proficiency with the package GEANT-4
- 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 Monte-Carlo 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 and their use.
- Auto and Cross- correlation functions with discrete and continuous variables
- The Wiener-Khintchine Theorem
- The Hilbert Transform and applications.

Monte-Carlo techniques (50%)
* Introduction to random simulation
* Random number generators, and tests
* GEANT-4

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 Application*s, AP

Contact information

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A/Prof Martin White
    Email: martin.white@adelaide.edu.au   Phone   8313 0624

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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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GENERAL RELATIVITY

Semester II

Lecturer

A/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
- Sylvester's law of inertia, vierbein field
- Type (p,q) tensors
- Forms and exterior derivatives

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
- Linearised gravity

Schwarzschild Metric
- Birkhoff's theorem
- Schwarzschild solution
- Black holes
- Killing vectors
- Deflection of light by Sun
- Precession of Mercury orbit

Introduction to Cosmology
- Friedman-Robertson-Walker metric
- Hubble constant: Universe closed, flat or open?
- Cosmic microwave background

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.

Contact information

A/Prof Martin White

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NON-LINEAR OPTICS

Semester I

Lecturer

Prof Peter Veitch, Dr Chris Perrella, Dr Ben Sparkes, Prof Andre Luiten

Aim

This course gives students:
- ❖ In depth exposure to non-linear optics
- ❖ Experience in applying nonlinear optics to advanced lasers, and optical fiber systems
- ❖ Sufficient knowledge to pursue research in these fields.

Objectives

On completion of the course, students should:
- ❖ Have an understanding of detailed nonlinear optics theory.
- ❖ An appreciation and knowledge of how to use and apply it to practical laser systems
- ❖ A working knowledge of how to approach new problems in nonlinear optics and applications.

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

- ❖ Introduction: Overview and review of nonlinear optics.
- ❖ Wave equation description of NLO: Second Harmonic Generation, phase matching,
- ❖ Second, Third and higher order
- ❖ Intensity dependent index of refraction, general tensor formulation of susceptibility.
- ❖ Nonlinear optical processes: intensity dependent index
- ❖ Semiconductor and molecular nonlinearities
- ❖ Inelastic nonlinear optical processes: Stimulated Raman, Brillouin etc.
- ❖ Optical Phase conjugation
- ❖ Nonlinear Fibre Optics: Fibre Fundamentals: overview of basic fibre concepts, types, properties and applications. Photonic Crystals: concepts, 1- 2- and 3-dimensional photonic crystals, Fibre Bragg Gratings
- ❖ Optical Glasses: concepts, optical and thermal properties, fabrication,
- ❖ Microstructured Fibres: guidance mechanisms, optical properties, fabrication and applications, Nonlinear fibre devices based on microstructured fibres: review of operation of a range of devices
- ❖ Thermonuclear laser fusion
- ❖ Quantum optics, quantum cryptography

Structure

Two hours of lectures/tutorials per week.

Assessment

Take-home midterm exam	30%
Take-home final exam	50%
Student seminar on relevant topic	20%

Texts

Class notes handed out

References

Milonni, P. and J. Eberly: *Lasers,* John Wiley & Sons, 1988

Ghatak A.K. and K. Thyagarajan: *Optical Electronics,* Cambridge 1989

Yariv, A.: *Optical Electronics*, Holt, Rinehart & Winston, 4th edition, 1991

Boyd, R.: *Nonlinear Optics,* Academic Press, 2003.

Butcher, P.N. and D. Cotter: *The Elements of Nonlinear Optics* Cambridge 1990

Agrawal, G.P.: *Nonlinear Fiber Optics* Academic Press 2001

Saleh & Teich: *Photonics*

Contact information

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<p align="center">**Nuclear and Radiation Physics**</p>

Semester I

Lecturer

Dr Alex Santos and Prof. Eva Bezak

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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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 operator, so neither is 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. Derek Leinweber

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 ½ 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 (75%)
- – 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 (25%)
- 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

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 per week.

Assessment

Practical Examination	50%
Workbook assessment	50%

Texts

References

The Art of Electronics, *Horowitz and Hill.*

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APPLICATIONS OF RELATIVITY

Lecturers

Dr Sam Drake

Aim

The focus of this course is on teaching those aspects of relativity theory that are relevant to applied physics in the areas of signal processing, navigation, tracking, imagining, cartography and optimal path planning. All of the material is presented so that each new concept is demonstrated through practical examples. For each topic we will discuss a relativistic concept, derive the mathematics and give fully worked examples

Objectives

On completion of the course, students should:

❖ Understand how to construct and use space-time tensor equations to solve practical problems in applied physics
❖ Determine under what conditions relativistic effects such as time dilation and Einstein velocity addition are important
❖ Calculate the pseudo acceleration caused by coordinate transformations

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)

Galilean Relativity
- Galilean transformation equations
- Principle of invariance
- The difference between phase and group velocity
- The Doppler effect for sound from the Galilean transformations

Lorentz transformations
- Derivation of the Lorentz transformations
- Consequences of the Lorentz transformations: The velocity addition formula, Angular aberration, time dilation, length contraction, lack of simultaneity
- The Doppler effect for light in a vacuum
- The relationship between causality and events inside or outside the light-cone
- The invariance of the Minkowski space-time interval under Lorentz transformations

Ring Laser Gyroscopes
- Beat frequency for the pedagogical RLG
- "Fresnel drag" for light in a medium

- Thomas procession (two Lorentz transformations produce a single Lorentz transformation and a rotation)

Tensors and the laws of physics
- Understand the difference between co and contra variant vectors
- Einstein summation convention
- The relationship between the metric tensor and the Jacobian matrices
- Know how to swap from tensor notation to linear algebra notation
- Understand how the Jacobian matrix can be used to calculate the error covariance matrix in different coordinate systems
- Derive the Doppler effect for light in a vacuum from the Lorentz transformations in tensor notation
- Express bias in tensor notation

Relativistic Dynamics
- Understand the Einstein velocity addition law is inconsistent with the conservation of Newtonian momentum
- $E^2 = p^2c^2 + m^2c^4$
- Conservation of four momentum (energy-momentum) and how to use it to calculate
- Energy efficiencies
- Momentum of photons
- De Broglie wavelength
- Compton scattering

Relativistic Electromagnetism
- The speed of light in a vacuum from Maxwell's equations
- The Levi-Civita symbol and its use in Cross products, Curl, Grad curl etc
- The electromagnetic field tensor and its role in the Lorentz force on a charged particle in and EM field
- Rewriting Maxwell's equations as tensor equations
- Invariances of the EM tensor
- The transformation of the EM tensor using the Lorentz transformations
- Derivation of the Biot-Savart law from Lorentz transformations of a moving particle in an EM

Cartography and Tensor Algebra
- Derive expressions for the Euclidean distance of various map projections
- Express the distortions (angle, distance and area) for different cylindrical projections
- Use the distortion formula to calculate: the speed and heading as a function of change in latitude and longitude, the distance along a loxodrome between points on a sphere, the error in latitude and longitude for a given GPS error
- Calculate the distortive effects of projecting the WGS84 ellipsoid onto a sphere

Tracking in non-Cartesian coordinates
- Derive the Coriolis force by considering rotating basis vectors
- Express this derivative in terms of the Christoffel symbols
- Express the derivative of a vector with respect to proper time in terms of the derivative of the components and the Christoffel symbols
- In 2D polar coordinates calculate: The Christoffel symbols, Grad Phi
- Express the covariant derivative of a covariant vector in terms of the Christoffel symbols
- Appreciate that minimising the distance also leads to the geodesic equation

General Relativity and the Global positioning system
- Given the metric tensor for a weak gravitational field calculate the difference in proper time for a clock on Earth and one in circular orbit

Structure

Two one-hour lectures per week.

Assessment

Assignments	20%
Question sets	30%
End of semester open-book exam	50%

(Hurdle: to pass the course, students must score at least 40% in the exam)

References

The following book, papers and web sites are recommended:
- S. P. Drake, "Was Einstein an Engineer?", Proceedings of the IEEE, vol. 102, pp. 1870-1872, 2014.
- J. Wolfe. Einstein Light. Available: http://newt.phys.unsw.edu.au/einsteinlight/
- A. P. French, Special relativity. New York: Norton, 1968.
- B. F. Schutz, A first course in general relativity. Cambridge: Cambridge University Press, 1985.
- S. P. Drake, "The equivalence principle as a stepping stone form special to general relativity: A Socratic dialog," American Journal of Physics, vol. 74, pp. 22-25, 2006.
- S. P. Drake and K. Dogancay, "Some applications of tensor algebra to estimation theory," in Wireless Pervasive Computing, 2008. ISWPC 2008. 3rd International Symposium on, 2008, pp. 106-110.
- S. P. Drake, B. D. O. Anderson, and C. Yu, "Causal association of electromagnetic signals using the Cayley--Menger determinant," Applied Physics Letters, vol. 95, p. 034106, 2009

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