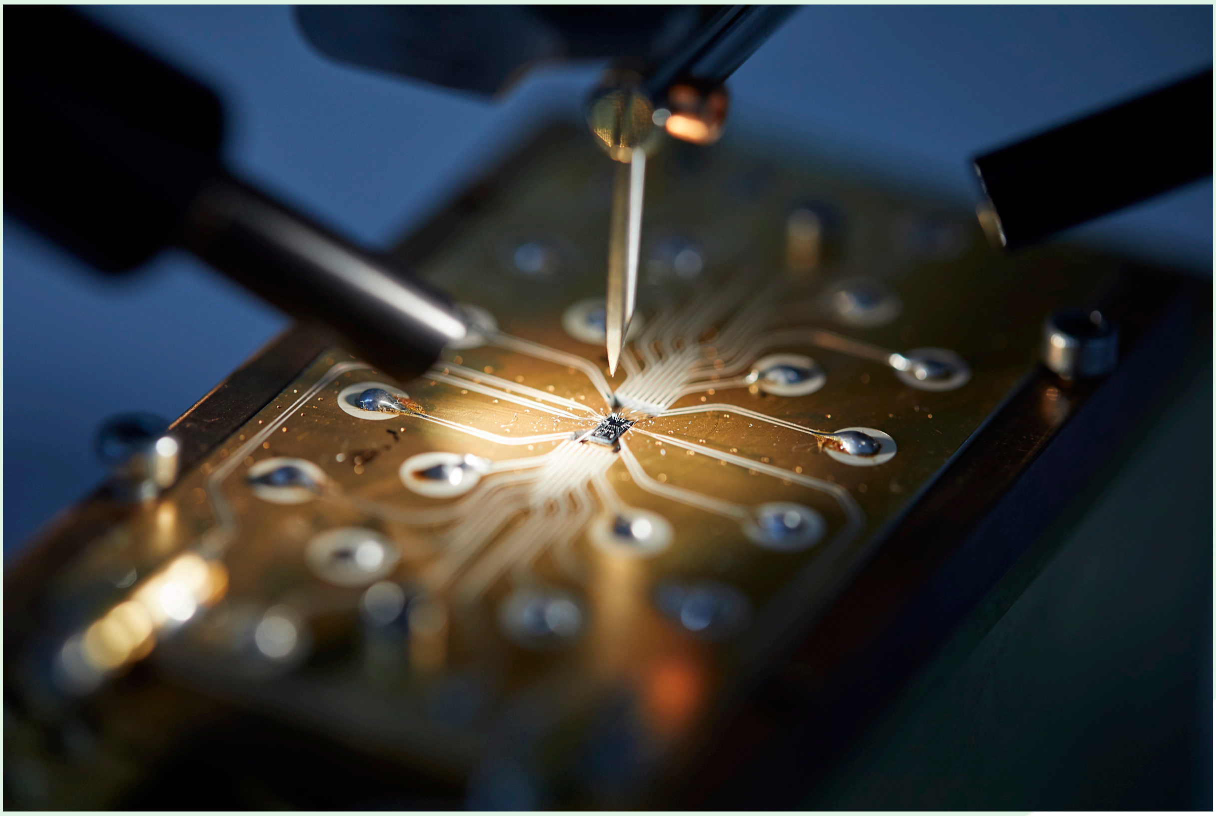
ELEC4605

Quantum Devices and Computers

Term 3, 2021



Course Overview

Staff Contact Details

Convenors

Name	Email	Availability	Location	Phone
Jarryd Pla	jarryd@unsw.edu.au	By email or Teams appointment	Room 103B, Level 1, Newton Building (J12)	

Lab Staff

Name	Email	Availability	Location	Phone
Arne Laucht	a.laucht@unsw.edu.au			

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

Engineering Student Support Services

Engineering Industrial Training

UNSW Study Abroad and Exchange (for inbound students)

UNSW Future Students

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)

Email

Engineering Student Support Services – current student enquiries

- e.g. enrolment, progression, 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

Course Details

Units of Credit 6

Summary of the Course

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 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:

- Provide students with an overview of the state-of-the-art devices and technologies that exploit Quantum Mechanics to achieve novel or improved functionalities.
- 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.

Course Learning Outcomes

After successfully completing this course, you should be able to:

Learning Outcome	EA Stage 1 Competencies
1. Apply the principles of quantum control to manipulate a quantum state and extend its coherence lifetime.	PE1.1, PE1.2, PE1.4, PE2.1, PE2.2, PE3.2, PE3.3
2. Develop code to simulate the response of a quantum system to arbitrary control sequences.	PE1.1, PE1.2, PE1.4, PE2.1, PE2.2, PE3.2, PE3.3, PE3.1, PE3.4, PE3.5
3. Argue the relative merits of the different physical platforms for	PE1.1, PE1.2, PE1.3, PE1.4,

Learning Outcome	EA Stage 1 Competencies
quantum computation.	PE3.2
4. Construct quantum algorithms using primitive quantum logic gates.	PE1.1, PE1.2, PE1.3, PE1.4, PE2.2, PE3.2, PE3.3, PE3.1, PE3.4, PE3.5
5. Assemble advanced quantum experiments and use them to make fundamental demonstrations in spin resonance and quantum computation (e.g. quantum control, entanglement, logic gates).	PE1.1, PE1.2, PE1.3, PE1.4, PE2.1, PE2.2, PE3.2, PE3.3, PE3.5
6. Show a broad understanding of the quantum-enhanced techniques and devices used in quantum sensing and amplification.	PE1.1, PE1.2, PE1.3, PE1.4

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 digital and information literacy and lifelong learning skills through assignment work.

Teaching Strategies

Delivery Mode

The course will be delivered through the following methods:

- Lectures: Online (and face-to-face if possible) lectures will be used to present students with core material essential for an understanding of quantum devices and computation.
- Laboratory: A weekly three-hour laboratory session will provide students with experience in assembling quantum experimental apparatus and making demonstrations of fundamental quantum effects, such as superposition and entanglement.
- Tutorials: A weekly one-hour tutorial (6 in total) will be used to solve tutorial problems assigned in the lectures.

Additional Course Information

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.

Assessment

Assessment task	Weight	Due Date	Course Learning Outcomes Assessed
1. Laboratory Exam	25%	Week 5 and Week 10	1, 2, 5
2. Assignments	25%	Week 4 and Week 8	1, 2, 4
3. Final Exam	50%	Not Applicable	1, 3, 4, 6

Assessment 1: Laboratory Exam

Due date: Week 5 and Week 10

Two in-class laboratory oral tests will be given, in weeks 5 and 10, at the end of each experiment topic (spins and optics). There, you will be expected to answer questions about the experiments you have been working on within the topic. You will also be required to submit a laboratory report summarizing your experimental results for each topic, due at the end of weeks 5 and 10, respectively. The oral test and lab report for each experiment will contribute a combined 12.5% to your final course grade.

Assessment 2: Assignments

Due date: Week 4 and Week 8

Two take-home assignments will be given, with submission deadlines in weeks 4 and 8 (5pm, Friday). Each assignment is worth 12.5% of your final grade.

Assignment submission will be handled through the Moodle portal. You will be expected to upload pdf files that summarize your answers to all the questions, plus every Matlab file you have used to arrive at the solutions. *Late reports will attract a penalty of 10% per day* (including weekends).

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

Assessment 3: Final Exam

The exam in this course is a standard closed-book 2 hour written examination. University approved calculators are allowed. 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. *Please note that you must pass the final exam in order to pass the course.*

Attendance Requirements

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

Course Schedule

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 (face-to-face when possible) 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**. An appropriate face mask will be provided upon entering the laboratory. 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.

View class timetable

Timetable

Date	Type	Content

Week 1: 13 September - 17 September	Lecture	Revision of key concepts in quantum engineering (matrix mechanics, operators, density matrices)
Week 2: 20 September - 24 September	Lecture	Controlling quantum systems (rotation operators, decoherence, filter-function formalism, Ramsey fringes, Hahn echo, dynamical decoupling, noise spectroscopy and magnetometry)
	Laboratory	Spins: Introduction to experiment (lock-in detection, data acquisition, optics)
	Tutorial	Tutorial 1: Revision
Week 3: 27 September - 1 October	Lecture	Quantum computation (classical computing, quantum circuit model, one and two-qubit logic gates, conditional unitary operators, universal gates, approximating quantum gates)
	Laboratory	Spins: ESR spectrum, Zeeman splitting, Rabi oscillations
	Tutorial	Tutorial 2: Spins and control
Week 4: 4 October - 8 October	Lecture	Quantum algorithms (quantum simulation, quantum Fourier transform, quantum search)
	Laboratory	Spins: Coherence (T2) time, two-axis control, dynamical decoupling
	Assessment	Assignment 1 due
Week 5: 11 October - 15 October	Lecture	The quantum harmonic oscillator (raising and lowering operators, number operator, quantum LC circuit, quantisation of EM fields, vacuum fluctuations)
	Laboratory	Spins: Assessment
	Tutorial	Tutorial 3: Quantum computing (gates)
	Assessment	Lab report 1 due and oral assessment
Week 6: 18 October - 22 October		Study week, no activities planned
Week 7: 25 October - 29 October	Lecture	Quantum optics (photonic qubits, single and two-qubit gates)
	Laboratory	Optics: Measuring single photons and generating bi-photons
	Tutorial	Tutorial 4: Quantum computing (algorithms)
Week 8: 1 November - 5 November	Lecture	Quantum transport and the single-electron transistor (Aharonov-Bohm effect, Coulomb

		blockade, quantum dots)
	Laboratory	Optics: Quantum states and indistinguishability of photons
	Tutorial	Tutorial 5: QHO and quantum optics
	Assessment	Assignment 2 due
Week 9: 8 November - 12 November	Lecture	Superconductivity (Cooper pairs, the Josephson effect, flux quantisation, SQUIDs)
	Laboratory	Optics: Entangled photons
Week 10: 15 November - 19 November	Lecture	Superconducting qubits (charge, transmon and flux qubits); Atomic clocks
	Laboratory	Optics: Assessment
	Tutorial	Tutorial 6: Quantum transport and superconductivity
	Assessment	Optics: Lab report 2 due and oral assessment

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.

Academic Honesty and Plagiarism

Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see https://student.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

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.

Academic Information

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. Current alerts and a list of hotspots can be found here. **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.

Dates to note

Important Dates available at: https://student.unsw.edu.au/dates

Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see https://student.unsw.edu.au/policy), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **15 hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both formal classes and *independent, self-directed study*. In periods where you need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You can apply for special consideration when illness or other circumstances beyond your control interfere with an assessment performance. If you need to submit an application for special consideration for an exam or assessment, you must submit the application **prior to the start** of the exam or before the assessment is submitted, except where illness or misadventure prevent you from doing so. Be aware of the “fit to sit/submit” rule which means that if you sit an exam or submit an assignment, you are declaring yourself well enough to do so and cannot later apply for Special Consideration. For more information and how to apply, see https://student.unsw.edu.au/special-consideration.

Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:

https://student.unsw.edu.au/guide

https://www.engineering.unsw.edu.au/electrical-engineering/resources

CRICOS

CRICOS Provider Code: 00098G

Acknowledgement of Country

We acknowledge the Bedegal people who are the traditional custodians of the lands on which UNSW Kensington campus is located.

Appendix: Engineers Australia (EA) Professional Engineer Competency Standard

Program Intended Learning Outcomes	
Knowledge and skill base	
PE1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline	✓
PE1.2 Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline	✓
PE1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline	✓
PE1.4 Discernment of knowledge development and research directions within the engineering discipline	✓
PE1.5 Knowledge of engineering design practice and contextual factors impacting the engineering discipline	
PE1.6 Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline	
Engineering application ability	
PE2.1 Application of established engineering methods to complex engineering problem solving	✓
PE2.2 Fluent application of engineering techniques, tools and resources	✓
PE2.3 Application of systematic engineering synthesis and design processes	
PE2.4 Application of systematic approaches to the conduct and management of engineering projects	
Professional and personal attributes	
PE3.1 Ethical conduct and professional accountability	✓
PE3.2 Effective oral and written communication in professional and lay domains	✓
PE3.3 Creative, innovative and pro-active demeanour	✓
PE3.4 Professional use and management of information	✓
PE3.5 Orderly management of self, and professional conduct	✓
PE3.6 Effective team membership and team leadership	