INTERMEDIATE PHYSICS
SECOND SEMESTER, 2009

PHYS 2012    PHYSICS 2B
HANDBOOK

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1 GENERAL INFORMATION

1.1 UNIT DESCRIPTION

The School of Physics offers students in the Faculty of Science one six credit point unit in first semester (at both Normal and Advanced levels) and two in second semester (again at both Normal and Advanced levels). The outline content of these six units is given in the following Table:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sem</th>
<th>Lectures</th>
<th>Computational Physics</th>
<th>Experimental lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 2011/2911</td>
<td>1</td>
<td>Optics 12; Nuclear Physics 10</td>
<td>Optics 9 wks</td>
<td>9 weeks</td>
</tr>
<tr>
<td>PHYS 2012/2912</td>
<td>2</td>
<td>Quantum Physics 19; EM Properties 19</td>
<td>Quantum 10 wks</td>
<td>_</td>
</tr>
<tr>
<td>PHYS 2013/2913</td>
<td>2</td>
<td>Stellar Astrophysics 12; Special Relativity 10</td>
<td>_</td>
<td>12 weeks</td>
</tr>
</tbody>
</table>

This Unit of Study Handbook describes PHYS 2012, the second semester Normal-level ‘core’ unit. This unit is designed for students continuing with the study of physics at the general Intermediate level, and represents the beginning of a more in-depth study of the main topics of classical and modern physics. Note that this unit cannot be counted with PHYS 2102 or 2104 or 2902 or 2002 or 2912.

The unit is split into a number of modules, combining lectures on Quantum Physics and Electromagnetic Properties of Matter with sessions on computational physics in the Computational Science Laboratory on the topic of Quantum Physics. Some of these activities are in common with the unit of study PHYS 2912 Physics 2B (Advanced).

1.2 CONTRIBUTION OF THE UNIT TO PROGRAMS OF STUDY

Students intending to major in Physics are strongly encouraged to take all three of the above units. The Advanced versions can be taken by students who have achieved a credit or better in their previous Physics units.

Progression to Senior Physics: The prerequisites for most Senior Physics units are PHYS 2011/2911 and PHYS 2012/2912. However, students intending to major in Physics are strongly encouraged to take PHYS 2013/2913 as well. See the Senior Physics web pages\(^1\) for more details.

Senior Physics also assumes knowledge of Intermediate mathematics – see Section 1.4.

1.3 ENTRY REQUIREMENTS

The prerequisite for entry to PHYS 2012 is PHYS (1003 or 1004 or 1902) and PHYS (1001 or 1002 or 1901 or 2001 or 2901 or 2011 or 2911). The assumed knowledge consists of MATH 1001/1901 and 1002/1902 and 1003/1903, while MATH 1005/1905 would also be useful.

\(^1\) http://www.physics.usyd.edu.au/current/spc.shtml
1.4 RELATED COURSES IN THE SCHOOL OF MATHEMATICS AND STATISTICS

Students should note that MATH 2961/2061 (Linear Mathematics and Vector Calculus) is a prerequisite for most Senior Physics units, and you should take this unit if you are planning to major in Physics. An acceptable alternative is MATH 2067 (Differential Equations and Vector Calculus for Engineers). Other useful units are: MATH 2963/2063 (Mathematical Computing and Nonlinear Systems), MATH 2965/2065 (Introduction to Partial Differential Equations), STAT 2911/2011 (Statistical Models) and STAT 2912/2012 (Statistical Tests).

1.5 INFORMATION SESSION

An information session about the Unit of Study will be held at the beginning of your first scheduled lecture.

1.6 LECTURE ARRANGEMENTS

All Intermediate Physics lectures, practical sessions and computational physics sessions are held in the School of Physics. Room assignments are shown in section 4 of this Handbook. Please check the notice boards (see next subsection) for any last minute changes.

The Intermediate Physics Laboratory is located at the Western (‘downhill’) end of the School of Physics on level 4 (street level is level 2).

The Computational Physics Laboratory is room 359, at the Western end of level 3 (far end of corridor).

Physics Lecture theatres are located as follows:-
• LT1 Eastern end, level 4
• LT2 Western end level 4 (opposite the Second Year Physics Laboratory)
• LT4 Just West of the middle of the building level 3
• LT5 West of the middle of the building level 3
• Slade Theatre (LT8) Eastern end level 2

1.7 INFORMATION ABOUT INTERMEDIATE PHYSICS

The Intermediate Physics noticeboard is located outside the Physics Student Support Office (Rm 202, Eastern end of level 2 - street level). Please check this notice board regularly for important information.

The ‘Information for Undergraduate Students’ link on the School of Physics web page\(^2\) provides resources to help you with your studies. Please spend time getting acquainted with this site, and the specific page relative to this unit of study. Unit webpages are provided under the University’s\(^5\) WebCT environment, which can be accessed from the Intermediate Physics webpages\(^3\) or the USYDnet site\(^4\). Access requires a Unikey (Extro account) Username and Password that is issued with your confirmation of enrolment.

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\(^4\) [http://myuni.usyd.edu.au](http://myuni.usyd.edu.au)
The University provides computer facilities in the Access Centres\(^5\). A brief introduction to web access is available on the Intermediate Physics web page.

### 1.8 CONSULTATION

Students who have general questions about the unit should ask at the Student Support Office. If necessary, questions about organisation and administration may be referred to the Coordinator of Intermediate Physics.

Questions about specific lecture modules should be directed to the lecturer concerned. Questions about computational laboratory matters should be directed to the laboratory supervisor in the first instance.

### 1.9 PRINTED NOTES

It is highly recommended that each student of PHYS 2012 purchase the current edition of ‘Computational Physics Quantum Mechanics Notes’. Copies of these notes are available at the University Copy Centre. A booklet of lecture notes (entitled ‘Quantum Physics Lecture Notes’) will also be sold through the University Copy Centre.

Other materials (lecture handouts, assignment questions and solutions) may be handed out during lectures and will subsequently be available on WebCT and on request from the Physics Student Support Office (room 202). There is no charge for these materials.

### 1.10 SCHOLARSHIPS AND PRIZES

There are a number of scholarships and prizes available to students enrolled in Intermediate Physics courses. They are awarded at the end of the year on the basis of academic merit in units taken in both semesters.

The **prizes** are:

- **Slade Prize for Physics** (value $350) for Merit in Intermediate Experimental Physics.
- **Geoffrey Builder – AWA Prize** (value $250) for Merit in Intermediate Experimental Physics.

Only students who take both PHYS 2011/2911 and PHYS 2013/2913 will be eligible for these prizes, which are based on laboratory. (Such students will normally take PHYS 2012/2912 as well.)

The scholarships are awarded on the basis of the sum of the two best marks from the three Intermediate Physics units but only to students with confirmed enrolment in at least 6 Credit Points of Senior Physics.

The **scholarships** are:

- **The School of Physics – Julius Sumner Miller Scholarship for Academic Excellence No.2** (value $800). Up to two are awarded annually.
- **Science Foundation for Physics Scholarships No.2** (value $800). Up to five are awarded annually.

2 ASSESSMENT OF THE UNIT OF STUDY

2.1 GENERAL

This unit is assessed through a final examination, a mid-term examination, assignments taken throughout the semester, participation in computational physics sessions and a project and computational test at the end of semester.

Proof of identification is required at all examinations.

Except where otherwise noted, candidates will not be allowed to bring books or papers into the examination room. However, examinations are not meant to be tests of rote memorisation, and formula sheets will normally be included in the examination papers.

A preliminary examination timetable is released late in the semester and students are asked to report all clashes to the Student Centre (in the Carslaw Building). The final timetable may differ from the preliminary one and it is each student’s responsibility to determine the date, time and location of their scheduled examinations.

The weighting of the assessments in the various components of the unit to the final mark is as follows:

Final examination (3 hour paper):
- Quantum Physics: 60
- Electromagnetic Properties of Matter: 60

Mid-term examination (50 minute paper):
- 30

Assignments:
- 20

Computational Physics:
- 50

**Maximum Total:** 220

The final marks and merit grades are determined, allowing scaling of marks from separate modules, to take into account the class average of Annual Average Mark (AAM). The minimum Pass mark is never more than 50% of the final scaled mark.

2.2 ASSIGNMENTS

There will be two assignments from each of the two lecture modules. Assignment questions will be handed out in lectures, and each assignment will normally contain four questions. All questions may be marked. Students will submit individual assignments. Even though students may work in groups on solving the problems, the individually submitted answers must include explanations of how each individual has understood the problem and its solution.

Each handed in assignment must have a cover sheet, which may be obtained from the Physics Student Support office (Room 202, Physics building). In signing the cover sheet, each student is confirming awareness of the University’s policy on plagiarism and academic honesty, and agreement to comply with that policy.

Assignments will be handed in at the Student Support Office. **Late assignments will not be marked.**

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Your answers must identify the key physical principles; marks will not be awarded for simply putting numbers into formulae without explanation. Model solutions to all the questions or problems will be posted on the unit WebCT pages when the marked assignments are returned.

2.3 CONSIDERATION OF FACTORS AFFECTING YOUR STUDY

If your academic performance in a Science Faculty unit of study is adversely affected by illness or some other serious event, such as an accident, you should notify the Faculty of Science Student Information Office (level 2 of the Carslaw building) within 7 days after the period for which consideration is sought, by completing an Application for Special Consideration with accompanying documentation. This is especially important if you miss an examination.

If you have another reason for the Science Faculty to take account of your circumstances - religious commitments, legal commitments (e.g. Jury duty), elite sporting or cultural commitments (representing the University, state or country), or Australian Defence Force commitments (e.g. Army Reserve) - you should notify the Faculty of Science Student Information Office (level 2 of the Carslaw building) at least 7 days BEFORE the period for which consideration is sought, by completing an Application for Special Arrangements with accompanying documentation.

These two forms of Consideration should cover most allowable circumstances. However, if you have another reason for requiring the School of Physics to take account of your circumstances, you should notify the School of Physics Student Office (room 202 in the Physics building) beforehand (or at the latest within 7 days afterwards), by completing an Application for Consideration of Special Circumstances by Physics with accompanying documentation.

You should not submit an application of any type if
* there is no assessment associated with a missed class, or
* you have a reasonable opportunity to make up any work you missed.

If, for example, you miss an assignment, an application for appropriate Consideration is required to allow late submission, but we do expect the assignment to be submitted. Sometimes catching up may be impossible, in which case we will consider a pro-rata adjustment of your marks on the basis of an application for Consideration.

2.3.1 SPECIAL CONSIDERATION OR SPECIAL ARRANGEMENTS

To submit an application for Special Consideration or Special Arrangements you should:

1. Obtain the appropriate Application pack from the Student Information Office of the Faculty of Science, the Faculty website7, or the Physics Student Office.

2. Complete the forms and obtain whatever original documentary evidence is appropriate. Note especially that the Professional Practitioner's Certificate is essential for Special Consideration on grounds of serious illness - Medical Certificates will NOT be accepted.

3. Take the original copy of all forms and documents, plus sufficient copies for each unit of study affected and yourself, to the Faculty of Science Student Information Office

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(NOT any other Faculty Office if you are seeking Consideration in a unit taught by Physics). They will sign/stamp both the original application form and the copies. In the case of Physics units, one copy of the documentation must then be submitted to the Physics Student Office. Keep one copy yourself. A formal decision on your application will be sent to your university email address within 14 days.

Further details on University policy regarding Considerations can be found in policy documents entitled Assessment and Examination at the University Policy web site.  

2.3.2 CONSIDERATION BY PHYSICS

An application for Consideration by Physics requires you to:

1. Obtain an Application for Consideration of Special Circumstances by Physics from the School of Physics Student Office or the Physics web page.

2. Complete the form and obtain whatever original documentary evidence is appropriate.

3. Take the original copy of the form and supporting documents, plus a copy for yourself, to the Physics Student Office. They will sign/stamp both the original application form and the copy. A formal decision on your application will be sent to your university email address within 14 days.

Students unsure what type of Consideration is appropriate, or unhappy with a Consideration decision, should consult the Physics Student Office.

It is important to realise that the policies on Special Consideration apply throughout the University. Policies on other forms of Consideration are specific to Physics and may be different in Departments responsible for your other units of study.

3 GENERAL AIMS OF THE UNIT OF STUDY

The unit is made up of three modules:

- Quantum Physics lectures
- Electromagnetic Properties of Matter lectures
- Computational Physics sessions on Quantum Physics

The aims and specific objectives of the modules are linked to the required generic attributes of graduates of the University in knowledge skills (in Quantum Physics and Electromagnetic Properties of Matter), thinking skills (the analysis of problems in physics), personal skills and attributes (the ability to work independently and in groups, and to present the results of physics experiments), and practical skills (the use of computers).

Specific objectives of the modules making up this unit of study are given in Section 5.

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### Lecture Theatres:

Note that most lectures on Quantum Physics will be held in common with PHYS 2912, and will take place in the lecture theatre designated for PHYS2912. A small number of lectures on Quantum Physics will be in separate lecture theatres. Lecturers will advise the dates of the split classes. Lectures on Electromagnetic Properties of Matter will be separate for PHYS2012.

For the first lecture, on Quantum Physics, go to Lecture Theatre 2.

<table>
<thead>
<tr>
<th>Monday Date</th>
<th>Lectures</th>
<th>Lectures</th>
<th>Lectures</th>
<th>Computational Physics Lab.</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Jul 2009</td>
<td>QP 1</td>
<td>QP 2</td>
<td>QP 3</td>
<td>No Class</td>
</tr>
<tr>
<td>03 Aug 2009</td>
<td>QP 4</td>
<td>QP 5</td>
<td>QP 6</td>
<td>Set 1</td>
</tr>
<tr>
<td>10 Aug 2009</td>
<td>QP 7</td>
<td>QP 8</td>
<td>QP 9</td>
<td>Set 2</td>
</tr>
<tr>
<td>17 Aug 2009</td>
<td>QP 10</td>
<td>QP 11</td>
<td>QP 12</td>
<td>Set 3</td>
</tr>
<tr>
<td>24 Aug 2009</td>
<td>QP 13</td>
<td>EMP 1</td>
<td>EMP 2</td>
<td>Set 4</td>
</tr>
<tr>
<td>31 Aug 2009</td>
<td>EMP 3</td>
<td>EMP 4</td>
<td>EMP 5</td>
<td>Set 5</td>
</tr>
<tr>
<td>07 Sep 2009</td>
<td>EMP 6</td>
<td>EMP 7</td>
<td>EMP 8</td>
<td>Set 6</td>
</tr>
<tr>
<td>14 Sep 2009</td>
<td>EMP 9</td>
<td>EMP 10</td>
<td>EMP 11</td>
<td>Set 6</td>
</tr>
<tr>
<td>21 Sep 2009</td>
<td>EMP 12</td>
<td>EMP 13</td>
<td>TEST</td>
<td>Projects</td>
</tr>
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<td>27 Sep 2009</td>
<td>MSB</td>
<td>MSB</td>
<td>MSB</td>
<td>MSB</td>
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<tr>
<td>05 Oct 2009</td>
<td>QP 14</td>
<td>QP 15</td>
<td>QP 16</td>
<td>No Class</td>
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<tr>
<td>12 Oct 2009</td>
<td>QP 17</td>
<td>QP 18</td>
<td>QP 19</td>
<td>Projects</td>
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<tr>
<td>19 Oct 2009</td>
<td>EMP 14</td>
<td>EMP 15</td>
<td>EMP 16</td>
<td>Review</td>
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<tr>
<td>26 Oct 2009</td>
<td>EMP 17</td>
<td>EMP 18</td>
<td>EMP 19</td>
<td>Exam</td>
</tr>
</tbody>
</table>

**MSB** Mid-semester break  
**QP** Quantum Physics  
**EMP** Electromagnetic Properties of Matter

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum Physics</td>
<td>Tues 10am</td>
</tr>
<tr>
<td></td>
<td>Wed 12 noon</td>
</tr>
<tr>
<td></td>
<td>Thurs 10 am</td>
</tr>
<tr>
<td>Electromagnetic Properties of Matter</td>
<td>LT2 (most)</td>
</tr>
<tr>
<td></td>
<td>LT5 (some)</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Public holiday</td>
<td>5 October</td>
</tr>
<tr>
<td>Quantum Physics</td>
<td></td>
</tr>
<tr>
<td>Electromagnetic Properties of Matter</td>
<td></td>
</tr>
</tbody>
</table>
5 PHYS 2012 MODULE DESCRIPTIONS

5.1 INTRODUCTION

For each module we have defined broadly what we expect you to learn and understand. Understanding implies that you should be able to discuss and explain fundamental concepts and principles including examples of their application.

Understanding in the lecture modules on Quantum Physics and Electromagnetic Properties of Matter will be tested in the end of semester examination by asking you to write descriptive answers to qualitative questions and by evaluating your explanations of physical principles and reasoning in answers to quantitative questions. Ability to memorise formulae and manipulate them without understanding the associated physics will not be rewarded.

Specific objectives define what you should learn and understand about the detailed content of each part of the module. Understanding a term or concept means that you should be able to:

• explain its meaning in writing and give examples,
• interpret it correctly when you read or hear it,
• use it correctly in your own writing,
• apply it correctly to examples and problems.

5.2 QUANTUM PHYSICS

The 19 lectures will be given by Assoc. Prof I. Johnston and Dr. G. Robertson.

5.2.1 AIMS

The aims of this module are:

• to lay out the fundamental concepts underlying quantum mechanics, built on the basic ideas covered in Junior Physics;
• to develop competence in using the Schrödinger equation to solve simple one-dimensional problems in atomic and solid state physics;
• to show how quantum ideas bring new understandings to the classical disciplines of thermodynamics and electrical conductivity; and
• to demonstrate some of the many ways that modern technologies depend on quantum mechanical insights.

The material in 74% (14 lectures) of the Normal course is in common with the Advanced course. The remaining 26% (5 lectures) revisits some of the common material and offers the opportunity of more illustrative exercises than in the Advanced course.

5.2.2 TEXT AND REFERENCE BOOKS

The textbook for this course is:

• Note: the second edition (Thomson 1997) may also be used.
Other reference books are:

- Eisberg and Resnick, *Quantum Physics* 2nd edn, (Wiley & Sons), 1985. Rather more detailed than you need, but a good book to keep if you go further with this subject.
- French and Taylor, *An Introduction to Quantum Mechanics*, (Van Nostrand, 1978). Lacks some of the more up-to-date topics, but very good on understanding the basics.
- Kittel, *Introduction to Solid State Physics*, 8th edn (Wiley & Sons, 2005). More or less the canonical text for solid state physics, which occupies the last part of this course.

There are quite a few books in the Library at 530.12, most covering far more quantum mechanics than you will see in this course. Some popular level books on the interpretation of Quantum theory may also be of interest. A couple are:

- Gamow, *The New World of Mr. Tompkins* (a new edition of a classic)
- Whitaker, *Einstein, Bohr and the Quantum Dilemma*

### 5.2.3 WEB SITES

Complete lecture notes for this course can be found at the WebCT page for this unit of study.

Some web links relevant to the course content can be found at
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

### 5.2.4 COMPUTATIONAL PHYSICS AND EXPERIMENTAL PHYSICS

Note that the Computational Physics course this semester is entirely concerned with quantum mechanics, in particular with methods of solving the Schrödinger equation for one-dimensional bound state problems. The computational course is considered to be supplementary to the lecture course. Material covered in the former can be part of the assessment of the latter.

Several of the experiments in the Intermediate Physics Experimental Laboratory (which you may take as part of PHYS 2011 or 2013) are relevant to quantum physics, namely:

- Holes and Electrons in Semiconductors
- The Photoelectric Effect
- Fine Structure of Spectral Lines
- Photons and the Wave-Particle Dilemma
- Atomic Emission Spectra

### 5.2.5 ASSESSMENT

Assessment is by examination of material presented in the lectures and by assignment (see section 2.1). Note the remark (Section 5.2.4) that material in the Computational Physics module may be assessed along with the lecture material.

### 5.2.6 ASSIGNMENTS

There will be **two** assignments associated with this lecture module, as noted in Section 2.2. Some of the final examination questions will be taken from the assignments with only minor changes. There will also be supplementary questions distributed. You are encouraged to attempt as many of the assignment and supplementary questions as possible.
5.2.7 COURSE OUTLINE

(References given are to sections in the text Serway, Moses and Moyer — both the 2nd and 3rd editions, in that order.)

PART 1. THE FORMULATION OF QUANTUM MECHANICS

1.1 The conceptual basis of quantum mechanics
Einstein and de Broglie relations. Uncertainty principle (§4.5/§5.5). Wave-particle duality (§4.6,7/§5.6,7). Copenhagen interpretation (§5.1/§6.1). Wave packets (§5.2/§6.2). The Schrödinger wave equation (§5.3/§6.3). Probability and normalization (§5.7/§6.7). Operators, expectation values (§5.8/§6.8).

Specific objectives — after studying this material you will be able to:
• recall and apply the Einstein and de Broglie relations,
• discuss how wave-particle duality relates to the concept of wave packets,
• recall and apply mathematical statements of the uncertainty principle,
• understand how the Copenhagen interpretation is applied,
• discuss the Schrödinger equation,
• discuss what normalization means and how it is applied, and
• discuss quantum operators and expectation values.

1.2 Motion in one dimension

Specific objectives — after studying this material you will be able to,
• discuss the wave-packet model of wave-particles, both free and in a field of force;
• discuss the travelling wave model of wave-particles, both free and in a field of force;
• describe the scattering (reflection and transmission) of wave-particles by potential steps.
• discuss analytically the scattering of wave-particles from potential steps and hills,
• describe semi-quantitatively the phenomena of barrier penetration and tunnelling, and
• discuss applications of tunnelling, including alpha decay of a radioactive nucleus.

1.3 Bound states and energy levels
Eigenvalues and eigenfunction (§5.3/§6.3). Particle in a box, infinite wells (§5.4/§6.4). Square wells (§5.5/§6.5). Harmonic oscillator wells (§5.6/§6.6). 1D models of atomic systems, energy levels

Specific objectives — after studying this material you will be able to
• derive and apply the time-independent Schrödinger equation,
• describe mathematically the properties of a particle in an infinite one-dimensional box,
• discuss the meaning of eigenstates and eigenvalues,
• discuss the application of computational techniques to the study of a particle in a box,
• discuss the meaning and properties of potential wells,
• discuss other one-dimensional potential wells, and describe their computed properties,
• discuss how these concepts are applied to simple atomic and molecular systems,
• describe quantitatively the eigenvalues of a wave-particle in a harmonic oscillator potential,
• describe qualitatively the eigenstates of a wave-particle in a harmonic oscillator, and
• discuss how the Schrödinger equation can be applied to atomic & molecular systems.

PART 2. APPLICATIONS OF QUANTUM MECHANICS

2.1 Quantum statistical behaviour
Statistical behaviour of classical particles (§9.1/§10.1). Maxwell-Boltzmann
distribution (§9.1/§10.1). Indistinguishability and the Pauli principle (§9.2/§10.2)
Bose-Einstein statistics (§9.3/§10.3). Applications: superfluidity (§9.4/§10.4). Fermi-
Dirac statistics, the Fermi energy (§9.3/§10.3). Applications: electron gas,
(§9.5/§10.5).
Specific objectives — after studying this material you will be able to,
• describe the Maxwell-Boltzmann distribution function and explain its origin,;
• discuss the concept of indistinguishability and the Pauli exclusion principle,
• describe the Bose-Einstein and Fermi-Dirac distribution functions,
• discuss quantitatively condition for using quantum vs classical statistics,
• describe the differences between fermions and bosons
• describe quantitatively the meaning of the Fermi energy,
• discuss applications of BE statistics, including superfluidity, and
• discuss applications of FD statistics, including electrons in a metal.

2.2 Band theory of conduction
Classical theory of conduction (§11.2/§12.2). Thermal and electrical conductivities
(§11.1/§12.2). Quantum theory of metals (§11.3/§12.3). Band theory of solids
(§11.4/§12.4). Conductors, insulators, semiconductors (§11.4/§12.4). p- and n-type
conduction, doping (§11.5/§12.5).
Specific objectives — after studying this material you will be able to:
• discuss the successes and failures of the classical free electron model of metals,
• discuss the application of Fermi-Dirac statistics to free electrons in metals,
• describe the quantum behaviour of electrons in a one-dimensional periodic lattice,
• explain the origin of energy bands and describe some of their simpler properties,
• explain the concepts of holes and effective mass,
• explain electrical conductivity properties of metals in terms of energy bands,
• discuss the effects of doping on energy band structures, and
• explain the electrical properties of semiconductors.

2.3 Quantum technologies
Semiconductor devices (§11.5/§12.5). Transistors, ICs (§11.5/§12.5). Photovoltaic
Gas lasers, semiconductor lasers (§11.6/§12.7).
Specific objectives — after studying this material you will be able to discuss, in general
terms, the role of quantum phenomena in:
• transistors and other semiconductor devices,
• light emitting diodes and photovoltaic devices, and
• masers and gas lasers, and
• semiconductor lasers.
### 5.3 ELECTROMAGNETIC PROPERTIES OF MATTER

The 19 lectures will be given by Mr Ian Cooper.

#### 5.3.1 TEXT

There is no single readily available text which treats this subject at the appropriate level for this course.

- Griffiths, “Introduction to Electrodynamics”, 3rd edition, published by Benjamin Cummings (2008), is more detailed than you need, but a good book to purchase if you continue with physics.
- The text “Fundamentals of Electricity and Magnetism” (2nd Ed) by A. F. Kip is a useful reference, and several copies are available in the library. Further references will be given during the lectures.
- The course notes referred to will consist of copies of the lecture slides plus additional notes provided by the lecturers.

#### 5.3.2 SPECIFIC OBJECTIVES

The following specific objectives of this module will be tested by qualitative and quantitative questions in the written examination and the assignments.

**Electrostatics, Gauss's Law, Electric Potential**  
Reference sections: course notes, Y&F 21-7, 23-5.

**Specific Objectives - after studying this part you will be able to:**
- explain Gauss’s law and use it to determine electric field in suitable circumstances
- determine electric potential from electric field and vice versa
- interpret the relation between electric field and electric potential written in terms of the vector differential operator, \( \nabla \)
- interpret the relationship between divergence of electric field and charge density
- explain the concept of electric dipole and electric dipole moment
- calculate the electric field for an electric dipole in the approximation \( r >> d/2 \)
- calculate the electric potential for an electric dipole in the approximation \( r >> d/2 \)
- generalise the concept of electric dipole to electric multipoles

**Capacitance and Dielectrics**  
Reference sections: course notes, Y&F 24-4 to 24-6

**Specific Objectives - after studying this part you will be able to:**
- discuss the concept of polarization and define the polarization vector
- discuss the physical basis of dielectric materials in terms of electric dipoles
- apply Gauss' law to dielectric materials
- discuss the use of dielectrics in capacitors
- use the terms electric susceptibility, dielectric constant, and relative permeability
- perform calculations involving electric field, potential difference, charge density and stored energy for dielectric-filled capacitors
- perform calculations of capacitors filled or partially filled with dielectric materials
- discuss the electric displacement vector and its relation to the electric field and polarization vector
- apply Gauss’s’s law written in terms of the electric displacement vector to problems involving dielectric materials
- discuss the concept of polarizability of atoms and molecules
• use the Clausius-Mossotti equation, and its approximate form for dilute media
• use and explain in qualitative terms to Langevin equation for polar dielectric materials
• discuss the physical mechanisms of piezoelectricity, ferroelectrics and electrets

Conductors
Reference sections: Reference sections: course notes, Y&F 25-6
Specific Objectives - after studying this part you will be able to:
• use the concept of (vector) current density
• discuss the microscopic theory of conduction
• explain the difference conduction mechanisms in metals, plasmas and semiconductors
• explain the difference in temperature dependence of conductivity for metals and semiconductors

Magnetism and Magnetic Materials: Ferromagnetism, Paramagnetism, Diamagnetism
Reference sections: course notes, Y&F 28-2, 28-6 to 28-8
Specific Objectives - after studying this part you will be able to:
• explain the Hall effect
• calculate the magnetic field from the Biot-Savart law and Ampere's law
• interpret the differential form of Ampere’s law
• discuss the magnetic dipole moment
• derive the torque on, and the potential energy of, a magnetic dipole
• discuss the physical mechanism of magnetism in terms of magnetic dipoles
• discuss and apply the concepts of the $H$ field, magnetization $M$ and permeability
• explain the relationship between $B$, $H$ and $M$
• perform calculations for electromagnets
• discuss the basis of ferromagnetism
• discuss hysteresis
• discuss the processes of magnetic recording
• discuss the physical mechanism of paramagnetism and diamagnetism

Superconductivity
Reference sections: course notes, Y&F 29-8
Specific Objectives - after studying this part you will be able to:
• describe the phenomenon of superconductivity, including the concepts of critical temperature, critical field and critical current
• describe the difference between type I and type II superconductors
• describe the Meissner effect
• explain qualitatively the BCS theory of superconductivity
• describe the phenomenon of high $T_c$ superconductivity
• discuss applications of superconductivity, including SQUIDs

Electromagnetic Waves
Reference sections: course notes, Y&F 29-7, 32-1 to 31-6
Specific Objectives - after studying this part you will be able to:
• explain the concept of displacement current
• discuss the meaning of Maxwell's equations (integral form)
• describe the differential form of Faraday’s law
• discuss the meaning of Maxwell's equations (differential form)
• derive the wave equation for electromagnetic waves
• discuss and apply energy and momentum flow in electromagnetic waves
• discuss the propagation of electromagnetic waves in matter and the meaning of refractive index
• discuss the propagation of electromagnetic waves in a wave guide

5.4 COMPUTATIONAL PHYSICS

The module is an introduction to the use of computers for investigating problems of physical interest. MatLab programming will be used, but \textit{no prior knowledge of computing is required}.

The material covered in the computational physics course is coordinated with that in the Quantum Physics lecture module.

5.4.1 TEXT

The module is defined in terms of chapters of the Computational Physics Quantum Mechanics Notes, available from the University Copy Centre. It is highly recommended that each student purchase the current edition of these notes.

5.4.2 SESSION ARRANGEMENTS

Students attend one 2-hour session per week in the Physics Computational Laboratory (Room 359) for 11 weeks, beginning in week 2 of the semester. See Section 4 for timetable details. Your allocation to one of these classes will be finalised at the registration sessions at the start of the semester. Students are arranged in groups of 2 or 3 for each computer.

The sessions are run by a supervisor from the academic staff, and there are a number of tutors at each session. The coordinator for Intermediate Computational Physics Laboratories is Assoc/Prof M. Sharma.

5.4.3 ASSESSMENT

The total mark for this module is 50 marks. Of these, 7 marks are awarded on the basis of participation at the seven weekly sessions during which Exercise Sets 1-6 are done. In the following two sessions each group does a short project related to previous work, and prepares a short report on the results of the project. The report will be marked out of 20, and each member of the group will receive that mark. The remainder of the assessment (worth 24 marks) will be an in-lab exam, undertaken by each student individually, in the final computational lab session for the semester. The total mark for the module will be returned as being out of 50 (not 51).

5.4.4 GENERAL AIMS

• to teach quantum physics, particularly those parts of the subject which benefit from a computational approach;
• to support the lecture course by allowing students to explore some topics in detail;
• to allow students to become comfortable with using computers in solving physics problems;
• to allow students gain further experience in the use of MatLab.

Quantum mechanics is a subject particularly well suited to the use of computer simulation, because analytic solutions to the Schrödinger equation can be difficult or
impossible to find for even some simple physical systems. Computer simulations on the other hand, can readily find solutions, and graphically illustrate the results.

5.4.5 SPECIFIC OBJECTIVES

Set 1 – Unbound quantum states
Specific Objectives - after working through this set you will be able to:
• Use MatLab as a programming language at a basic level
• Find traveling wave solutions for a one-dimensional second order differential equation.
• Display and interpret plots of complex traveling waves, with both transmission and reflection
• Discuss how complex traveling waves are reflected and/or transmitted at discontinuous potential barriers.

Set 2 – Bound quantum states
Specific Objectives - after working through this set you will be able to
• Find the energy eigenfunctions and eigenvalues of Schrödinger’s Equation for a one-dimensional infinite square potential well.
• Find the energy eigenfunctions and eigenvalues of Schrödinger’s Equation for a one-dimensional finite square potential well.
• Display plots of the bound state eigenfunctions and probability distribution functions.

Set 3 – Matrix mechanics
Specific Objectives - after working through this set you will be able to:
• Find the eigenvalues and eigen matrices of a square matrix.
• Find the energy eigenfunctions and eigenvalues of Schrödinger’s Equation for a one-dimensional infinite square potential well by matrix methods.
• Re-investigate the eigenvalues and eigenfunctions of square potential wells.

Set 4 – Other Potential Wells
Specific Objectives - after working through this set you will be able to:
• Find the energy eigenfunctions and eigenvalues of Schrödinger’s Equation for potentials of different shapes and sizes.
• Explain the behaviour and number of states for well-type potentials.
• Obtain and explain eigenfunctions and eigenvalues for a harmonic oscillator potential.

Set 5 – One-dimensional Lattices
Specific Objectives - after working through this set you will be able to:
• Find the eigenfunctions and eigenvalues of Schrödinger’s Equation for a number of potential wells arranged in line.
• Relate the energy eigenfunctions and eigenvalues to energy bands and energy gaps, and to the Bloch theorem.

QM Projects
Specific Objectives - you will be able to:
• Use the software to investigate a topic in computational quantum physics, and write a report on your findings.

Last modified 13 July 2009