PHYS3180

Condensed Matter and Statistical Physics

Session 1, In person-scheduled-weekday, North Ryde 2023

School of Mathematical and Physical Sciences

Contents

General Information

Unit convenor and teaching staff
Convenor and first half lecturer
Michael Steel
michael.steel@mq.edu.au
12WW room 413

Lecturer and laboratory supervisor
Thomas Volz
thomas.volz@mq.edu.au
12WW 4th floor

Third year laboratory senior scientific officer
Gina Dunford
regina.dunford@mq.edu.au
3000 level physics laboratory, 14 SCO

Credit points
10

Prerequisites
(PHYS201 or PHYS2010) and (PHYS202 or PHYS2020) and (MATH235 or MATH2010)

Corequisites
PHYS301 or PHYS3010

Co-badged status

Unit description
This unit introduces basic thermodynamic principles and connects them with the physical laws and the statistical nature of the microscopic world governing the behaviour of the matter around us. We start out with the concept of temperature and investigate the emergence of the Boltzmann factor in the canonical ensemble. We then proceed with the kinetic theory of gases and discuss transport properties and thermal diffusion. The first and second law of thermodynamics form the foundation for understanding the basic working principles of thermodynamic engines. We next introduce three key pillars of statistical physics: the equipartition theorem, partition functions and the influence of distinguishability on the counting statistics of particles. This sets us up for a discussion of basic solid-state phenomena as they were known in early 20th century, including Debye theory of the heat capacity of solids, the basics of Drude transport theory and Sommerfeld's electron model.

In order to understand more intricate properties of solid crystals, the periodic nature of the underlying crystal lattice must be considered. The unit will first introduce the 1D solid as a model system for illustrating the basic consequence of having a periodic lattice. The powerful concept of reciprocal lattice is introduced and subsequently generalized to all three dimensions, with specific examples given for the different cubic lattice structures. Wave scattering by crystals and its connection to the reciprocal lattice is discussed with particular view to the X-ray experiment on offer in the labs. Electronic properties are mapped to the existence of band structure and the emergence of band-filling patterns in different materials. Finally, the unit concludes with a discussion of a couple of cutting-edge research topics in modern solid-state physics.

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:

ULO1: demonstrate an understanding of fundamental thermodynamic principles and their connection to the microscopic dynamics of matter, particularly for gases and crystalline solids.

ULO2: describe how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity, demonstrating insight into the concept of crystal momentum and its implications for band structures and scattering experiments.

ULO3: use mathematical descriptions based in real- and momentum-space to solve problems in scattering theory.

ULO4: discuss the connection between electronic band structure and certain material

properties, with specific examples of low-dimensional electronic systems.

ULO5: carry out advanced labs, analysing, interpreting and reporting results in accordance with professional standards.

General Assessment Information

Planning your time

The 'estimated time on task' for each assessment item is an estimate of the *additional* time needed to complete each assessment outside of all scheduled learning activities. These estimates assume that you actively engage with all scheduled learning activities *and* spend an additional 31 hours of self-led study during the session.

If you receive special consideration for the final exam, a supplementary exam will be scheduled after the end of the normal exam period. 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. Approved applicants will receive an individual notification one week prior to the exam with the exact date and time of their supplementary examination.

Requirements to Pass the Unit

There are no hurdle tasks specified in this unit. Consequently, the requirement to pass is to obtain an overall mark of at least 50% across the three assessment components.

Late Assessment Submission Penalty

Unless a Special Consideration request has been submitted and approved, a 5% penalty (of the total possible mark of the task) will be applied for each day a written assignment or laboratory report is not submitted, up until the 7th day (including weekends and holidays). After the 7th day, a grade of **0** will be awarded even if the assessment is submitted. The submission time for all uploaded assessments is 11:55 pm. A 1-hour grace period will be provided to students who experience a technical concern.

For any late submission of time-sensitive tasks, such as scheduled tests/exams, performance assessments/presentations, and/or scheduled practical assessments/labs, please apply for Special Consideration.

Specific assessment information regarding lab experiments and reports

Students will have to conduct four out of the six following experiments available in the practical part of PHYS3180:

- Debye Temperature
- X-ray Diffraction

- Properties of Semiconductors
- Nuclear Magnetic Resonance
- Superconductors
- Fabrication and Imaging of 2D materials

Please note the following points

1. You are required to complete four of the experiments.
2. Students should make a booking for two lab sessions for each experiment they undertake. A booking gives priority provided the students arrive punctually at the start of the laboratory session.
3. A set of resources folder is available for each project which can be downloaded from iLearn.
4. 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. You are required to write reports for two of the four experiments, one for experiment 1 or 2, and one for experiment 3 or 4.
5. 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 expected that you produce your own original figures wherever possible, either hand-drawn or computer generated. Anything taken from another source must be clearly acknowledged.
6. Besides two formal reports, you are required to write *extensive* (Python-based) electronic lab notes that provide the base for the lab report writing. After each 2-week experimental session, the electronic lab notes will be pulled and assessed (worth half of the total lab mark, that is 15% in total). The lab notes should reflect the in-class prac work.

Assessment Tasks

Name	Weighting	Hurdle	Due
Lab reports	30%	No	As advised in week 1.
Assignments	30%	No	Approx 10-12 days after release
Final exam	40%	No	Scheduled in formal exam period

Lab reports

Assessment Type [1]: Lab report

Indicative Time on Task [2]: 12 hours
Due: **As advised in week 1.**
Weighting: **30%**

Documentation of experiments, including formal reports and digital labbook record.

On successful completion you will be able to:

- carry out advanced labs, analysing, interpreting and reporting results in accordance with professional standards.

Assignments

Assessment Type [1]: Problem set
Indicative Time on Task [2]: 24 hours
Due: **Approx 10-12 days after release**
Weighting: **30%**

Problem sets, released every two weeks.

On successful completion you will be able to:

- demonstrate an understanding of fundamental thermodynamic principles and their connection to the microscopic dynamics of matter, particularly for gases and crystalline solids.
- describe how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity, demonstrating insight into the concept of crystal momentum and its implications for band structures and scattering experiments.
- use mathematical descriptions based in real- and momentum-space to solve problems in scattering theory.
- discuss the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems.

Final exam

Assessment Type [1]: Examination
Indicative Time on Task [2]: 20 hours
Due: **Scheduled in formal exam period**
Weighting: **40%**

Examination in the university exam period, covering the entire content from the unit.

On successful completion you will be able to:

- demonstrate an understanding of fundamental thermodynamic principles and their connection to the microscopic dynamics of matter, particularly for gases and crystalline solids.
- describe how the periodicity of a crystal affects measurable quantities such as heat capacity or conductivity, demonstrating insight into the concept of crystal momentum and its implications for band structures and scattering experiments.
- use mathematical descriptions based in real- and momentum-space to solve problems in scattering theory.
- discuss the connection between electronic band structure and certain material properties, with specific examples of low-dimensional electronic systems.

---

[1] If you need help with your assignment, please contact:

- the academic teaching staff in your unit for guidance in understanding or completing this type of assessment
- the Writing Centre for academic skills support.

[2] Indicative time-on-task is an estimate of the time required for completion of the assessment task and is subject to individual variation

Delivery and Resources

Reference book covering weeks 1-6:

Concepts in Thermal Physics, 2nd edition, by S.J. & K.M. Blundell

Required textbook covering weeks 7-13:

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: Macrostates and microstates, thermodynamic equilibrium, the equilibrium state, and the zeroth law

- week 2: State and path variables; work, heat and the first law
- week 3: Ideal gas processes and heat capacity
- week 4: The second law, reversibility and engines
- week 5: Principles of statistical mechanics and the Boltzmann distribution
- week 6: Free energy and the partition function; The Planck distribution
- week 7: Electron transport in solids, Drude model
- week 8: Sommerfeld theory of electrons
- week 9: 1D solid: phonons and electrons
- week 10: Crystal Structure & Reciprocal Lattice
- week 11: Wave Scattering by crystals
- week 12: Electrons in solids – band structure
- week 13: Topics from modern solid-state physics

Note: The division by week and topics is only approximate and will change depending on progress.

Labs schedule (location E7B 252)

- week 1: short online (ZOOM) intro session to introduce electronic lab books and the suite of experiments on offer
- week 2: experiment 1
- week 3: experiment 1
- week 4: free week
- week 5: experiment 2
- week 6: experiment 2
- week 7: free week
- week 8: experiment 3
- week 9: experiment 3
- week 10: free week
- 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 bi-weekly with the exact dates announced on iLearn.

Labwork

The due dates for lab reports will be announced in class and on iLearn well in advance.

Note: 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 deadlines announced in class and on iLearn. See above **General Faculty Policy on assessment submission deadlines and late submissions.**

Policies and Procedures

Macquarie University policies and procedures are accessible from Policy Central (https://policies.mq.edu.au). 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
- Assessment Procedure
- Complaints Resolution Procedure for Students and Members of the Public
- Special Consideration Policy

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

To find other policies relating to Teaching and Learning, visit Policy Central (https://policies.mq.edu.au) and use the search tool.

Student Code of Conduct

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

Results

Results published on platform other than eStudent, (eg. iLearn, Coursera etc.) 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 or if you are a Global MBA student contact globalmba.support@mq.edu.au

Academic Integrity

At Macquarie, we believe academic integrity – honesty, respect, trust, responsibility, fairness and courage – is at the core of learning, teaching and research. We recognise that meeting the expectations required to complete your assessments can be challenging. So, we offer you a

range of resources and services to help you reach your potential, including free online writing and maths support, academic skills development and wellbeing consultations.

Student Support

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

The Writing Centre

The Writing Centre provides resources to develop your English language proficiency, academic writing, and communication skills.

- Workshops
- Chat with a WriteWISE peer writing leader
- Access StudyWISE
- Upload an assignment to Studiosity
- Complete the Academic Integrity Module

The Library provides online and face to face support to help you find and use relevant information resources.

- Subject and Research Guides
- Ask a Librarian

Student Services and Support

Macquarie University offers a range of Student Support Services including:

- IT Support
- Accessibility and disability support with study
- Mental health support
- Safety support to respond to bullying, harassment, sexual harassment and sexual assault
- Social support including information about finances, tenancy and legal issues
- Student Advocacy provides independent advice on MQ policies, procedures, and processes

Student Enquiries

Got a question? Ask us via AskMQ, or contact Service Connect.

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.