
QUANTUM PHYSICS

PHYS3040

Lecturer
A/Professor Tim Ralph

Quantum Physics

PHYS3040

School of Physical Sciences

2004

Units: #2
4C (34L, 18T)
Semester 1

Purpose of the course

Quantum Physics aims at the theoretical understanding of the physical properties of systems, generally of microscopic size, such as atoms, molecules or nuclei, but sometimes also systems occurring on the macroscopic scale, such as superfluids or superconductors. Unlike the deterministic world of classical physics, the quantum regime is intrinsically random, though the probabilities of events can be predicted. The particular development presented here is the standard approach based on the ideas of Heisenberg, Schrodinger, Bohr, Dirac and Born. The mathematical formalism used is due to Dirac. Key applications of the theory to atoms, molecules, solids, light fields and other physical systems will be treated.

The course provides part of a comprehensive, complete and coherent program of education in Physics intended for students aiming to become professional physicists. It is a compulsory course for entry into Physics Postgraduate Honours.

Staff

Lecturing Staff

A/Professor Tim Ralph
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Office Hours: to be advised

Web page The course profile and course material can be found on the web via the following address: www.physics.uq.edu.au. This also contains up-to-date news about the course material. Please check the course website regularly during the semester.

Assumed background

Prerequisites: (PH242 or PHYS2041) + [(MATH2000 or MT250) + (MATH2100 or MT253)]

Intending students need to be competent in multivariable calculus, including the theory of multiple integrals, ordinary and partial differential equations, Taylor series. They should also be familiar with vectors, matrix algebra and complex numbers. The subject is presented on the assumption that the student is familiar with the experimental background to quantum physics as outlined, for example, in the textbook by Weidner and Sells (*Elementary Modern Physics*: Allyn and Bacon 1968) and covered in PHYS2041. The development proceeds from an assumed background that includes all the basic results of a course in elementary classical mechanics such as PHYS1001

Course goals

Through studying PHYS3040 students will:

- Develop an understanding of the basic features and laws of quantum physics
- Develop an understanding of the key concepts in quantum physics such as quantum probabilities, superposition states, quantization, wave-particle duality, simultaneous measurement, symmetry and conservation laws, density operator, Heisenberg and Schrodinger pictures, particle identity.
- Develop an understanding of and ability to apply the Dirac mathematical formalism of quantum mechanics.
- Develop an understanding of and an ability to apply techniques such as matrix mechanics, wave mechanics, perturbation theory to quantum physics situations.
- Develop an understanding of the quantum behaviour of important physical systems in fields such as atomic physics, molecular physics, solid state physics, quantum optics via the application of quantum physics methods.
- Develop an ability to apply the methods of quantum physics to new physical systems and obtain analytical and numerical results describing the behaviour.

Graduate Attributes:

The following graduate attributes will be developed in the course –

- In-Depth Knowledge in the Field of Study
- Effective Communication
- Independence and Creativity
- Critical Judgement
- Ethical and Social Understanding

The development of graduate attributes through course content, learning modes and assessment is outlined in the following tables.

For more information on the University policy on development of graduate attributes in courses, refer to the web:

<http://www.uq.edu.au/hupp/contents/view.asp?s1=3&s2=20&s3=5>.

PHYS3040 Graduate Attributes developed and how achieved (ie embedding)

Learning experience	In-Depth Knowledge of the Field of Study	Effective Communication	Independence and Creativity	Critical Judgment	Ethical And Social Understanding
Lectures	subject matter covered	listening, note-taking, questioning, accessing web information		identification of essential physics of situation and synthesise links between pieces of information	a knowledge and respect of the scientific method
Small group tutorials	understanding and synthesising links between pieces of information	comprehending, effective interaction, conveying ideas in written, spoken and symbolic forms	Identifying problems and producing own solutions		Ethical standards in collaborations
Independent study	use of texts and other resource material, problem solving		working independently		

For more information on development of Graduate Attributes in courses refer to http://www.uq.edu.au/teaching_learning/ then Graduate Attributes and Curriculum Review

PHYS3040 Graduate Attributes assessed (ie mapping)

Assessment task	In-Depth Knowledge of the Field of Study	Effective Communication	Independence and Creativity	Critical Judgment	Ethical And Social Understanding
Solutions to tutorial problems	encompassing competency in mathematical and analytical skills	writing, understanding of questions, drawing diagrams	ability to understand principles and develop own coherent solution	critical evaluation of solutions presented	applications of ethical standards in qualitative and quantitative solutions
End of semester exam (conceptual short answer + problem-solving)	in depth understanding and application of standard techniques, conceptualising physical situations, numerical problem-solving	writing, drawing diagrams, comprehending written questions	supervised independent work, free response, adaptation to unfamiliar problems	identification & analysis of problem	

For more information on development of Graduate Attributes in courses refer to http://www.uq.edu.au/teaching_learning/ then Graduate Attributes and Curriculum Review

Teaching and learning methods

Lectures (35 hrs) Mon 12noon-1pm in 7-302, Tues 9am-10am in 5-207 and Fri 9am-10am 7-326, will cover the formal course content. The lectures will be supplemented by tutorials Fri 1pm-2pm 7-326. The lecture and tutorial times may be interchanged. In the tutorials set tutorial problems will be discussed.

Assessment program

Eight take home assignments will be issued throughout the course and will comprise 30% of the assessment.

There will be a end-of-semester centrally-timetabled three hour examination. The exam is worth 70%.

Assessment criteria

Assessment will be criterion based, and not norm based, as required by University policy. The students understanding of the subject will be shown by their being able to:

- Define, explain and interrelate the key concepts involved in the subject
- Recognise the regime of applicability of the theory presented
- Use the basic theory to describe quantitatively the behaviour of important physical systems treated in the subject.
- Apply the theory to new physical problems and obtain correct analytical and numerical results in the appropriate units of measurement
- Utilise the appropriate mathematical and other techniques to derive relationships for physical quantities

This understanding will be assessed by requiring the student to:

- Complete written assignments
- Attend written examinations and tests

which in total will range over the topics, key concepts and class of problems covered in the subject as set out in the Course Profile (unless notified to the contrary by the Course Coordinator(s)). The assessment program will not necessarily address every topic covered in the syllabus.

Assessment and grading

Grading

To earn a Grade of 7, a student must demonstrate an excellent understanding of the course material. This includes clear expression of nearly all their deductions and explanations, the use of appropriate and efficient mathematical techniques and accurate answers to nearly all questions and tasks with appropriate justification. They will be able to apply mathematical techniques to completely solve both theoretical and practical problems. A student satisfying this criterion will normally achieve a final mark between 85 - 100 %.

To earn a Grade of 6, a student must demonstrate a comprehensive understanding of the course material. This includes clear expression of most of their deductions and explanations, the general use of appropriate and efficient mathematical techniques and accurate answers to most questions and tasks with appropriate justification. They will be able to apply mathematical techniques to partially solve both theoretical and practical problems. A student satisfying this criterion will normally achieve a final mark between 75 - 84 %.

To earn a Grade of 5, a student must demonstrate an adequate understanding of the course material. This includes clear expression of some of their deductions and explanations, the use of appropriate and efficient mathematical techniques in some situations and accurate answers

to some questions and tasks with appropriate justification. They will be able to apply mathematical techniques to solve fundamental problems. A student satisfying this criterion will normally achieve a final mark between 65 - 74 %.

To earn a Grade of 4, a student must demonstrate an understanding of the basic concepts in the course material. This includes occasionally expressing their deductions and explanations clearly, the occasional use of appropriate and efficient mathematical techniques and accurate answers to a few questions and tasks with appropriate justification. They will have demonstrated knowledge of techniques used to solve problems and applied this knowledge in some cases. A student satisfying this criterion will normally achieve a final mark between 50 - 64 %.

To earn a Grade of 3, a student must demonstrate some knowledge of the basic concepts in the course material. This includes occasional expression of their deductions and explanations, the use of a few appropriate and efficient mathematical techniques and attempts to answer a few questions and tasks accurately and with appropriate justification. They will have demonstrated knowledge of techniques used to solve problems. A student satisfying this criterion will normally achieve a final mark between 45 - 49 %.

To earn a Grade of 2, a student must demonstrate some knowledge of the basic concepts in the course material. This includes attempts at expressing their deductions and explanations and attempts to answer a few questions accurately. A student satisfying this criterion will normally achieve a final mark between 20 - 44%.

A student will earn a Grade of 1 if they show a poor knowledge of the basic concepts in the course material. This includes attempts at answering some questions but showing an extremely poor understanding of the key concepts. A student satisfying this criterion will normally achieve a final mark between 0 - 19 %.

Assessment policies

Students should be familiar with the rules which relate to assessment in their degrees as well as general university policy such as found in the General Award Rules. These are all set out on the myAdvisor page on the UQ website

<http://www.uq.edu.au/student/GeneralRules2003/2003GARs.htm>.

Plagiarism

Below is the University's definition of plagiarism

Plagiarism is the action or practice of taking and using as one's own the thoughts or writings of another (without acknowledgement). The following practices constitute acts of plagiarism and are a major infringement of the University's academic values:

- (a) where paragraphs, sentences, a single sentence or significant part of a sentence which are copied directly, are not enclosed in quotation marks and appropriately footnoted;*
- (b) where direct quotations are not used, but are paraphrased or summarised, and the source of the material is not acknowledged either by footnoting or other simple reference within the text of the paper;*
- (c) where an idea which appears elsewhere in print, film or electronic medium is used or developed without reference being made to the author or the source of that idea.*

When a student knowingly plagiarises someone's work, there is intent to gain an advantage and this may constitute misconduct.

Students are encouraged to study together and to discuss ideas, but this should not result in students handing in the same or similar assessment work. Do not allow another student to copy your work. While students may discuss approaches to tackling a tutorial problem, care must be taken to submit individual and different answers to the problem. Submitting the same or largely similar answers to an assignment or tutorial problem may constitute misconduct.

For more information on the University policy on plagiarism, please refer to <http://www.uq.edu.au/hupp/contents/view.asp?s1=3&s2=40&s3=12>

Supplementary examinations

A supplementary examination may be awarded in one course to students who obtain a grade of 2 or 3 in the final semester of their program and require this course to finish their degree. You should check the rules for your degree program for information on the possible award of supplementary examinations. Applications for supplementary examinations must be made to the Director of Studies in the Faculty.

EPSA Faculty policy on the award of supplementary exams may be found via the Faculty Guidelines from the EPSA student page <http://www.epsa.uq.edu.au/index.html?id=9329&pid=7564>

Special examinations

If a student is unable to sit a scheduled examination for medical or other adverse reasons, she/he can and should apply for a special examination. Applications made on medical grounds should be accompanied by a medical certificate; those on other grounds must be supported by a personal declaration stating the facts on which the application relies; other corroborative evidence may also be accepted.

Applications for special examinations for central exams must be made through the Student Centre. Applications for special examinations in departmental exams must be made to the course coordinator.

More information on the University's assessment policy may be found <http://www.uq.edu.au/hupp/contents/view.asp?s1=3&s2=30&s3=5>

EPSA Faculty policy on the award of special and supplementary exams may be found at <http://www.epsa.uq.edu.au/index.html?id=9329&pid=7564>

Feedback on assessment:

You may request feedback on assessment in this course progressively throughout the semester from the course coordinator. Feedback on assessment may include discussion, written comments on work, model answers, lists of common mistakes and the like.

Information on the University's policy on access to feedback on assessment may be found at <http://www.uq.edu.au/hupp/contents/view.asp?s1=3&s2=30&s3=6>

EPSA Faculty policy on feedback and re-marking may be found at <http://www.epsa.uq.edu.au/index.html?id=7674&pid=7564>

Textbook and references

These are listed in the course notes available on the course web page.

Library contact:

The liaison librarian for Physics is located in the Physical Sciences and Engineering Library in the Hawken Building and may be consulted for assistance in the course:

Physics: Leith Woodall
Email: l.woodall@library.uq.edu.au
Extension: 52367

Assistance for Students:

Students with English language difficulties should contact the course coordinator or tutors for the course.

Students with English language difficulties who require development of their English skills should contact the Institute for Continuing and TESOL Education on extension 56565.

The Learning Assistance Unit located in the Relaxation Block in Student Support Services. You may consult learning advisers in the unit to provide assistance with study skills, writing assignments and the like. Individual sessions are available. Student Support Services also offers workshops to assist students. For more information, phone 51704 or consult the web: <http://www.sss.uq.edu.au/index.html>.

Student Liaison Officer:

The School of Physical Sciences has a Student Liaison Officer as an independent source of advice to assist students with resolving academic difficulties.

The Student Liaison officer during 2004 will be Dr Peter Adams, Room 547 Priestley building, (email pa@maths.uq.edu.au)

Students with disabilities

- Any student with a disability who may require alternative academic arrangements in any course offered by this Department is encouraged to seek advice at the commencement of the semester from a Disability Adviser at Student Support Services.

Recommended texts and references

Textbook:

No specific textbook is recommended.

Important reference books are:

- Modern Quantum Mechanics, J.J. Sakurai. Addison-Wesley (Revised Edition)
- Quantum Mechanics, A.S. Davydov. Pergamon. 1st Edition.
- Quantum Mechanics, L. Shiff. McGraw-Hill. 3rd Edition.
- Quantum Mechanics, L. Merzbacher. Wiley. 2nd Edition.
- Quantum Mechanics, C. Cohen-Tannoudji, B. Diu and F. Laloe. Wiley. 1st Edition. Two volumes.
- Quantum Mechanics, A. Messiah. North-Holland. 1st Edition. Two volumes.

Other reference books are:

- Quantum Mechanics, P. Dirac. Oxford. 4th Edition.
- Lectures on Physics, R. Feynman. Addison-Wesley.

Syllabus/Lecture Timetable

Syllabus

Thirty Five Lectures

1. *General features of quantum physics* — T. Ralph *Two lectures*
 Probabilistic nature of quantum physics, superposition principle, quantization, wave-particle duality, lack of simultaneous measurability, entanglement, non-classical physical quantities, creation and destruction of matter, conservation laws, causality, classical limit.
2. *Mathematical basis for quantum physics* — T. Ralph *Five lectures*
 State space and ket vectors. Scalar products. Bra vectors and linear functionals. Dual Space. Bases. Orthogonality. Subspaces. Linear operators and their algebra. Projection operators. Completeness identity. Matrix elements. Operators acting on bras. Adjoint of an operator. Representations. Eigenvalue equations. Hermitean operators. Observables. Simultaneous eigenvectors. Unitary operators. Tensor products of state spaces.
3. *Basic laws of quantum physics* — T. Ralph *Three lectures*
 States of quantum systems. Physical quantities. Measurement values of physical quantities. Probabilities of measurement. Reduction of state vector after measurement. Quantum dynamics in Schrodinger picture. Time dependent Schrodinger equation (TDSE).
4. *Mean value and variance* — T. Ralph *One lecture*
 Mean value. Variance and standard deviation. Classical measurement. Quantum noise. Rate of change of mean value.
5. *Wave mechanics of particle in 3D space* — T. Ralph *Three lectures*
 x and p representations. Translation operator. x representation of p $|\psi\rangle$. x representation of TDSE and energy eigenvalue equation. Momentum eigenfunctions. Schrodinger wave function for free particle and de Broglie waves. Relation between Schrodinger and momentum wave functions. p representation of x $|\psi\rangle$.
6. *Energy eigenvalues: exact methods* — T. Ralph *Three lectures*
 Particle in a box, square well potential. Harmonic oscillator in 1D and 3D. Normal modes in solids.

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7. *Simultaneous measurement of two physical quantities* — T. Ralph *One lecture*
Simultaneous eigenvectors and commutation law. Heisenberg uncertainty principle. Minimum uncertainty states. System with two parts.
 8. *Energy eigenvalues: perturbation theory* — T. Ralph *Three lectures*
First and second order non-degenerate perturbation theory. First order degenerate perturbation theory. Secular equation. Applications to perturbed 1D and 3D harmonic oscillator.
 9. *Conservation laws* — T. Ralph *Two lectures*
Conservation and commutation law. Energy conservation and stationary states. Time-energy uncertainty principle. Symmetry and conservation laws.
 10. *Quantum dynamics in Heisenberg picture* — T. Ralph *Two lecture*
Evolution operator. Heisenberg equations. Classical limit of quantum physics. Interaction picture.
 11. *Quantum processes and perturbation theory* — T. Ralph *Two lectures*
Quantum processes and transition probabilities. Superposition of probability amplitudes. Addition of transition probabilities. Feynman path integrals. First order time dependent perturbation theory. Fermi golden rule.
 12. *Quantum density operator* — T. Ralph *Two lecture*
Pure and mixed states. Ensemble averages. Quantum density operator. Populations and coherences. Liouville-von Neumann equation. Entropy in quantum physics.
 13. *Angular momentum* — T. Ralph *Two lectures*
Commutation laws. Simultaneous eigenvectors for J^2 and J_z . Angular momentum and magnetic quantum numbers. Orbital and spin angular momentum. Coupling of angular momenta.
 14. *Central field problem* — T. Ralph *Two lectures*
Central field energy eigenfunctions, spherical harmonics and radial wave function. Hydrogen atom. Fine structure effects in hydrogen.
 15. *Systems of identical particles* — T. Ralph *Two lectures*
Product states. Permutation operators. Symmetrization principle. Bosons and Fermions. Pauli exclusion principle. Central field model for many electron atoms and periodic table.