UNSW Course Outline

ELEC3705 Fundamentals of Quantum Engineering - 2024

Published on the 25 Aug 2024

General Course Information

Course Code : ELEC3705
Year : 2024
Term : Term 3
Teaching Period : T3
Is a multi-term course? : No
Faculty : Faculty of Engineering
Academic Unit : School of Electrical Engineering & Telecommunications
Delivery Mode : In Person
Delivery Format : Standard
Delivery Location : Kensington
Campus : Sydney
Study Level : Undergraduate
Units of Credit : 6

Useful Links

Handbook Class Timetable

Course Details & Outcomes

Course Description

The progress of nanotechnology allows the fabrication of devices whose physical dimensions are approaching the atomic scale. At that scale, the laws of Quantum Mechanics become important. For classical electronics, an understanding of quantum phenomena and their impact on nanoscale devices is essential to further improve their performance. On the other hand, quantum effects can also be deliberately harnessed and exploited to create unprecedented functionalities.

The course "Fundamentals of Quantum Engineering" provides a modern, accessible, engineering-oriented introduction to the laws of Quantum Mechanics, and their relevance and applications in the emerging field of quantum technologies. The course teaches Quantum Mechanics using a matrix-oriented approach, which allows the students to write simple computer code to simulate the behaviour of surprisingly complex quantum devices.

The key learning outcomes of the course are the ability to understand and quantitatively describe the behaviour of quantum mechanical systems and devices, and to appreciate the potential of quantum phenomena to be applied for the construction of revolutionary systems such as quantum computers, quantum-enhanced sensors, and secure quantum communication channels. The course has a rather minimal set of prerequisities, and provides the necessary knowledge base to attend more advanced courses on the theory and applications of Quantum Mechanics.

Course Aims

This course provides foundational knowledge in quantum engineering. The course aims to:

- Teach students the fundamental principles of quantum mechanics, with no prior assumed knowledge of the topic.
- Equip students with the tools required to simulate simple quantum systems using self-developed computer code.
- Provide students with the background knowledge necessary to understand the operating principles of the quantum devices driving today's technology.

Relationship to Other Courses

ELEC3705 - Fundamentals of Quantum Engineering is the first introductory course in the Quantum Engineering curriculum, as well as an entry port to all students interested in learning about quantum technologies in elective subjects. It is the prerequiste to ELEC4605 Quantum Devices and Computers.

Course Learning Outcomes

Course Learning Outcomes
CLO1 : Explain the fundamental concepts in quantum mechanics (e.g., wave-particle duality, Schrodinger's equation, Heisenberg's uncertainty principle, quantum tunneling and entanglement).
CLO2 : Apply the mathematics behind quantum mechanics to calculate the basic properties (e.g., energy and wavefunction) of a quantum system, as well as their time evolution.
CLO3 : Develop code to simulate a quantum system using numerical software packages, such as Python.
CLO4 : Demonstrate knowledge of the various physical systems with which it is possible to observe and exploit quantum phenomena.
CLO5 : Recognise the impact of quantum engineering on the creation of innovative technology industries, and demonstrate the conceptual knowledge to participate and contribute in these industries.
CLO6 : Possess some insight into how quantum mechanics underpins the physical properties of semiconductors.

Course Learning Outcomes	Assessment Item
CLO1 : Explain the fundamental concepts in quantum mechanics (e.g., wave-particle duality, Schrodinger's equation, Heisenberg's uncertainty principle, quantum tunneling and entanglement).	• Assignments • Final Exam
CLO2 : Apply the mathematics behind quantum mechanics to calculate the basic properties (e.g., energy and wavefunction) of a quantum system, as well as their time evolution.	• Quizzes • Assignments • Final Exam
CLO3 : Develop code to simulate a quantum system using numerical software packages, such as Python.	• Quizzes • Assignments
CLO4 : Demonstrate knowledge of the various physical systems with which it is possible to observe and exploit quantum phenomena.	• Final Exam • Assignments
CLO5 : Recognise the impact of quantum engineering on the creation of innovative technology industries, and demonstrate the conceptual knowledge to participate and contribute in these industries.	• Final Exam
CLO6 : Possess some insight into how quantum mechanics underpins the physical properties of semiconductors.	• Quizzes

Learning and Teaching Technologies

Moodle - Learning Management System

Learning and Teaching in this course

The teaching materials (lecture notes, laboratory instructions, reading materials) will be delivered through Moodle.

All in-term assessments (quizzes and assignments) will be managed through Moodle.

Moodle forums will be used for asynchronous communication.

Other Professional Outcomes

Relationship to Engineers Australia Stage 1 competencies:

The Course Learning Outcomes (CLOs) contribute to the Engineers Australia (National Accreditation Body) Stage I competencies as outlined below

Engineers Australia (EA), Professional Engineer Stage 1 Competencies

PE1: Knowledge and Skill Base:
PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals: CLO 1, 2, 3, 6
PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing: CLO 1, 2, 3, 6
PE1.3 In-depth understanding of specialist bodies of knowledge: CLO 2, 3, 4, 5, 6
PE1.4 Discernment of knowledge development and research directions: CLO 4, 5, 6
PE1.5 Knowledge of engineering design practice: CLO 4
PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice: n/a

PE2: Engineering Application Ability:
PE2.1 Application of established engineering methods to complex problem solving: CLO 2, 3, 4
PE2.2 Fluent application of engineering techniques, tools and resources: CLO 4, 5
PE2.3 Application of systematic engineering synthesis and design processes: n/a
PE2.4 Application of systematic approaches to the conduct and management of engineering projects: n/a

PE3: Professional and Personal Attributes:
PE3.1 Ethical conduct and professional accountability: n/a
PE3.2 Effective oral and written communication (professional and lay domains): CLO 1
PE3.3 Creative, innovative and pro-active demeanour: CLO 5

PE3.4 Professional use and management of information: CLO 3

PE3.5 Orderly management of self, and professional conduct: n/a

PE3.6 Effective team membership and team leadership: n/a

This course is also designed to provide the course learning outcomes which arise from targeted graduate capabilities. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate capabilities (also listed below).

Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;
- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;
- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning

UNSW Graduate Capabilities

The course delivery methods and course content directly or indirectly addresses a number of core UNSW graduate capabilities, as follows:

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.
- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments and lab exams during the labs.
- Developing capable independent and collaborative enquiry, through a series of tutorials

spanning the duration of the course.
- Developing independent, self-directed professionals who are enterprising, innovative, creative and responsive to change, through challenging design and project tasks.
- Developing citizens who can apply their discipline in other contexts, are culturally aware and environmentally responsible, through interdisciplinary tasks, seminars and group activities

Additional Course Information

Credits

This is a 6 UoC course and the expected workload is 15 hours per week throughout the 10-week trimester.

Relationship to Other Courses

This is a 2nd / 3rd year course in the School of Electrical Engineering and Telecommunications. It is offered in 3rd year as an elective course for students following a BE (Electrical) or (Telecommunications), and in 2nd year as a core course for students enrolled in the BE (Quantum).

Pre-requisites and Assumed Knowledge

The pre-requisites for this course are PHYS1231 and MATH2099 (or equivalent). We assume only a basic understanding of Physics and Mathematics. In particular, the student should have had some exposure to linear algebra (vector spaces, matrices, matrix operations, eigenvalues and eigenvectors). It is highly beneficial if the students have already attended ELEC3115, because the description of wave propagation in electromagnetism is very similar to particle propagation in quantum mechanics. Please contact the lecturer if you are unsure whether you have the required background knowledge.

Assessments

Assessment Structure

Assessment Item	Weight	Relevant Dates
Assignments Assessment Format: Individual Short Extension: Yes (3 days)	40%	Start Date: Week 5, Week 8 Due Date: Week 7: 21 October - 27 October, Week 10: 11 November - 17 November
Final Exam Assessment Format: Individual	50%	
Quizzes Assessment Format: Individual	10%	

Assessment Details

Assignments

Assessment Overview

There will be two take-home assignments. They will be based on numerical calculations to predict the dynamics and the properties of some quantum systems. They will constitute extended versions of the Python exercises taught during the Laboratory sessions. The assignments will also have a pedagogical value, in the sense that the students will discover highly non-trivial and intellectually profound results by examining the outcomes of their calculations. Marking will be based on a rubric with feedback provided within two weeks after the submission due date.

Course Learning Outcomes

- CLO1 : Explain the fundamental concepts in quantum mechanics (e.g., wave-particle duality, Schrodinger's equation, Heisenberg's uncertainty principle, quantum tunneling and entanglement).
- CLO2 : Apply the mathematics behind quantum mechanics to calculate the basic properties (e.g., energy and wavefunction) of a quantum system, as well as their time evolution.
- CLO3 : Develop code to simulate a quantum system using numerical software packages, such as Python.
- CLO4 : Demonstrate knowledge of the various physical systems with which it is possible to observe and exploit quantum phenomena.

Assignment submission Turnitin type

This is not a Turnitin assignment

Generative AI Permission Level

Generative AI Software-based Assessments

This assessment is designed for you to use generative AI as part of the assessed learning outcomes. Please refer to the assessment instructions for more details.
For more information on Generative AI and permitted use please see here.

The assignments involve writing Python code to describe the behaviour of quantum systems. Students are permitted to use generative AI in helping them write and debug the code, as per modern software development practices.

Final Exam

Assessment Overview

The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course (including laboratory), unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses.

Course Learning Outcomes

- CLO1 : Explain the fundamental concepts in quantum mechanics (e.g., wave-particle duality, Schrodinger's equation, Heisenberg's uncertainty principle, quantum tunneling and entanglement).
- CLO2 : Apply the mathematics behind quantum mechanics to calculate the basic properties (e.g., energy and wavefunction) of a quantum system, as well as their time evolution.
- CLO4 : Demonstrate knowledge of the various physical systems with which it is possible to observe and exploit quantum phenomena.
- CLO5 : Recognise the impact of quantum engineering on the creation of innovative technology industries, and demonstrate the conceptual knowledge to participate and contribute in these industries.

Assignment submission Turnitin type

Not Applicable

Generative AI Permission Level

No Assistance

This assessment is designed for you to complete without the use of any generative AI. You are not permitted to use any generative AI tools, software or service to search for or generate information or answers.

For more information on Generative AI and permitted use please see here.

Quizzes

Assessment Overview

Several online quizzes will be given throughout the term, to help the students receive timely feedback on their understanding of the course material. After having covered the specified material, a quiz will be opened in Moodle, and will close before the start of the subsequent topic.

Course Learning Outcomes

- CLO2 : Apply the mathematics behind quantum mechanics to calculate the basic properties (e.g., energy and wavefunction) of a quantum system, as well as their time evolution.

- CLO3 : Develop code to simulate a quantum system using numerical software packages, such as Python.
- CLO6 : Possess some insight into how quantum mechanics underpins the physical properties of semiconductors.

Assignment submission Turnitin type

Not Applicable

Generative AI Permission Level

Not Applicable

Generative AI is not considered to be of assistance to you in completing this assessment. If you do use generative AI in completing this assessment, you should attribute its use.
For more information on Generative AI and permitted use please see here.

General Assessment Information

Grading Basis

Standard

Requirements to pass course

Passing the course requires achieving a composite mark - that is, the mark obtained by combining the contributions of quizzes, assigments and final exam - of at least 50 out of 100. There is no requirement to achieve more than 50/100 at the final exam alone.

Course Schedule

Teaching Week/Module	Activity Type	Content
Week 1 : 9 September - 15 September	Lecture	Introduction to fundamental concepts in quantum mechanics (wave-particle duality, Heisenberg's uncertainty principle and Schrodinger's equation)
Week 2 : 16 September - 22 September	Lecture	Postulates of quantum mechanics (observables, measurements and time evolution) and their application to spins
	Laboratory	Introduction to Python coding relevant to quantum systems
Week 3 : 23 September - 29 September	Lecture	Quantum mechanics in real space: Potential well, quantum confinement
	Laboratory	Matrix formalism of quantum systems
Week 4 : 30 September - 6 October	Lecture	Quantum tunnelling, ammonia molecule; position and momentum operators
	Laboratory	Time evolution of an electron spin
Week 5 : 7 October - 13 October	Lecture	General description of quantum two-level systems (qubits)
	Laboratory	Bouncing particles in a potential well
	Assessment	Assignment 1 released
Week 6 : 14 October - 20 October	Homework	Flexibility week: individual revision and consultations
Week 7 : 21 October - 27 October	Lecture	Qubit coupling and entanglement
	Laboratory	Dynamical control of a qubit
	Assessment	Assignment 1 due date
Week 8 : 28 October - 3 November	Lecture	Quantum statistics of identical particles
	Laboratory	Quantum tunneling and evanescent waves
	Assessment	Assignment 2 released
Week 9 : 4 November - 10 November	Lecture	From atoms to solids
	Laboratory	Defining and quantifying entanglement
Week 10 : 11 November - 17 November	Lecture	Quantum transport of charge; single-electron quantum devices
	Laboratory	Qiskit - advanced Python packages for quantum engineering
	Assessment	Assignment 2 due date

Attendance Requirements

Students are strongly encouraged to attend all classes and review lecture recordings.

General Schedule Information

The schedule below is indicative and subject to change.

Course Resources

Prescribed Resources

Textbooks

Prescribed textbook

- There is no formally prescribed textbook for the course. The course materials constitute sufficient resources.

Recommended Resources

Reference books

Students are encouraged to inspect the reference books in order to deepen their understanding of the subject (including more extensive mathematical treatments) and expand the scope of topics beyond the ones covered in the course.

- Claude Cohen-Tannoudji, Bernard Diu & Frank Laloe. Quantum Mechanics. Edn. 1 Vol. 1 (Wiley, 1991).
- Supriyo Datta. Quantum Transport: Atom to Transistor. Edn. 2 (Cambridge University Press, 2005).
- David A. B. Miller. Quantum mechanics for scientists and engineers. Edn. 1 (Cambridge University Press, 2008).
- Dennis M. Sullivan. Quantum mechanics for electrical engineers. Edn. 1 (IEEE Press, 2012)

Course Evaluation and Development

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the course convener or via the online student survey myExperience. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods.

Since T3 2021, we have converted from Matlab to Python as the chosen software for the laboratory and assignments. Python is the de-facto standard for coding in quantum information systems. It is adopted by all quantum computer platforms available online, and widely supported in the quantum engineering community. It is also entirely free and open source.

Following students feedback in 2022, we will anticipate by one week the release and deadline of Assignment 2, to ensure it does not encroach past week 10.

Staff Details

Position	Name	Email	Location	Phone	Availability	Equitable Learning Services Contact	Primary Contact
Convenor	Andrea Morel lo		Newton Building, room 103D	90651143		No	Yes
Lecturer	Danielle Hol mes		Newton Building, room 103C			No	No

Other Useful Information

Academic Information

I. Special consideration and supplementary assessment

If you have experienced an illness or misadventure beyond your control that will interfere with your assessment performance, you are eligible to apply for Special Consideration prior to, or within 3 working days of, submitting an assessment or sitting an exam.

Please note that UNSW has a Fit to Sit rule, which means that if you sit an exam, you are declaring yourself fit enough to do so and cannot later apply for Special Consideration.

For details of applying for Special Consideration and conditions for the award of supplementary assessment, please see the information on UNSW's Special Consideration page.

II. Administrative matters and links

All students are expected to read and be familiar with UNSW guidelines and polices. In particular, students should be familiar with the following:

- Attendance
- UNSW Email Address
- Special Consideration
- Exams
- Approved Calculators
- Academic Honesty and Plagiarism
- Equitable Learning Services

III. Equity and diversity

Those students who have a disability that requires some adjustment in their teaching or learning environment are encouraged to discuss their study needs with the course convener prior to, or at the commencement of, their course, or with the Equity Officer (Disability) in the Equitable Learning Services. Issues to be discussed may include access to materials, signers or note-takers, the provision of services and additional exam and assessment arrangements. Early notification is essential to enable any necessary adjustments to be made.

IV. Professional Outcomes and Program Design

Students are able to review the relevant professional outcomes and program designs for their streams by going to the following link: https://www.unsw.edu.au/engineering/student-life/student-resources/program-design.

Note: This course outline sets out the description of classes at the date the Course Outline is published. The nature of classes may change during the Term after the Course Outline is published. Moodle or your primary learning management system (LMS) should be consulted for the up-to-date class descriptions. If there is any inconsistency in the description of activities between the University timetable and the Course Outline/Moodle/LMS, the description in the Course Outline/Moodle/LMS applies.

Academic Honesty and Plagarism

UNSW has an ongoing commitment to fostering a culture of learning informed by academic integrity. All UNSW students have a responsibility to adhere to this principle of academic integrity. Plagiarism undermines academic integrity and is not tolerated at UNSW. *Plagiarism at UNSW is defined as using the words or ideas of others and passing them off as your own.*

Plagiarism is a type of intellectual theft. It can take many forms, from deliberate cheating to accidentally copying from a source without acknowledgement. UNSW has produced a website with a wealth of resources to support students to understand and avoid plagiarism, visit: student.unsw.edu.au/plagiarism. The Learning Centre assists students with understanding academic integrity and how not to plagiarise. They also hold workshops and can help students one-on-one.

You are also reminded that careful time management is an important part of study and one of the identified causes of plagiarism is poor time management. Students should allow sufficient time for research, drafting and the proper referencing of sources in preparing all assessment tasks.

Repeated plagiarism (even in first year), plagiarism after first year, or serious instances, may also be investigated under the Student Misconduct Procedures. The penalties under the procedures can include a reduction in marks, failing a course or for the most serious matters (like plagiarism in an honours thesis or contract cheating) even suspension from the university. The Student Misconduct Procedures are available here:

www.gs.unsw.edu.au/policy/documents/studentmisconductprocedures.pdf

Submission of Assessment Tasks

Work submitted late without an approved extension by the course coordinator or delegated authority is subject to a late penalty of five percent (5%) of the maximum mark possible for that assessment item, per calendar day.

The late penalty is applied per calendar day (including weekends and public holidays) that the assessment is overdue. There is no pro-rata of the late penalty for submissions made part way through a day. This is for all assessments where a penalty applies.

Work submitted after five days (120 hours) will not be accepted and a mark of zero will be awarded for that assessment item.

For some assessment items, a late penalty may not be appropriate. These will be clearly indicated in the course outline, and such assessments will receive a mark of zero if not completed by the specified date. Examples include:

- Weekly online tests or laboratory work worth a small proportion of the subject mark;
- Exams, peer feedback and team evaluation surveys;
- Online quizzes where answers are released to students on completion;
- Professional assessment tasks, where the intention is to create an authentic assessment that has an absolute submission date; and,
- Pass/Fail assessment tasks.

Faculty-specific Information

Engineering Student Support Services – The Nucleus - enrolment, progression checks, clash requests, course issues or program-related queries

Engineering Industrial Training – Industrial training questions

UNSW Study Abroad – study abroad student enquiries (for inbound students)

UNSW Exchange – student exchange enquiries (for inbound students)

UNSW Future Students – potential student enquiries e.g. admissions, fees, programs, credit transfer

Phone

(+61 2) 9385 8500 – Nucleus Student Hub

(+61 2) 9385 7661 – Engineering Industrial Training

(+61 2) 9385 3179 – UNSW Study Abroad and UNSW Exchange (for inbound students)

School-specific Information

General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

COVID19 - Important Health Related Notice

Your health and the health of those in your class is critically important. You must stay at home if you are sick or have been advised to self-isolate by NSW health or government authorities. **You will not be penalised for missing a face-to-face activity due to illness or a requirement to self-isolate**. We will work with you to ensure continuity of learning during your isolation and have plans in place for you to catch up on any content or learning activities you may miss. Where this might not be possible, an application for fee remission may be discussed.

If you are required to self-isolate and/or need emotional or financial support, please contact the Nucleus: Student Hub. If you are unable to complete an assessment, or attend a class with an attendance or participation requirement, please let your teacher know and apply for special consideration through the Special Consideration portal. To advise the University of a positive COVID-19 test result or if you suspect you have COVID-19 and are being tested, please fill in this form.

UNSW requires all staff and students to follow NSW Health advice. Any failure to act in accordance with that advice may amount to a breach of the Student Code of Conduct. Please refer to the Safe Return to Campus guide for students for more information on safe practices.

School Contact Information

Consultations: Lecturer consultation times will be advised during the first lecture. You are welcome to email the tutor or laboratory demonstrator, who can answer your questions on this course and can also provide you with consultation times. ALL email enquiries should be made from your student email address with ELEC/TELExxxx in the subject line; otherwise they will not be answered.

Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms – in this course, we will use Moodle https://moodle.telt.unsw.edu.au/login/index.php. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

Student Support Enquiries

For enrolment and progression enquiries please contact Student Services

Web

Electrical Engineering Homepage