PHYS308

Condensed Matter and Nanoscale Physics

S1 Day 2018

Dept of Physics and Astronomy

Contents

General Information

Unit convenor and teaching staff Unit Convenor, Lecturer, Lab instructor Douglas Little douglas.little@mq.edu.au Contact via email E8B 315 Wednesday 2-3 pm Lecturer Lachlan Rogers lachlan.rogers@mq.edu.au Contact via email E6B 2.404 by appointment Senior Scientific Officer Gina Dunford regina.dunford@mq.edu.au Contact via email E7B 252 by appointment
Credit points 3
Prerequisites PHYS201 and PHYS202 and MATH235
Corequisites PHYS301
Co-badged status

Unit description
Many basic properties of solid crystals can be understood through the periodic nature of the underlying crystal lattice. From the formation of phononic and electronic bands in a solid, to the thermodynamics of a solid, to its interaction with light - all these phenomena can be understood by taking into account the scattering of electrons and lattice vibrations off the periodic crystal lattice. Furthermore, modern (quantum) optics experiments with semiconductor nano-structures employ the very same principles of wave scattering off periodic structures for confining and transporting light in a variety of important technological applications. This course discusses both the fundamental well-established principles of solid-state physics and at the same time explores the fascinating world of modern solid-state experiments, ranging from novel semiconductor devices, to exotic low-dimensional materials such as graphene, to nanoscale quantum optics experiments aimed at taming single light particles.

Important Academic Dates

Information about important academic dates including deadlines for withdrawing from units are available at https://www.mq.edu.au/study/calendar-of-dates

Learning Outcomes

On successful completion of this unit, you will be able to:

Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.

Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.

Students will develop an understanding of basic concepts of statistical physics for explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.

Students will understand the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems such as semiconductor quantum wells, quantum dots and graphene.

Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.

Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

General Assessment Information

Lab experiments and reports

The four compulsory experiments conducted during the practical part of PHYS308 are:

- Debye Temperature
- X-ray Diffraction
- Properties of Semiconductors
- Superconductors

Please note the following points

1. You are required to complete all of these experiments.
2. Students should make a booking for two afternoons for each experiment they undertake. A booking gives priority provided the students arrive punctually at the start of the laboratory session.
3. A resource folder is available for each project, containing useful background information. These may be taken away from the lab, but must be returned within two weeks for other students to use.
4. You are required to submit a first draft report by the deadline given below (see 'Unit Schedule'). This will be carefully reviewed and returned to you with corrections and feedback to enable you to make necessary changes to produce a final polished version to resubmit for grading. This **compulsory submission of a first draft** is a necessary part of acquiring the skills for constructing a professional scientific report.
5. You should refer to the document *Recommendations for Laboratory Report Writing* when preparing reports. Please ensure that your reports conform to these guidelines, and feel free to discuss this with any of the staff.
6. Reports should not contain text that has been copied from the instructional notes. You should provide background and discussion material in your own words. It is preferred that you produce your own original figures, either hand-drawn or computer generated. Anything taken from another source must be clearly acknowledged.
7. Draft reports will not be formally assessed. They will be returned to you annotated with suggestions for improvements, which you should act on in your final report submitted for assessment.
8. When you submit your final report after a draft phase **you must attach the original draft to it**.
9. Photocopies of all relevant pages for the experiment from your log-book must be

attached to your draft and/or final report.

10. Submissions should be to Dr Gina Dunford by 4:00pm on the due dates listed in the Unit Schedule. Please place your work under the door if the room is not occupied.

Assessment Tasks

Name	Weighting	Hurdle	Due
Exam	40%	No	set by the University
Problem-based Assignments	20%	No	continuous
Literature Assignment	10%	No	TBA
Lab Reports	30%	No	continuous

Exam

Due: **set by the University**
Weighting: **40%**

A three-hour final exam will be set. It will consist of questions aimed at testing some of the maths discussed in the course and to a larger extent at testing the student's conceptual understanding.

If you receive special consideration for the final exam, a supplementary exam will be scheduled in the interval between the regular exam period and the start of the next session. By making a special consideration application for the final exam you are declaring yourself available for a resit during the supplementary examination period and will not be eligible for a second special consideration approval based on pre-existing commitments. Please ensure you are familiar with the policy prior to submitting an application. You can check the supplementary exam information page on FSE101 in iLearn (bit.ly/FSESupp) for dates, and approved applicants will receive an individual notification one week prior to the exam with the exact date and time of their supplementary examination.

On successful completion you will be able to:

- Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.
- Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.
- Students will develop an understanding of basic concepts of statistical physics for

explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.

- Students will understand the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems such as semiconductor quantum wells, quantum dots and graphene.
- Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.

Problem-based Assignments

Due: **continuous**
Weighting: **20%**

Assignments based on worked problems will be set, corrected and marked for assessment purposes. During the first half of the course, there will be short weekly assignments. Later in the course, the assignments will become longer and will be set only on a three-weekly basis. We anticipate 4 short and 1 longer problem-based assignment.

On successful completion you will be able to:

- Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.
- Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.
- Students will develop an understanding of basic concepts of statistical physics for explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.
- Students will understand the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems such as semiconductor quantum wells, quantum dots and graphene.

Literature Assignment

Due: **TBA**
Weighting: **10%**

The last assignment will be based on individual literature research and review (both journal publications and text books).

On successful completion you will be able to:

- Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.
- Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.
- Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.

Lab Reports

Due: **continuous**
Weighting: **30%**

Students must complete four experiments over the course of the semester, each lasting two weeks. Students will document their experiments in a laboratory notebook form for all experiments. The first; **and** either the second or third experiments will be written up as full reports and handed in for correction. Before the first report is due, the students will have the opportunity to receive individual feedback on a draft report. Lab books will also be individually marked (contributing a third to the Lab Report mark, i.e. 10% overall).

On successful completion you will be able to:

- Students will develop an understanding of basic concepts of statistical physics for explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.
- Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

Delivery and Resources

Required textbook covering the first 7 weeks:

Oxford Solid State Basics, by Steven H. Simon.

Note: Lecture materials, additional reading and assignments will be posted to iLearn

Unit Schedule

Lecture content

- week 1: Solid state physics without microscopic structure
- week 2: The 1D solid - vibrations and electrons
- week 3: Crystal Structure and Reciprocal Lattice
- week 4: Wave Scattering by Crystals
- week 5: Phonons in a Solid
- week 6: Electrons in a Solid
- week 7: Energy Bands and Implications
- week 8: Semiconductor Physics + Devices
- week 9: Photonic crystals
- week 10: Metamaterials
- week 11: Low-dimensional semiconductor systems (Quantum dots, quantum wells)
- week 12: Low-dimensional carbon-based systems (Graphene)
- week 13: Current topics in solid-state physics

Labs schedule (location E7B 252)

- week 1: short intro session to give an overview of experiments
- week 2: experiment 1
- week 3: experiment 1
- week 4: free week to write draft report for experiment 1
- week 5: experiment 2
- week 6: experiment 2
- week 7: free week to write final report for experiment 1
- week 8: experiment 3
- week 9: experiment 3
- week 10: free week to write final report for experiment 2 or 3
- week 11: experiment 4
- week 12: experiment 4
- week 13: no experiments.

Schedule of assessable tasks and related materials

Assignments

The assignments will be handed out according to the following approximate timetable

Assignment No.	Date available on iLearn	Date due
1 Solid1	Friday 2 March	Thursday 15 March
2 Solid2	Friday 16 March	Thursday 29 March
3 Solid3	Friday 30 March	Thursday 12 April
4 Solid4	Friday 16 April	Thursday 3 May
5 Nano1	not determined yet	not determined yet
6 Nano2 (LitAssign)	not determined yet	not determined yet

We understand that at times due dates for assignments from several different units can collide and we are happy to accommodate changes in due dates, *provided the request occurs well in advance of the due date*.

Laboratory Work

You are required to carry out four experiments, each taking no more than two weeks to complete, and to submit reports on two of them according to the following timetable. These dates are not negotiable except in cases of serious illness or misadventure. A late penalty may otherwise be imposed.

Draft 1st report	Monday 2 April	Week 6
Final submission 1st report	Monday 7 May	Week 9
Final submission 2nd report (including laboratory logbook)	Monday 28 May	Week 12

Policies and Procedures

Macquarie University policies and procedures are accessible from Policy Central (https://staff.mq.edu.au/work/strategy-planning-and-governance/university-policies-and-procedures/policy-central). Students should be aware of the following policies in particular with regard to Learning and Teaching:

- Academic Appeals Policy
- Academic Integrity Policy
- Academic Progression Policy
- Assessment Policy
- Fitness to Practice Procedure

- Grade Appeal Policy
- Complaint Management Procedure for Students and Members of the Public
- Special Consideration Policy *(**Note:** The Special Consideration Policy is effective from 4 December 2017 and replaces the Disruption to Studies Policy.)*

Undergraduate students seeking more policy resources can visit the Student Policy Gateway (https://students.mq.edu.au/support/study/student-policy-gateway). It is your one-stop-shop for the key policies you need to know about throughout your undergraduate student journey.

If you would like to see all the policies relevant to Learning and Teaching visit Policy Central (https://staff.mq.edu.au/work/strategy-planning-and-governance/university-policies-and-procedures/policy-central).

Student Code of Conduct

Macquarie University students have a responsibility to be familiar with the Student Code of Conduct: https://students.mq.edu.au/study/getting-started/student-conduct

Results

Results shown in *iLearn*, or released directly by your Unit Convenor, are not confirmed as they are subject to final approval by the University. Once approved, final results will be sent to your student email address and will be made available in eStudent. For more information visit ask.mq.edu.au.

Student Support

Macquarie University provides a range of support services for students. For details, visit http://students.mq.edu.au/support/

Learning Skills

Learning Skills (mq.edu.au/learningskills) provides academic writing resources and study strategies to improve your marks and take control of your study.

- Workshops
- StudyWise
- Academic Integrity Module for Students
- Ask a Learning Adviser

Student Services and Support

Students with a disability are encouraged to contact the Disability Service who can provide appropriate help with any issues that arise during their studies.

Student Enquiries

For all student enquiries, visit Student Connect at ask.mq.edu.au

IT Help

For help with University computer systems and technology, visit http://www.mq.edu.au/about_us/offices_and_units/information_technology/help/.

When using the University's IT, you must adhere to the Acceptable Use of IT Resources Policy. The policy applies to all who connect to the MQ network including students.

Graduate Capabilities

Creative and Innovative

Our graduates will also be capable of creative thinking and of creating knowledge. They will be imaginative and open to experience and capable of innovation at work and in the community. We want them to be engaged in applying their critical, creative thinking.

This graduate capability is supported by:

Learning outcomes

- Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.
- Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.
- Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

Assessment task

- Exam

Commitment to Continuous Learning

Our graduates will have enquiring minds and a literate curiosity which will lead them to pursue knowledge for its own sake. They will continue to pursue learning in their careers and as they participate in the world. They will be capable of reflecting on their experiences and relationships with others and the environment, learning from them, and growing - personally, professionally and socially.

This graduate capability is supported by:

Assessment tasks

- Problem-based Assignments

- Literature Assignment

Discipline Specific Knowledge and Skills

Our graduates will take with them the intellectual development, depth and breadth of knowledge, scholarly understanding, and specific subject content in their chosen fields to make them competent and confident in their subject or profession. They will be able to demonstrate, where relevant, professional technical competence and meet professional standards. They will be able to articulate the structure of knowledge of their discipline, be able to adapt discipline-specific knowledge to novel situations, and be able to contribute from their discipline to inter-disciplinary solutions to problems.

This graduate capability is supported by:

Learning outcomes

- Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.
- Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.
- Students will develop an understanding of basic concepts of statistical physics for explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.
- Students will understand the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems such as semiconductor quantum wells, quantum dots and graphene.
- Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.
- Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

Assessment tasks

- Exam
- Problem-based Assignments
- Literature Assignment
- Lab Reports

Critical, Analytical and Integrative Thinking

We want our graduates to be capable of reasoning, questioning and analysing, and to integrate and synthesise learning and knowledge from a range of sources and environments; to be able to critique constraints, assumptions and limitations; to be able to think independently and systemically in relation to scholarly activity, in the workplace, and in the world. We want them to have a level of scientific and information technology literacy.

This graduate capability is supported by:

Learning outcomes

- Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.
- Students will develop an understanding of basic concepts of statistical physics for explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.
- Students will understand the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems such as semiconductor quantum wells, quantum dots and graphene.
- Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.
- Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

Assessment tasks

- Exam
- Problem-based Assignments
- Lab Reports

Problem Solving and Research Capability

Our graduates should be capable of researching; of analysing, and interpreting and assessing data and information in various forms; of drawing connections across fields of knowledge; and they should be able to relate their knowledge to complex situations at work or in the world, in order to diagnose and solve problems. We want them to have the confidence to take the initiative in doing so, within an awareness of their own limitations.

This graduate capability is supported by:

Learning outcomes

- Students will understand how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity. In particular, they should develop an intuition for the concept of crystal momentum and its implications for band structures and scattering experiments.
- Students will be able to make a connection between real and momentum space. In particular, they will be familiar with the concept of a Fourier transform naturally occurring in scattering theory.
- Students will develop an understanding of basic concepts of statistical physics for explaining some of the phenomenology in condensed-matter physics. In particular, the concept of density of states will form a central part of this learning outcome.
- Students will understand the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems such as semiconductor quantum wells, quantum dots and graphene.
- Students will be able to apply the ideas developed for naturally occurring periodic solids to artificially engineered periodic systems, such as photonic crystals, metamaterials and optical lattices for ultracold atoms.
- Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

Assessment tasks

- Exam
- Problem-based Assignments
- Literature Assignment
- Lab Reports

Effective Communication

We want to develop in our students the ability to communicate and convey their views in forms effective with different audiences. We want our graduates to take with them the capability to read, listen, question, gather and evaluate information resources in a variety of formats, assess, write clearly, speak effectively, and to use visual communication and communication technologies as appropriate.

This graduate capability is supported by:

Learning outcome

- Students will carry out basic condensed matter experiments closely connected to the lectures. This will further enlarge their experimental toolbox and at the same time train their scientific writing skills through creating formalized lab reports.

Assessment tasks

- Exam
- Problem-based Assignments
- Lab Reports

Changes from Previous Offering

The first half of this unit is exactly the same as offered previously. The content of the second half is almost the same, but the sequence has been adjusted to improve conceptual flow.