PHYS308

Condensed Matter and Nanoscale Physics

S1 Day 2017

Dept of Physics and Astronomy

Contents

General Information

Unit convenor and teaching staff

Unit Convenor, Lecturer, Lab instructor
Thomas Volz
thomas.volz@mq.edu.au
Contact via thomas.volz@mq.edu.au
E6B 2.609
by appointment

Lecturer
Michael Steel
michael.steel@mq.edu.au
Contact via michael.steel@mq.edu.au

Lecturer
Ewa Goldys
ewa.goldys@mq.edu.au
Contact via ewa.goldys@mq.edu.au

Senior Scientific Officer
Gina Dunford
regina.dunford@mq.edu.au
Contact via regina.dunford@mq.edu.au
E7B 252

David Spence
david.spence@mq.edu.au

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. Available for each project is a resource folder 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 apply for Disruption to Study for your final examination, you must make yourself available for the week of July 24 – 28, 2017. If you are not available at that time, there is no guarantee an additional examination time will be offered. Specific examination dates and times will be determined at a later date.

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 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: Low-dimensional semiconductor systems (Quantum dots, quantum wells)
- week 10: Low-dimensional carbon-based systems (Graphene)
- week 11: Photonic crystals
- week 12: Metamaterials
- week 13: Ultracold atoms in optical lattices

Labs schedule (location E7B 252)

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

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 3 March	Thursday 16 March

2 Solid2	Friday 17 March	Thursday 30 March
3 Solid3	Friday 31 March	Thursday 13 April
4 Solid4	Friday 14 April	Thursday 27 April
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 24 April	Week 6
Final submission 1st report	Monday 8 May	Week 9
Final submission 2nd report (including laboratory logbook)	Monday 29 May	Week 12

Policies and Procedures

Macquarie University policies and procedures are accessible from Policy Central. Students should be aware of the following policies in particular with regard to Learning and Teaching:

Academic Honesty Policy http://mq.edu.au/policy/docs/academic_honesty/policy.html

Assessment Policy http://mq.edu.au/policy/docs/assessment/policy_2016.html

Grade Appeal Policy http://mq.edu.au/policy/docs/gradeappeal/policy.html

Complaint Management Procedure for Students and Members of the Public http://www.mq.edu.au/policy/docs/complaint_management/procedure.html

Disruption to Studies Policy (in effect until Dec 4th, 2017): http://www.mq.edu.au/policy/docs/disruption_studies/policy.html

Special Consideration Policy (in effect from Dec 4th, 2017): https://staff.mq.edu.au/work/strategy-planning-and-governance/university-policies-and-procedures/policies/special-consideration

In addition, a number of other policies can be found in the Learning and Teaching Category of 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/support/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

This is a new unit. The first part is based on the previously delivered PHYS303 course (second half).