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School of Electrical Engineering and Telecommunications

Term 3, 2020
Course Outline

ELEC3705
Fundamentals of Quantum Engineering

COURSE STAFF

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Consultations: Lecturer consultation times and modes will be advised during the first lecture. Furthermore, ongoing support and advice will be provided through the MS Teams platform. Should you wish to email the lecturer or laboratory demonstrator, ALL email enquiries should be made from your student email address with ELEC3705 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 MS Teams. Please note that once any information is published to MS teams you will be deemed to have received this information in a timely manner, so you should carefully note all announcements.

COURSE SUMMARY

Contact Hours

The course consists of 4 hours of lectures, a 1-hour live consultation, and a 2-hour computer laboratory session each week, as per the timetable below:

	Day	Time	Location
Lectures	Monday (weeks 1 – 3, 5 – 10)	10am – 1 pm	Microsoft Teams Meeting
	Wednesday (weeks 1 – 10)	3pm - 4pm	Microsoft Teams Meeting
Labs	Tuesday (weeks 2 – 10)	10am – 12noon	Microsoft Teams Meeting
Consultation	To be announced during week 1	TBA	On-campus (location TBA), with additional video link

Context and Aims

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.

Designing and operating devices that behave according to Quantum Mechanics opens the possibility to exploit the peculiar laws of quantum physics to perform otherwise cumbersome or impossible tasks. These include the efficient solution of computationally hard problems, or the secure teleportation of information. Examples of computationally hard problems can be found in all branches of science and technology – including medical research. A recent document prepared by CSIRO estimates that the quantum technologies field will grow to create 16,000 new jobs and $4b revenues in Australia by 2040.

The course "Fundamentals of Quantum Engineering" aims to:

- Teach students the fundamental principles of quantum mechanics, with no prior assumed knowledge of the topic.
- Equip students with the conceptual and practical tools required to write computer programs that simulate the behavior of complex quantum systems.
- Provide students with the background knowledge necessary to understand the operating principles of the quantum devices driving today's technology.
- Give a brief but rigorous quantum mechanical description of the electronic properties of semiconductor devices, which underpin all of solid-state electronics. It will also briefly introduce the macroscopic quantum phenomenon of superconductivity.

Indicative Lecture Schedule

Period	Summary of Lecture Program
Week 1	Introduction to fundamental concepts in quantum mechanics (wave-particle duality, Heisenberg's uncertainty principle and Schrodinger's equation)
Week 2	Postulates of quantum mechanics (observables, measurements and time evolution) and their application to spins
Week 3	Quantum mechanics in real space: Potential well, quantum confinement
Week 4	Quantum tunnelling, ammonia molecule
Week 5	Quantum harmonic oscillator **Assignment #1 released end of week 5**
Week 6	**Flexibility week**: revision and extended consultations
Week 7	General description and control of quantum bits (qubits) **Assignment #1 due end of week 7**
Week 8	Coupling and entanglement of multiple qubits
Week 9	Identical particles; representation of quantum states **Assignment #2 released end of week 9**
Week 10	From atoms to solids: hydrogen atom, periodic table, electrons in a periodic potential, band structure **Assignment #2 due end of week 11**

Indicative Laboratory Schedule

Period	Summary of Laboratory Program
Week 2	Introduction to Matlab coding relevant to quantum systems, eigenstates
Week 3	Time evolution of a spin state (electron Larmor precession)
Week 4	Dynamical control of a qubit (electron Rabi flopping)
Week 5	Bouncing particles, potential well, harmonic oscillator
Week 6	**Flexibility week**: no new content, revision of past exercises
Week 7	Quantum tunnelling
Week 8	Defining and quantifying entanglement
Week 9	Representing quantum systems
Week 10	Particle in a periodic potential

Assessment

Quizzes	15%
Assignments	30%
Final Exam (2 hours)	55%

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.

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COURSE DETAILS

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 lecturers if you are unsure whether you have the required background knowledge.

Following Courses

This course is a pre-requisite for the 4th year course ELEC4605 Quantum Devices and Computers.

Learning outcomes

After successful completion of this course, you will be able to:

1. Explain the fundamental concepts in quantum mechanics (wave-particle duality, Schrodinger's equation, Heisenberg's uncertainty principle, quantum tunneling, entanglement etc.).
2. Apply the mathematics behind quantum mechanics (matrix mechanics) to calculate the evolution of quantum systems.
3. Develop and apply computer code to simulate a quantum system using numerical software packages.
4. Demonstrate knowledge of the various physical systems with which it is possible to observe and exploit quantum phenomena.
5. Quantitatively estimate the time, length and energy scales at which quantum phenomena become apparent, in a wide variety of systems of practical interest.

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in ***Appendix A***. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate capabilities (listed in ***Appendix B***). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

TEACHING STRATEGIES

Delivery Mode

The teaching in this course aims at establishing a good fundamental understanding of the areas covered using:

- Lectures: Formal online lectures will provide students with a focus on the core conceptual material in the course, together with qualitative, complementary explanations to aid their understanding of quantum mechanics and engineered quantum systems. During the lectures we will also illustrate and execute examples of Matlab simulation code that will be further developed during the laboratory work;
- Consultation: in-person (with additional video link) consultation will allow students time to ask questions on the lecture contents and the conceptual aspects of the laboratory work.
- Laboratory: A two-hour online laboratory session will support the formal lecture material and provide students with experience in simulating quantum systems using the numerical software package MATLAB.

Learning in this course

You are expected to attend all lectures and laboratory sessions in order to maximise learning. You must prepare for your laboratory classes; this work is closely related to the assessment tasks. In addition to the lecture notes, you should read widely from a variety of relevant sources – you are expected to develop the skills to be able to research these concepts independently. Reading additional texts (see for example "Reference Books" below) will further enhance your learning experience. UNSW assumes that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Lectures

Lectures cover theoretical concepts in quantum mechanics and examples of their practical application. They will provide you with the background knowledge necessary for completing the laboratory and assignment tasks.
The lectures will be delivered online via MS Teams during the lecture hours prescribed in the course calendar (see page 1). Although the online lectures will be recorded, **students are strongly encouraged to attend the online lectures in live mode**, i.e. be online during the lecture delivery. This will give them the opportunity to engage with the lecturer and ask questions in real time.

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. The practical component is achieved by learning how to write Matlab code to simulate the behavior of the quantum systems described during the lectures.

This component of the course will be delivered through **live online Matlab laboratory sessions** that coincide with the time slot allocated in the calendar (see page 1). Prior to each laboratory, you will be given a set of problems to solve. It is essential that you attempt these problems BEFORE attending your laboratory, as you may require the solutions to complete your exercise.

Matlab can be obtained from UNSW IT via:
https://au.mathworks.com/academia/tah-portal/university-of-new-south-wales-341489.html.
A free Matlab emulator, such as Octave, may also be used. Octave can obtained via:
http://wiki.octave.org/Main_Page
and a version of Octave for Windows with GUI from:
https://www.gnu.org/software/octave/download

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.

ASSESSMENT

The assessment scheme in this course is designed to provide you with ample opportunity to check your learning progress throughout the trimester, and receive timely feedback on it.

Quizzes

Several online quizzes will be given throughout the session, to help the students receiving timely feedback on their understanding of the course material.
The quizzes will be organized by topic, where a "topic" is defined as the contents of a particular channel within the MS Teams course page. After having covered the specified material, a quiz will be opened in Moodle, and will close before the start of the subsequent topic. Exact dates and deadline for the quizzes will be communicated through both Moodle and MS Teams throughout the session.
The quizzes are assessable activities that will contribute to 15% of the final course mark.

Assignment

Two take-home assignments will be given, with submission deadlines in week 7 and week 11 (5pm, Friday). The assignments will be based on numerical calculations to predict the dynamics and the properties of some quantum system. They will constitute extended versions of the Matlab 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.

The assignment submission will be handled through the Moodle portal. You will be expected to upload a pdf file that summarizes 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).
The two assignments contribute to 30% of the final course mark.

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.
The final exam contributes to 55% of the final course mark.

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes				
Assessment	**1**	**2**	**3**	**4**	**5**
Quizzes	✓	✓	✓	✓	✓
Assignments	✓	✓	✓	✓	-
Final exam	✓	✓	-	✓	✓

COURSE RESOURCES

Textbooks

Prescribed textbook

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

Online resources

Microsoft Teams

All the lecture materials, lecture recordings, and laboratory materials will be shared through the MS Teams course page. MS Teams also provides a natural platform for discussion threads, sharing information, and creating a collaborative student experience.

The Teams page will be structured in Channels, each one covering a section of the lecture material, or one of the laboratory sessions. All discussions should be posted and answered in the pertinent MS Teams channel, so that the topics remain self-contained

Moodle

Moodle will be used as the platform through which we host gradable assignments and quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php.
All non-assessable teaching materials (lectures, labs, discussion forums) will be posted through MS Teams instead.

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).

OTHER MATTERS

Dates to note

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

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.

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.

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.

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.

Continual Course Improvement

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.

For T3 2020, we have taken on board some feedback from last year's students, who pointed out that the lab exams constituted an unnecessary double-up of the assessment of Matlab proficiency which is already extensively covered in assignments. Therefore, we have replaced in-class lab exams with online quizzes that test the understanding of the lecture material. These quizzes will hopefully also help keeping the students engaged, and provide timely feedback on how their understanding is progressing.

The Matlab-based examples and laboratory work have been updated to make use of the Matlab Live Script capability, which allows a more streamlined and visually compact way to link the code with its outputs.

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

APPENDICES

Appendix A: 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.

Appendix B: 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, 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.
- Developing digital and information literacy and lifelong learning skills through assignment work.

Appendix C: Engineers Australia (EA) Professional Engineer Competency Standard

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	✓
	PE1.5 Knowledge of engineering design practice	
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	
PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex 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	
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	✓
	PE3.2 Effective oral and written communication (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	