School of Electrical Engineering and Telecommunications

Semester 2, 2018
Course Outline

ELEC3705
Fundamentals of Quantum Engineering

COURSE STAFF

Course Conveners:	Prof. Andrea Morello, Rm: 210, Level 2, Newton Building, CQC2T, a.morello@unsw.edu.au
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Consultations: You are encouraged to ask questions on the course material, after the lecture class times in the first instance, rather than via email. Lecturer consultation times will be advised during lectures. 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 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.

COURSE SUMMARY

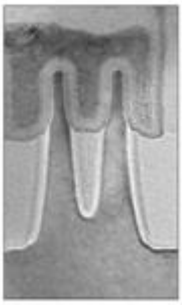
Contact Hours

The course consists of 3 hours of lectures (1 x 2 hour + 1 x 1 hour) and a 2-hour computer laboratory session each week. The laboratories begin in Week 3.

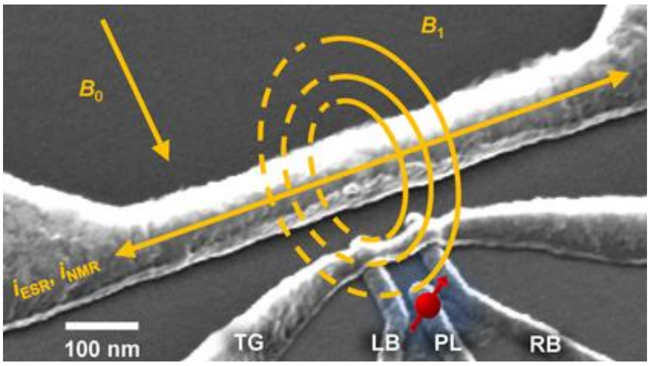
	Day	Time	Location
Lectures	Monday	5pm - 6pm	Business School 216 (K-E12-216)
	Wednesday	1pm - 3pm	Business School 205 (K-E12-205)
Laboratory	Wednesday	10am – 12noon	ChemSci 713 Computer Lab (K-F10-713)

Context and Aims

The progress of nanotechnology allows the fabrication of devices whose physical dimensions are approaching the atomic scale. The figure on the right shows an electron microscope image of the cross-section of a state-of-the-art transistor, as found in every modern computer and mobile phone. The width of the transistor channel is 14 nm, that is, ~50 atoms across. In undergraduate electronics courses, you have learned how to design circuits that use transistors for amplification, logic operations, etc… and you never needed to know anything beyond simple circuit rules to do so.



Since over 100 years, it has been known that the behaviour of physical systems at the atomic scale does not obey the familiar laws of classical physics. Atomic-size systems behave according to Quantum Mechanics, which allows them to exhibit rather spectacular properties and dynamics. But what happens when nano-engineered devices approach the atomic scale? The figure on the right is an electronic device fabricated at UNSW using silicon microelectronics techniques. But it is not just a transistor. It is a 'quantum bit' that can store and manipulate information encoded in the quantum state of a single atom inserted in the silicon chip.



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.

It should also be noted that even classical electronic devices like state-of-the-art transistors are designed using deep understanding of quantum mechanics. In a 14 nm wide transistor, great care must be used to prevent the electrons from travelling straight across the channel by means of a phenomenon called "quantum tunneling"! Therefore, a good understanding of the role of Quantum Mechanics in modern devices is becoming an increasingly essential knowledge set for modern engineers.

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 tools required to simulate simple quantum systems with a numerical software package.
- 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); Magnetic moment, angular momentum, spin
Week 3	Time evolution, coherent spin control
Week 4	Magnetic resonance and its applications
Week 5	Potential well, quantum confinement
Week 6	Ammonia molecule, Quantum tunnelling
Week 7	Multiple-particle systems, entanglement
Week 8	Exchange interaction, hydrogen atom **Assignment #1 due end of week 8**
Week 9	Fundamentals of solid-state physics – formation of bands
Break	
Week 10	Electrical conduction in solids
Week 11	Fundamentals of superconductivity
Week 12	Cooper pairs, Bardeen-Cooper-Schrieffer theory

Week 13	Review **Assignment #2 due end of week 13**

Indicative Laboratory Schedule

Period	Summary of Laboratory Program
Week 3	Introduction to Matlab coding relevant to quantum systems, eigenstates
Week 4	Matrix description of spin systems
Week 5	Time evolution of quantum spin systems
Week 6	Bouncing particles, potential well, oscillators
Week 7	**Laboratory test #1**
Week 8	Quantum tunnelling
Week 9	Defining and quantifying entanglement
Break	
Week 10	Particle in a periodic potential
Week 11	Semiconductors' band structure
Week 12	**Laboratory test #2**

Assessment

Laboratory Exams	25%
Assignments	25%
Final Exam (2 hours)	50%

COURSE DETAILS

Credits

This is a 6 UoC course and the expected workload is 10–12 hours per week throughout the 13 week semester.

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). 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 elective ELEC4605 Quantum Devices and Computers.

Learning outcomes

After successful completion of this course, you should 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 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. Recognise the applications of quantum devices in everyday life.
6. Possess some insight into how quantum mechanics underpins the physical properties of semiconductors and superconductors.

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 face-to-face lectures will provide students with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid their understanding of quantum mechanics and engineered quantum systems.;
- Laboratory: A two-hour laboratory session will support the formal lecture material and provide students with experience in simulating quantum systems using the numerical software package MATLAB. The laboratory will also be used to solve tutorial problems assigned in the lectures;

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 assessable. 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 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.

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 3 to week 12. Laboratory attendance WILL be kept, and you MUST attend at least 80% of labs to pass the course.

This component of the course will be run in a computer laboratory, where students will have access to Matlab. 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. The first hour of each laboratory will be used to summarise concepts covered in the lectures and answer student questions on the tutorial problem sets.

For practicing at home, Matlab can be obtained from UNSW IT via:
https://www.it.unsw.edu.au/students/software/matlab.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

<u>There is no laboratory exemption for this course</u>. 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.

ASSESSMENT

The assessment scheme in this course reflects the intention to assess your learning progress through the semester.

Laboratory Exam

Two in-class laboratory tests will be given, in weeks 7 and 12. There, you will be expected to solve Matlab problems that summarize the knowledge acquired in the course until that point. Each Laboratory Test will last 2 hours, and will contribute 12.5% towards the total course assessment.

Assignment

Two take-home assignments will be given, with submission deadlines in week 8 and week 13 (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).

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.*

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes					
Assessment	**1**	**2**	**3**	**4**	**5**	**6**
Lab exam	-	✓	✓	-	-	✓
Assignment	-	✓	✓	✓	-	-
Final exam	✓	✓	-	✓	✓	✓

COURSE RESOURCES

Textbooks

Prescribed textbook

- Claude Cohen-Tannoudji, Bernard Diu & Frank Lalo. *Quantum Mechanics*. Edn. 1 Vol. 1 (Wiley, 1991).

Reference books

- 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)

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).

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/guide), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **ten to twelve hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and *independent, self-directed study*. In periods where you need to 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 should seek assistance early if you suffer illness or misadventure which affects your course progress. All applications for special consideration must be **lodged online through myUNSW within 3 working days of the assessment**, not to course or school staff. For more detail, consult 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.

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 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 lab exams.
- 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.

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	
l n g A p	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	