

Module guide

This item contains selected online content. It is for use alongside, not as a replacement for the module website, which is the primary study format and contains activities and resources that cannot be replicated in the printed versions.

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1 Introduction

This guide will help you to navigate SM380. It explains what the module is about, its mode of assessment, the prior knowledge required, how to plan and what to expect.

It is particularly important that you go through this document carefully, to make sure your study experience is successful.

2 Module overview

This module will take you on a journey from the fundamental concepts of quantum physics through to contemporary applications in quantum systems and quantum computing.

Quantum physics is considered one of the most fascinating subjects, yet it is one of the most counter-intuitive. It presents you with a range of strange phenomena, like a photon that travels along two different paths at once and particles that seem to be instantaneously aware of one another's behaviour although they are separated by a distance that makes any known communication impossible. At the same time, quantum physics gives us a precise formalism and a set of principles that allow us to make quantitative predictions about phenomena at the nanoscale and below.

All this is not mere curiosity or a theoretical construct: applied physicists, chemists and technologists use quantum physics to interpret and control quantum phenomena.

Quantum physics is a highly active research area that has brought in an incredible range of life-changing technologies. We are now in the middle of a new quantum revolution, with quantum computers and quantum sensors on the horizon and a range of technologies of unprecedented finesse, sensitivity and power being developed.

This module will give you a thorough understanding of the core principles, formalisms, and mathematical techniques of quantum mechanics. Building on this understanding, you will discover how quantum mechanics is used to model and control the behaviour of complex physical systems, from atoms and molecules to lattices of atoms. You will have the unique opportunity to carry out your own experiments on entanglement and critically interpret your results, developing distinctive and innovative skills and understanding of *qubits* and quantum logic operations, which are the building blocks of quantum computing.

2.1 What you will study

SM380 will teach you the core concepts of quantum physics, including:

- wave functions, expectation values and uncertainties,
- Schrödinger's equation for simple models such as a particle in a box and the quantum harmonic oscillator,
- the quantum processes of tunnelling, barrier penetration and reflection,
- Dirac notation and how quantum states can be represented by vectors in an abstract vector space, with observable quantities represented by operators that act on the vectors,
- the properties of orbital and spin angular momentum and the extraordinary properties of systems of identical particles,
- the hydrogen atom and useful techniques of approximation that will enable you to model a more complex system with the help of Python™,
- fascinating concepts in the interpretation of quantum mechanics, like entanglement, superposition, and the probabilistic nature of quantum mechanics.

This module focuses on problem-solving and the ability to reason clearly and to discuss complex ideas. It will enable you to confidently use the fundamental concepts and mathematical formalism to solve problems relating to simple quantum systems.

You'll carry out experiments on entanglement, developing distinctive and innovative skills and understanding of qubits and quantum logic operations – the building blocks of quantum computing.

You'll learn to tackle problems relating to more complex quantum systems by using approximations and computational approaches.

Finally, you will see how quantum-mechanical methods are used to understand the behaviour of matter, from the scale of nuclei and atoms to molecules and lattices.

By the end of your study, you'll be able to critically discuss fundamental concepts in quantum mechanics (superposition and entanglement), basing the arguments on your own experimental data.

2.2 What you will learn

You will learn:

- the key ideas, concepts, fundamental principles and methods of quantum mechanics and its contemporary applications,
- to discuss the underlying concepts and interpretation of quantum phenomena at a graduate level,
- to describe quantum systems using an appropriate level of mathematics,
- to simulate quantum systems using computing and purpose-written modelling tools,
- to use and apply the concepts, formalism and methods of core quantum mechanics to formulate and solve a range of problems, including some that will probably be new to you,
- to make order-of-magnitude estimates and apply approximation methods to real systems, interpret the results and critically evaluate the extent to which these are applicable,
- to prepare, process, interpret and present data to accurately communicate scientific information, arguments and ideas in quantum physics,
- to effectively use written, visual and numerical forms in a style that suits the purpose and audience,
- to initiate, design, conduct and report on investigations that may involve the acquisition of data,
- to obtain, record, collate and analyse data derived from investigations and interpret and report their significance considering underlying theory, practical issues and relevant information from other sources,
- to manage your own learning time and work independently,
- to engage effectively with feedback.

2.3 Qualifications and external recognition

This module is designed to teach quantum physics at Level 3 in the Open University. The module is compliant with the Subject Benchmark Statement and fulfils the requirements for the Institute of Physics (IoP) accreditation of our degrees (particularly Q64 Physics pathway, Q77 Maths and Physics and the R51 BSc Physics).

2.4 Learning outcomes and their assessment

Knowledge and understanding

Description of learning outcome(s)	Assessment method(s)
KU1: Demonstrate understanding of key ideas, concepts, fundamental principles and methods of quantum mechanics and its contemporary applications.	Examination + TMA03

Cognitive skills

Description of learning outcome(s)	Assessment method(s)
CS1: Discuss the underlying concepts and interpretation of quantum phenomena at a graduate level.	Examination + TMA03
CS2: Describe quantum systems using mathematics at an appropriate level.	Examination
CS3: Simulate quantum systems using computing and purpose-written modelling tools.	Examination
CS4: Use and apply the concepts, formalism and methods of core quantum mechanics to formulate and solve a range of problems, including unfamiliar ones.	Examination
CS5: Make estimates and apply approximation methods to real systems, interpret the results and critically evaluate the extent to which these are applicable.	Examination

Key skills

Description of learning outcome(s)	Assessment method(s)
KS1: Select, access and exploit a wide range of digital tools and resources to retrieve, use, create, analyse and share data, information and knowledge as appropriate.	TMA03
KS2: Prepare, process, interpret and present data to communicate scientific information, arguments and ideas in quantum physics accurately and effectively using written, visual and numerical forms in a style that suits purpose and audience.	TMA03

Practical and professional skills

Description of learning outcome(s)	Assessment method(s)
P1: Obtain, record, collate and analyse data derived from investigations and interpret and report their significance in light of underlying theory, practical issues and relevant information from other sources.	TMA03
P2: Initiate, design, conduct and report on investigations that may involve the acquisition of primary or secondary data.	TMA03
P3: Manage own learning time and work independently.	Examination
P4: Engage effectively with feedback.	TMA01 + TMA02 + TMA04

3 How the module is presented

The study material is organised in units, each of which includes content presented in the two books, accompanied by online videos, interactive activities, Python-based activities and a remote activity using the IBM quantum computer.

On the VLE you will find clear guidance about how to navigate the different activities and presentation tools.

The spine of the module will be the module website, which will direct you to printed books for the more fundamental content. The *Study planner* will be structured to show tasks week by week.

Forums will be used for discussions of interesting points raised in the interpretation of data from the activities and for more general discussion.

Self-assessed questions in the module will feature at the end of blocks of units.

4 Teaching and assessment

Throughout your module studies, you'll get help and support from your assigned module tutor. They'll help you by:

- Marking your assignments (TMAs) and providing detailed feedback for you to improve.
- Guiding you to additional learning resources.
- Providing individual guidance, whether that's for general study skills or specific module content.
- Facilitating online discussions between your fellow students, in the dedicated module and tutor group forums.
- Module tutors also run online tutorials throughout the module. Where possible, recordings of online tutorials will be made available to you. While these tutorials won't be compulsory for you to complete the module, you're strongly encouraged to take part.

4.1 Assessment

Purely formative: During the first week, a self-assessment maths and physics tool will guide you to the appropriate places in the online *Mathematics revision material* and *Physics revision material*.

At the end of each unit a brief self-assessment quiz will help to identify any issues with the learning. You are advised to contact your associate lecturer (AL) if necessary.

Formative and summative: Tutor Marked Assignments TMA01, TMA02 and TMA04 are used by you to practice exam-style questions. Associate lecturers (ALs) will provide detailed feedback and tutorials so that you will have the opportunity to improve your understanding and your confidence in preparation for the exam. These TMAs will include a reflection statement demonstrating that you have engaged with the tutor's feedback on the previous TMA. On TMA01 the reflection will be on the self-assessment tool and revision material. This demonstration of effective engagement with feedback will count for 2% of the final mark.

TMA03 covers exclusively the IBM application and counts for 24% of the final mark. The content covered by this TMA will not be assessed at the exam.

Single-component assessment OES: TMA03 assessing individual work on entanglement (IBM experiment) contributing 24%, TMAs 01, 02 and 04 contributing 2% each (based on the reflection statement on feedback engagement) and final exam contributing 70%.

5 How to study this module

5.1 Preparatory work

This is an OU (Open University) Level 3 module that builds on study skills and subject knowledge acquired from previous studies at OU Levels 1 and 2. It is intended for students who have recent experience of higher education in a related subject at this level.

The module is designed to follow MST224 *Mathematical methods* or MST210 *Mathematical methods, models and modelling* and S217 *Physics: from classical to quantum*.

It's essential that you establish whether your background and experience give you a sound basis on which to tackle SM380.

During the first week of the module, you will have plenty of time to self-assess your knowledge base and catch up on maths and physics.

We've produced a [self-assessment quiz](#) to help you decide whether you already have the **recommended** background knowledge and experience to start the module or whether you need some extra preparation. You can find PDFs containing [support and revision material](#) here to help you brush up on your knowledge.

5.2 Course-led versus student-led content

The module is structured so that on average 60% of the study time has to be devoted to directed learning, while 40% of the time is to be dedicated to enrichment or student-directed learning.

A major component of your directed learning in SM380 is studying the material presented in the books, doing compulsory exercises and online activities.

Other activities, additional material and further exercises will be clearly marked as enrichment material and these should be studied if you have the time and want to reach a deeper knowledge and understanding.

All the non-compulsory activities and tasks will be marked on the VLE as enrichment material.

5.3 Software requirements

For the activities in the later part of the module, you will need to be able to run the Python™ scripts that are provided. We recommend that you install the Anaconda™ distribution that you can find by typing this link into your favourite search engine:

- [Anaconda™ installation](#),

The site is well documented and there are clear instructions. We also provide a detailed guide called [Python using the Anaconda distribution](#), which can also be found on the module website under *Resources*.

It is a good idea to prepare for the applications early on, so if you have some issues with the installation, this can be sorted with time to spare.

An alternative way to run the Python™ scripts is to use Google Colab:

- [Google™ Colab](#).

Here, you can simply upload your script and run it remotely, without the need to install Python™ on your machine. Bear in mind that Colab can be platform-dependent. So if you

meet difficulties, you may have to try another browser. This is something for which we do not offer support.

To access Google Colab, you will need a Google™ account. If you already have a Google account, your existing credentials will gain you access to Colab. If you don't have a Google account, we recommend setting one up immediately.

For the IBM activity, you will need to access the IBM quantum computing site:

- [IBM Quantum™](#),

You will almost certainly need to create an account to access this service. It is a good idea to set this up and familiarise yourself with the interface as soon as you can, although you will have plenty of time and guidance to do so in the weeks dedicated to the quantum computing activity.

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