UNSW Course Outline

ELEC4605 Quantum Devices and Computers - 2024

Published on the 25 Aug 2024

General Course Information

Course Code : ELEC4605
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 : Postgraduate, Undergraduate
Units of Credit : 6

Useful Links

Handbook Class Timetable

Course Details & Outcomes

Course Description

Quantum Engineering is concerned with the design and production of devices that exploit the laws of Quantum Mechanics, unlocking novel functionalities and improved performance. This course will provide an Engineering-oriented and in-depth treatise of the conceptual and practical

tools required to model, design and understand natural and engineered quantum systems, such as quantum computers and quantum-enhanced sensors. Particular attention will be given to platforms and algorithms for quantum computation, a technology synonymous with the new quantum revolution.

The course includes a laboratory component that will introduce fundamental quantum effects, ranging from spin resonance to superposition and entanglement. The experiments will demonstrate the tangible applications of these quantum effects, including quantum logic operations, quantum cryptography and quantum state control.

A primary outcome of the course is to train and empower students to become active contributors to the emerging field of quantum technologies, which is undergoing an explosive growth, accompanied by an accelerating demand for highly skilled quantum engineers in the workforce.

Course Aims

The course aims to:

- Develop and reinforce core principles in quantum engineering
- Equip students with the conceptual and practical tools to model, design and understand engineered quantum devices, such as quantum computers and quantum-enhanced sensors.
- Introduce students to algorithms and high-level programming languages for quantum computation.
- Provide students with a hands-on experience in assembling quantum experimental apparatus and making fundamental demonstrations of quantum effects in a laboratory setting.
- Empower students to become active contributors to the emerging field of quantum technologies.

Relationship to Other Courses

Relationship to Other Courses

This is a 4th year elective course in the School of Electrical Engineering and Telecommunications.

Pre-requisites and Assumed Knowledge

The pre-requisite for this course is ELEC3705, or an equivalent combination of mathematics and physics courses. Please contact the lecturers if you are unsure whether you have the required background knowledge.

Following Courses

There are no courses that directly follow from this course. However, students interested in this stream might want to consider TELE9757, Quantum Communications.

Course Learning Outcomes

Course Learning Outcomes
CLO1 : Apply the principles of quantum control to manipulate a quantum state and extend its coherence lifetime.
CLO2 : Develop code to simulate the response of a quantum system to arbitrary control sequences.
CLO3 : Argue the relative merits of the different physical platforms for quantum computation.
CLO4 : Construct quantum algorithms using primitive quantum logic gates.
CLO5 : Assemble advanced quantum experiments and use them to make fundamental demonstrations in spin resonance and quantum computation (e.g. quantum control, entanglement, logic gates).
CLO6 : Show a broad understanding of the quantum-enhanced techniques and devices used in quantum sensing.

Course Learning Outcomes	Assessment Item
CLO1 : Apply the principles of quantum control to manipulate a quantum state and extend its coherence lifetime.	• Take-Home Exam • Laboratory Exam
CLO2 : Develop code to simulate the response of a quantum system to arbitrary control sequences.	• Assignment • Take-Home Exam • Laboratory Exam
CLO3 : Argue the relative merits of the different physical platforms for quantum computation.	• Final Exam
CLO4 : Construct quantum algorithms using primitive quantum logic gates.	• Final Exam
CLO5 : Assemble advanced quantum experiments and use them to make fundamental demonstrations in spin resonance and quantum computation (e.g. quantum control, entanglement, logic gates).	• Laboratory Exam
CLO6 : Show a broad understanding of the quantum-enhanced techniques and devices used in quantum sensing.	• Final Exam

Learning and Teaching Technologies

Moodle - Learning Management System | Microsoft Teams

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, 3, 6

PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing: CLO 1, 2, 4

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, 5

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 3, 6

PE3.3 Creative, innovative and pro-active demeanour: CLO 1, 2, 4

PE3.4 Professional use and management of information: CLO 1, 3, 6

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

Assessments

Assessment Structure

Assessment Item	Weight	Relevant Dates
Take-Home Exam Assessment Format: Individual	10%	
Laboratory Exam Assessment Format: Individual	25%	
Assignment Assessment Format: Individual	15%	
Final Exam Assessment Format: Individual	50%	

Assessment Details

Take-Home Exam

Assessment Overview

One take-home exam (to be completed individually) worth 10% of the final grade, encompassing topics covered in the first 3 weeks of the course. Work will be marked against assessment criteria. Individual written feedback will be provided online and verbal class-wide feedback during the lectures. As an indication, it is anticipated that students will need to commit 6-8 hours of their time to this assessment.

Course Learning Outcomes

- CLO1 : Apply the principles of quantum control to manipulate a quantum state and extend its coherence lifetime.
- CLO2 : Develop code to simulate the response of a quantum system to arbitrary control sequences.

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.

Laboratory Exam

Assessment Overview

Two in-class laboratory oral tests will be administered at the end of each experiment topic.

Students are also required to submit a laboratory report summarising experimental results for each topic, due at the end of your laboratory sessions. The oral test and lab report for each experiment will contribute a combined 12.5% to final course grade.

Work will be marked against assessment criteria. Oral feedback will be provided at the conclusion of the in-class test and a grade will be given for the submitted report. Students are expected to spend 10-12 hours of their time per laboratory assessment, inclusive of the time spent doing the laboratories

Course Learning Outcomes

- CLO1 : Apply the principles of quantum control to manipulate a quantum state and extend its coherence lifetime.
- CLO2 : Develop code to simulate the response of a quantum system to arbitrary control sequences.
- CLO5 : Assemble advanced quantum experiments and use them to make fundamental demonstrations in spin resonance and quantum computation (e.g. quantum control, entanglement, logic gates).

Generative AI Permission Level

No Assistance

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Assignment

Assessment Overview

One take-home assignment (to be completed individually) worth 15% of the final grade. Work will be marked against assessment criteria. Individual written feedback will be provided online and verbal class-wide feedback during the lectures. As an indication, it is anticipated that students will need to commit 9-12 hours of their time to this assessment and deliver a concise report summarising their findings.

Course Learning Outcomes

- CLO2 : Develop code to simulate the response of a quantum system to arbitrary control sequences.

Assignment submission Turnitin type

This assignment is submitted through Turnitin and students do not see Turnitin similarity reports.

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.

Final Exam

Assessment Overview

The final examination will test students' knowledge of theoretical topics covered in the lectures. This will be a two-hour closed-book examination. Marks will be assigned according to the correctness of the responses with feedback returned in the form of a final grade.

Course Learning Outcomes

- CLO3 : Argue the relative merits of the different physical platforms for quantum computation.
- CLO4 : Construct quantum algorithms using primitive quantum logic gates.
- CLO6 : Show a broad understanding of the quantum-enhanced techniques and devices used in quantum sensing.

Hurdle rules

You must pass the final exam (i.e. recieve a 50% grade or higher) in order to pass this course.

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.

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General Assessment Information

<u>Grading Basis</u>

Standard

Course Schedule

Teaching Week/Module	Activity Type	Content
Week 1 : 9 September - 15 September	Lecture	Revision of key concepts in quantum engineering (matrix mechanics, operators, density matrices)
Week 2 : 16 September - 22 September	Lecture	Controlling quantum systems (rotation operators, decoherence, filter-function formalism, Ramsey fringes, Hahn echo, dynamical decoupling, noise spectroscopy and magnetometry)
	Tutorial	Tutorial 1: Revision
	Laboratory	Spins: Introduction to experiment (lock-in detection, data acquisition, optics)
Week 3 : 23 September - 29 September	Lecture	Quantum computation (classical computing, quantum circuit model, one and two-qubit logic gates, conditional unitary operators, universal gates, approximating quantum gates)
	Tutorial	Tutorial 2: Spins and control
	Laboratory	Spins: ESR spectrum, Zeeman splitting, Rabi oscillations
Week 4 : 30 September - 6 October	Lecture	Quantum algorithms (quantum simulation, quantum Fourier transform, quantum search)
	Laboratory	Spins: Coherence (T2) time, two-axis control, dynamical decoupling
	Assessment	Assessment 1 due (take-home exam)
Week 5 : 7 October - 13 October	Lecture	The quantum harmonic oscillator (raising and lowering operators, number operator, quantum LC circuit, quantisation of EM fields, vacuum fluctuations)
	Tutorial	Tutorial 3: Quantum computing (gates)
	Laboratory	Spins: Assessment
	Assessment	Assessment 2 due (lab report and oral exam for experiment 1)
Week 6 : 14 October - 20 October	Other	Study week, no activities planned
Week 7 : 21 October - 27 October	Lecture	Quantum optics (photonic qubits, single and two-qubit gates)
	Tutorial	Tutorial 4: Quantum computing (algorithms)
	Laboratory	Optics: Measuring single photons and generating bi-photons
Week 8 : 28 October - 3 November	Lecture	Quantum transport and the single-electron transistor (Aharonov-Bohm effect, Coulomb blockade, quantum dots)
	Tutorial	Tutorial 5: QHO and quantum optics
	Laboratory	Optics: Quantum states and indistinguishability of photons
	Assessment	Assessment 3 due (assignment)
Week 9 : 4 November - 10 November	Lecture	Superconductivity (Cooper pairs, the Josephson effect, flux quantisation, SQUIDs)
	Laboratory	Optics: Entangled photons
Week 10 : 11 November - 17 November	Lecture	Superconducting qubits (charge, transmon and flux qubits); Atomic clocks
	Tutorial	Tutorial 6: Quantum transport and superconductivity
	Laboratory	Optics: Assessment
	Assessment	Assessment 2 due (lab report and oral exam for experiment 2)

Attendance Requirements

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

General Schedule Information

Learning in this course

You are expected to attend all lectures, tutorials, labs, and the final exam in order to maximise learning. You must prepare well for your laboratory classes and your lab work will be assessed. In addition to the lecture notes/video, you should read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW assumes that self-directed study of this kind is undertaken in addition to attending online and/or face-to-face classes throughout the course.

Tutorial classes

You should attempt all of your problem sheet questions in advance of attending the tutorial classes. The importance of adequate preparation prior to each tutorial cannot be overemphasized, as the effectiveness and usefulness of the tutorial depends to a large extent on this preparation. Group learning is encouraged. Answers for these questions will be discussed during the tutorial and the tutor will cover the more complex questions in the tutorial class. In addition, during the tutorial, 1-2 new questions that are not in your notes may be provided by the tutor, for you to try in class. These questions and solutions may not be made available on the web, so it is worthwhile for you to attend your tutorial classes to gain maximum benefit from this course.

Laboratory program

The laboratory schedule is deliberately designed to provide practical, hands-on exposure to the concepts conveyed in lectures soon after they are covered in class. You are required to attend laboratory from Week 2 to Week 10. Laboratory attendance WILL be kept, and you MUST attend at least 80% of labs.

The laboratory experiments are performed as teams of 2-3 people. As such, those able to attend a physical laboratory will be required to wear a face mask for the duration of the class. Please notify course staff prior to your class if for any reason you are not able to comply with this rule (for example due to a medical condition).

Laboratory Exemption

There is no laboratory exemption for this course. Regardless of whether equivalent labs have

been completed in previous courses, all students enrolled in this course must take the labs. If, for medical reasons, (note that a valid medical certificate must be provided) you are unable to attend a lab, you will need to apply for a catch-up lab during another lab time, as agreed by the laboratory coordinator.

Course Resources

Prescribed Resources

Textbooks

Prescribed textbook

- Michael A. Nielsen & Isaac L. Chuang. Quantum Computation and Quantum Information. Edn. 10 (Cambridge University Press, 2010).

On-line resources

Moodle: As a part of the teaching component, Moodle will be used to disseminate teaching materials, host forums and occasionally quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php.

Mailing list: Announcements concerning course information will be given in the lectures and/or on Moodle and/or via email (which will be sent to your student email address).

Recommended Resources

Textbooks

Reference books

- Claude Cohen-Tannoudji, Bernard Diu & Frank Lalo. Quantum Mechanics. Edn. 1 Vol. 1 (Wiley, 1991).
- Supriyo Datta. Quantum Transport: Atom to Transistor. Edn. 2 (Cambridge University Press, 2005).
- Charles Kittel. Solid State Physics. Edn. 8 (Wiley, 2005).
- Grosso and Pastori Parravicini. Solid State Physics. (Academic Press, 2000).
- David A. B. Miller. Quantum mechanics for scientists and engineers. Edn. 1 (Cambridge University Press, 2008).

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.

Staff Details

Position	Name	Email	Location	Phone	Availability	Equitable Learning Services Contact	Primary Contact
Convenor	Jarryd Pla		Room 103B, Level 1, Newton Building (J12)		By email or Teams appointment	No	Yes
Lab staff	Arne Laucht					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.

Use of AI for assessments

Your work must be your own. If you use AI in the writing of your assessment, you must acknowledge this and your submission must be substantially your own work. More information can be found on this website.

Workplace Health & Safety (WHS)

WHS for students and staff is of utmost priority. Most courses involve laboratory work. You must follow the rules about conduct in the laboratory. About COVID-19, advice can be found on this website.

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