Disclaimer: The information contained in this handbook is correct at the time of your receiving it but the University, while retaining proper regard for the interests of students who have begun their programme, reserves the right to alter the programme or the timetable if the need arises.
Dear Student,

Welcome to the EPSRC CDT in Science and Applications of Graphene and Related Nanomaterials (Graphene NOWNANO CDT). Graphene NOWNANO is an interdisciplinary doctoral training centre bringing together research laboratories from several Schools of the University of Manchester (Physics, Chemistry, Materials, Computer Science, Electrical and Electronic Engineering, Chemical Engineering, Pharmacy, Biomedicine) and the Lancaster Materials Science Institute. Over the next four years you will be studying for a PhD in Nanoscience, with available research projects spanning different aspects of the behaviour of two-dimensional nanomaterials, including the ‘wonder material’ graphene, and their applications. As a doctoral training programme, Graphene NOWNANO grew out of the earlier CDT, North-West Nanoscience Doctoral Training Centre (NOWNANO).

In the first six months of the programme you will be introduced to different aspects of nanoscience and its applications – from the workings of biological cells to fundamental physics at the nanoscale and applications of two-dimensional materials in electronics, energy storage, composites, sensors, displays, packaging and separation techniques and other areas. During this time you will also select your PhD project from a range of interdisciplinary projects offered by academics from all participating schools. You will start PhD research in the second half of your first year. Our policy is that all PhD projects undertaken by Graphene NOWNANO students should cross conventional scientific boundaries, because this is where many of the interesting questions lie, so you are likely to have not just one but two supervisors and do research in not just one but two research groups.

The group of students that start at the same time as you will form your ‘cohort’. At the start of the programme you will study together, but even after you move on to your individual research projects, there will be regular opportunities to meet up and work together. In many ways you are in a privileged position compared to ‘conventional’ research students. Graphene NOWNANO studentships are very well resourced and you will have opportunities that are not available to other postgraduate students, such as extra training, industrial placements and international experience. In return we will expect you to be committed. Your programme of study will be challenging but hopefully interesting. You will need to work hard over the next 4 years and we make no apologies for that. In many ways, the amount that you get out of your time with us will depend upon the effort that you put in.

We aim to provide support for our students throughout the CDT programme. If you have any concerns or problems that are affecting your work, then my door is always open. Alternatively, you could approach one of the other academics responsible for administering the programme: Prof. Vladimir Falko (Co-director and Research Director of NGI); Prof. Tom Thomson (Chair of Graphene NOWNANO management board and Head of Nanomagnetism group); Prof. Kostas Kostarelos (Professor of Nanomedicine); Dr. Cinzia Casiraghi (Lecturer in Nanoscience and Spectroscopy); Dr. Paola Carbone (Senior Lecturer in Molecular Modelling, Simulation and Design); Dr. Dr. Tim Echtermeyer (Senior Lecturer in Electrical and Electronic Engineering); Dr Suelen Barg (School of Materials); Dr Ivan Vera Marun (Lecturer in Condensed Matter Physics); Dr Cyrill Bussy (Lecturer in Nanomedicine) and Prof. Rob Young (Royal Society Research Fellow at Lancaster University). The advisors that are allocated to you at the start of the programme are also there to help.

This handbook has been compiled to provide you with information about the Graphene NOWNANO programme and what is involved in studying at the Centre for Doctoral Training. In addition, it will offer you information that should be useful throughout your time here.

With my very best wishes for the next four years.

Prof. Irina Grigorieva, Director, Graphene NOWNANO CDT
Introduction

Programme Background

Nanoscience and nanotechnology is one of the most rapidly expanding fields of research and development. Much of the activities in this field are inherently interdisciplinary and for the UK to remain at the forefront of its development and exploitation requires training that crosses discipline boundaries and produces experts capable of communicating across professions. Our aim is to train the next generation of scientists who will be able to realise the huge potential of graphene and related two-dimensional (2D) materials, driving innovation in the UK, Europe and beyond. Graphene has been dubbed a miracle material due to the unique combination of superior electronic, mechanical, optical, chemical and biocompatible properties suitable for a large number of applications. The potential of other 2D materials (e.g. boron nitride, transition metal and gallium dichalcogenides) has become clear more recently and is now leading to the development of the so-called van der Waals heterostructures or ‘materials on demand’, i.e., materials with desired properties, not readily available in nature. There has been an explosion of research and development activity in these two areas all over the world in the last few years, with an average of 173 research papers and 154 recorded patents coming out every week in 2013.

The University of Manchester (UoM) is the birthplace of graphene research and has led the huge expansion from fundamental physics of graphene and related (2D) materials into chemistry, engineering, characterization and bioapplications. Lancaster University (LU) has been an important UoM partner in research on physics and device applications of graphene/2D materials, providing complementary expertise in theoretical modelling and niche experimental techniques.

Graphene NOWNANO is run jointly with its predecessor, North-West Nanoscience Doctoral Training Centre (OWNANO), providing a wide ranging interdisciplinary PhD programme that teaches the students to think and work across traditional discipline boundaries. The close involvement of the medical/life sciences with the physical sciences is an essential feature of the CDT that has been developed in the framework of NOWNANO and continues in the new CDT.

In addition to interdisciplinarity, an important feature of Graphene NOWNANO is its close engagement with a number of partners, academic and industrial, including our close partnership with the newly established National Graphene Institute in Manchester.

The full list of research interests of the participating staff is too long to include here but some of the highlights are:

- discovery of graphene – the first strictly two-dimensional material
- pioneering experimental and theoretical studies of a range of graphene properties:
  - novel electronic phenomena governed by the unique electronic spectrum of mono-, bi- and trilayer graphene;
  - novel type of transistor based on field-effect tunnelling between graphene layers;
  - van der Waals heterostructures as light-emitting diodes;
  - graphene-controlled plasmonic laser
  - tunable magnetic response of functionalised graphene;
  - unique properties of graphene membranes: impermeable to gases yet superpermeable to water;
- proton-conducting graphene membranes for fuel cells and hydrogen-isotope separation
- tuning graphene's electronic properties by strain engineering;
- first stable chemical derivatives of graphene: graphane and fluorographene;

- graphene-based chemical and stress sensors. innovative methods for using Raman spectroscopy and transmission electron microscopy to characterise graphene and other 2D materials;
- development of graphene-based devices for quantum metrology (resistance and current standards);
- licensed production and processing methods for carbon nanomaterials;
- design and fabrication of artificial metamaterials with negative index of refraction;
- superconductor-based devices (qubits) for quantum nanotechnologies;
- nano-transistors based on a single-layered 2D architecture;
- nanomechanical and nanothermal scanning technologies;
- development of oxidation-sensitive nanocarriers for inflammation-responsive drug delivery;
- development of enzyme based biosensors and biofuel cells;
- novel methods to study the interactions of graphene-related materials with cells and their components;
- using functionalised graphene for drug delivery.
CDT Contacts

The Graphene NOWNANO CDT programme is managed by the Centre Director and the CDT Management Board which includes representatives from the different Schools and Departments comprising the Centre:

### Management Board Members

#### University of Manchester

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Email</th>
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<tbody>
<tr>
<td>CDT Director</td>
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#### Lancaster University

| Department of Physics                           | Prof. Rob Young               | r.j.young@lancaster.ac.uk               |

#### Administrative Support

**University of Manchester**

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# Calendar for 2017/18 Academic Session

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<tr>
<th>Month</th>
<th>Event</th>
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<tr>
<td><strong>18th – 22nd Sept</strong></td>
<td>Registration and Induction Week</td>
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<tr>
<td>Oct – Dec 2017</td>
<td>Core Course 1 – Fundamentals of Graphene and Nanomaterials</td>
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<td>- Key aspects of the biological and medical applications of (nano)materials</td>
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<td>- 2D Materials from a Solid State Physics Perspective</td>
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<td>- Characterisation of Nanomaterials</td>
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<td>Core Course 2 - Introduction to Nanoengineering</td>
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<td>- Microfabrication Techniques</td>
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<td>- Building 3D architectures with 2D Materials</td>
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<td>- Applications of 2D Materials</td>
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<td>Group Lab Project</td>
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<td>Enquiry Based Learning (EBL) project</td>
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<td><strong>Jan - March 2018</strong></td>
<td>Core Course 3 - Techniques in Nanotechnology</td>
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<td></td>
<td>- Device Fabrication</td>
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<td>- Nanoparticles, Nanomaterials and Routes to their Preparation</td>
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<td>- Electron Microscopy and Electrical Measurements</td>
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<td>Option Module (choose one out of the following):</td>
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<td>- Fundamentals of Nanoelectronics</td>
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<td>- Fundamentals of Molecular Modelling</td>
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<td>Group Lab Project</td>
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<td>Enquiry Based Learning (EBL) project</td>
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<tr>
<td>April 2018</td>
<td>Commencement of research project</td>
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Programme of Study

Programme Summary

Graphene NOWNANO CDT students undertake a four-year doctoral training programme. A major aim of the CDT is to create a cohort of researchers able to draw on knowledge from a broad spectrum of sciences and to work in interdisciplinary teams. The challenge is to enable our students to understand the different languages and philosophies of disciplines as diverse as theoretical physics and medicine.

The aim of the first six months of the programme is to expose you to the full breadth of nanoscience and nanotechnology and to provide you with the skills and background knowledge that you will need during your PhD projects to understand the diverse concepts and knowledge that you will inevitably encounter. To this end, the programme includes not only lecture courses and directed self-study (enquiry-based learning) but also extended (12 weeks long) laboratory projects covering different experimental methods and different aspects of nanoscience and nanotechnology.

Also during this time you will have an opportunity to learn about the available PhD research projects through presentations by potential supervisors and visits to research labs. It is expected that many projects will be interdisciplinary, with co-supervision by academics from different Schools/Departments, providing you with access to the world class facilities.

Key Aims of the Programme

The aims of the training within Graphene NOWNANO are:

(i) create a cohesive group of students who will mutually benefit from their diverse backgrounds and developing projects and will form a longer lasting network of future movers and shakers.

(ii) support the development of cohort identity by having a physical hub for the CDT activities and regular CDT-wide events, such as seminars, conferences, summer schools and outreach events;

(iii) provide the CDT students with a wide range of innovative, collaborative research projects offered by UoM and LU cross-disciplinary teams of academics and industrial partners;

(iv) link the research projects to current and future industry needs by providing the CDT students with a range of secondment opportunities where they will carry out a part of their research projects in an industrial setting;

(v) provide specialist training in innovation and commercialisation of research and encourage the CDT students to participate in business and innovation competitions, e.g., the UoM Eli and Britt Harari Graphene Enterprise Award, Venture Out and Venture Further start-up competitions, Young Entrepreneur Award.

(vi) educate PhD students in the wider context of economic and societal needs by ensuring regular contacts with industry leaders and innovators from across the UK and Europe, as well as interactions with organisations promoting science and technology to the general public.

Module Outlines & Intended Learning Outcomes

Students undertake three compulsory core modules and select one optional module over the first six months in addition to the two group lab projects and two enquiry-based learning exercises. You will find details of these modules, lab projects and enquiry-based learning exercises on the following pages.
CORE 1: Fundamentals of Graphene and Nanomaterials
Course Code PHYS60151 (15 credits)

Part 1: Key aspects of the biological and medical applications of (nano)materials: The case study of graphene based materials

Tutors: Prof. K. Kostarelos, Dr C. Bussy
Prof. T. Freemont, Dr. M. Sherratt, Dr S. Vranic, Dr D. Jasim; Prof. J Garrido (ICN2 Spain)

Prerequisites: None

Classes: 14 lectures in Semester 1 (months 1-3)
Assessment: 20 minute group presentation (3-4 students)

Recommended texts
Relevant literature will be provided in form of recent research papers or reviews

Aims
1. To provide an overview of core concepts in the field of (nano)medicine and regenerative medicine, using graphene based materials as representative (nano)materials
2. To provide an overview of the currently developing applications of graphene and 2D materials in the healthcare sector.

Learning Outcomes
On completion of the course, students will be able to:
1. Understand the pros and cons of using nanomaterials for biomedical applications
2. Relate properties of materials to their biological and medical applications

Syllabus
The lectures will cover the following topics:

- **Graphene and 2D Material Impact on Health, Safety and the Environment**: 1. Toxic and biological responses to graphene exposure; 2. Engineering routes to make graphene based materials safer (Bussy)
- **Graphene cell biology**: 1. Introduction to cell structure and organization, extracellular matrix and corona; 2. Interaction of graphene with cell membranes (concepts of endocytosis, phagocytosis, exocytosis); 3. Interaction of graphene with cell cytoplasmic elements (intracellular trafficking, storage, cell imaging) (Vranic)
- **Overview of human diseases and nanomedical features**: pathologies affecting nano-organization of extracellular matrices (Freemont).
- **Graphene and 2D Materials Pharmacokinetics (ADME principles)**: 1. Introduction to basic physiology and anatomy; 2. Pharmacokinetics, biodistribution of graphene; 3. Implications and requirements for therapy and imaging, concept of targeting (Jasim).
- **Biological uses of AFM**: the application of Atomic Force Microscopy for imaging and characterisation of tissue morphology and biomolecule organisation (Sherratt)
- **Graphene sensors and electrodes for biomedicine**: (Garrido, ICN2, Spain)
- **Therapeutic and Diagnostic Applications of Graphene** (Kostarelos): applications of graphene for cancer therapy, gene therapy, regenerative therapy and their diagnosis
- **Overall view of 2D Materials in Nanomedicine** (Kostarelos): landscape of the potential of 2D materials for biomedical applications.
Part 2: 2D materials from a solid state physics perspective

Tutor: Dr. N. Drummond
Prerequisites: None
Classes: 12 lectures in Semester 1 (month 2)
Assessment: Continuous assessment – course work

Recommended texts

Supplementary reading
- C. Kittel, Introduction to Solid State Physics, Wiley&Sons 1966 or any later edition

Aims
1. To introduce the students to some of the key concepts in solid state physics, including the structural properties of crystalline solids and the idea of electronic band structures.
2. To familiarise the students with the language and methods of solid state physics.
3. To enable the students to develop their mathematical abilities and problem-solving skills.

Learning Outcomes
On completion of the course, students will be able to:

1. Describe the structural properties of crystalline solids.
2. Explain the origin of metallic and insulating behaviour in materials.
3. Show an awareness of some key concepts in the physics of semiconductor devices.
4. Use the free-electron model to explain the properties of metals.
5. Show an awareness of current developments in the physics of low-dimensional nanostructures.

Syllabus
Lectures will cover the following topics:

- Bragg scattering and X-ray crystallography. Reciprocal lattice and Brillouin zone.
Part 3: Characterisation of nanomaterials

Tutors: Dr. C. Casiraghi, Dr A. Thomas
Prerequisites: None
Classes: 7 Lectures and 1 practical in Semester 1 (Month 3)
Assessment: Coursework

Recommended texts (provisional)

Aims
1. To provide an overview of the advantages and properties of reducing the size of particles on the nanoscale.
2. To provide an overview of optical characterisation techniques.
3. To understand the suitability of different characterization techniques for particular applications.
4. To provide an introduction to photoelectron spectroscopy covering the basic principles and instrumentation required
5. To allow students to carry out basic analysis of photoelectron spectroscopy data, to identify surface chemistry and chemical states.

Learning Outcomes
On completion of the course, students will be able to:

1. Know the differences in the physical properties of nano and bulk materials.
2. Know and understand optical characterisation techniques suitable for studies of nanomaterials.
3. Describe the basic principles of photoelectron spectroscopy (PES).
4. Understand initial and final state process in PES and how these appear in spectra.
5. Describe the principles of instrumentation used in photoelectron spectroscopy.
6. Describe applications of PES beyond simple surface analysis.
7. Use a commercial software package to fit peaks and analyse PES data.
8. Calculate elemental compositions of surfaces from peak areas.

Syllabus (provisional)
The lectures will cover the following topics:
- Introduction to nanotechnology, including dimensionality and general properties. (e.g. crystal structure, optical properties and electronic structure)
- Optical characterisation techniques (Raman spectroscopy, SERS, Photoluminescence, etc.)
- The basic principles of photoelectron spectroscopy (PES)
- Instrumentation for PES
- Advanced PES Techniques
- Basics of analysing X-Ray Photoelectron Spectra using CASAXPS workshop
CORE 2: Introduction to Nanoengineering
Course code PHYS60131 (15 credits)

Part 1 - Microfabrication Techniques

Tutors: Prof. Aimin Song, Dr. Radha Boya, Dr. Alex Lincoln
Prerequisites: None
Classes: 9 lectures in semester 1 (months 1-2) plus practical lithography laboratory session
Assessment: End of course presentation

Recommended texts
- Fundamentals of Microfabrication and Nanotechnology – Marc J Madou

Supplementary reading
- Lyshhevski, MEMS and NEMS, Systems, devices, and structures, CRC Press, 2002
- Elwenspoek and Wiegerink, Mechanical Microsensors, Springer, 2001
- Soft lithography, Angewandte Chemie 1998, 37, 550-575
- Van der Waals heterostructures, Nature 2013, 499, 419–425
- 2D materials and van der Waals heterostructures, Science 2016, 353, 461
- Lithography, metrology and nanomanufacturing, Nanoscale 2011, 3, 2679

Aims
1. To provide an overview of photolithography technique and understand its limitation.
2. To provide an understanding of major lithographic techniques available for nano-scale fabrication.
3. To understand the major process flow for nano-scale device fabrication.
4. To understand the principles of scanning probe and scanning electron microscopy.
5. To show how scanning probe systems can be used for atomic/molecular manipulation.
6. To demonstrate how to do electron beam lithography practically.
7. To learn how to use stamp based lithography techniques
8. To learn how to build heterostructures of 2D-materials by manipulation.

Learning Outcomes:
On completion of the course, students will be able to:
1. Evaluate the limitations of a given lithographic technique.
2. Select a suitable lithographic technique given device scale and process flow.
3. Establish an appropriate process flow for fabrication of a given nano-scale device.
4. Describe the operating principles of an atomic force microscope and scanning electron microscope.
5. Appreciate the differences between “top-down” and “bottom-up” fabrication techniques.
6. Understand the differences between parallel (large area) and serial (small scale) patterning and appreciate the advantages and limitations of various beam based, probe based and stamp based lithographic techniques.
7. Know-how of manipulation of 2D-materials and atomic/molecular nanomanipulation.

Syllabus
The lectures will cover the following topics:
- Introduction to photolithography and flavour of nano-science
- Electron Beam lithography
- Focussed Ion Beam lithography
- Stamp based nanolithography & scanning probe lithography
- Atomic/molecular nanomanipulation & Nanomanipulation of 2D-materials
- Nanofabrication of devices
- Group presentation on EBL topics
- Lab session
**Part 2: Building 3D architectures with 2D materials**

**Tutors:** Dr. Suelen Barg, Dr. Will Williams, Dr. Nigel Hodson  
**Prerequisites:** None  
**Classes:** 3 lectures plus tour/demonstration  
**Assessment:** Coursework

**Recommended texts**  
- Nanoindentation, Fischer-Cripps, Anthony C. (Springer US) 2011

**Supplementary reading**  
- S Naficy, GG Wallace, Graphene oxide dispersions: tuning rheology to enable fabrication; Materials Horizons, 2014  
- Other relevant recent papers and reviews on will be provided throughout lectures  
- Foundations of Nanomechanics. Cleland, Andrew N. (Springer US) 2003

**Aims**

1. To introduce the students to the importance of assembling 2D materials in three-dimensions with an overview of their use in different applications (from energy to bio-medical);  
2. To provide an understanding of the processing routes that can be used to produce graphene-based 3D architectures with focus on the underpinning principles of wet processing.  
3. To demonstrate how processing can control structure and hence properties of 3D structures and how this relates to the requirements of specific applications.  
4. To introduce the students to the basics of nanomechanics, both in relation to simple materials and complex biomaterials. This will include practical advice.

**Learning Outcomes:**

On completion of the course, students will be able to:

1. To appreciate the advantages of 3D architectures based on 2D materials for key technological applications;  
2. Know the basics of 3D fabrication applied for 2D materials  
3. Understand how 3D architectures morphology can be tailored and relate structure to property and functionality.  
4. Have a basic understanding of what information can be derived from nanomechanical studies, and the means by which such investigations can be achieved.

**Syllabus**

The lectures will cover the following topics:

- Introduction: Why assemble a 2D material in Three-dimensions. Different types of architectures and their multi-functionalities  
- 3D assembly and manufacturing with graphene and related 2D materials: Processing routes, morphological control and properties  
- Overview of potential applications of tailored 3D architectures based on 2D materials: From super capacitors to bio-scaffolds.  
- Basic nano-mechanics and practical considerations.
Part 3: Applications of 2D Materials

Tutors: Dr. Leonid Ponomarenko
Prerequisites: None
Classes: 6 hours of lectures
Assessment: Coursework

Recommended texts

Aims
1. To provide an overview of recent developments in physics of 2D materials and their applications.
2. To introduce students to the cutting edge research carried out at NGI and familiarise them with experimental techniques for studying low dimensional materials.

Learning Outcomes:
On completion of the course, students will be able to:

1. Relate electronic properties of 2D materials to their 3D counterparts.
2. Understand physics behind operation of novel 2D electronic and optoelectronic devices.
3. Realise advantages of van der Waals heterostructures for various applications.

Syllabus
The lectures will cover the following topics:

- 2D transitors
- Sensors and detectors based on tunnelling phenomena
- Optical applications of 2D materials
- ‘Materials on demand’ – 2D heterostructures assembled from individual atomic layers and their applications.
CORE 3: Techniques in Nanotechnology
Course Code PHY60312 (15 credits)

Part 1: Device Fabrication

Tutors: Dr Artem Mishchenko, Dr Guillaume De Bo, Dr Scott Lewis
Prerequisites: None
Classes: 12 hours (Mixture of lectures and practical work)
Assessment: Problem sheets (50%); Poster presentation (50%)

Recommended texts
• Fabrication engineering at the micro- and nanoscale, S.A. Campbell (Oxford University Press) 2013.
• Supramolecular Chemistry, Paul D. Beer, Philip A. Gale and David K. Smith (Oxford University Primers) 1999.

Supplementary reading
Lecture notes and other related materials will be provided on Blackboard.

Aims
1. To provide a broad overview of materials and manufacturing technologies and their links to modern and beyond state-of-the-art nanodevices.
2. To overview relevant technological steps for device fabrication and characterisation.
3. To establish a better understanding of materials for future nanodevices.
4. To provide an overview on the use of supramolecular chemistry to build molecular machines.

Learning Outcomes
On completion of the course, students will be able to:
1. Make informed design choices as to the best microelectronic implementation strategy for a particular application.
2. Describe the fundamental processes involved in semiconductor manufacture
3. Have an insight into the enormous technical challenges (and their possible solutions) presented by modern and emerging device nanotechnologies
4. Identify a non-covalent interaction and its relative strength
5. Explain the operation principle of simple molecular machine in terms of non-covalent interactions, dynamic and energy.

Syllabus
The lectures will cover the following topics:
• Comparison of top-down and bottom-up manufacturing approaches for device fabrication. Scaling laws in miniature devices. The power of miniaturisation. (2 lectures)
• Overview of selected materials and processes used to fabricate state-of-the-art nanodevices. Characterisation, metrology and standardisation of fabricated devices (2 lectures)
• Device concepts and non-conventional nanodevices. Roadmap of miniaturisation, materials by design and van der Waals heterostructures. (2 lectures)
• Basics of supramolecular chemistry, beginning with simple ideas in bonding, including ionic, covalent and hydrogen bonding. (1 lecture)
• Use of supramolecular interactions to assemble and control the dynamic properties of interlocked structure. (1 lecture)
• Design of molecular machines. (1 lecture)
Part 2: Nanoparticles, Nanomaterials and Routes to their Preparation

Tutors: Prof. R. Dryfe
Prerequisites: None but students may be required to do some reading before lectures, depending on their background.
Classes: 6 hours of Lectures in Semester 2
Assessment: Coursework

Recommended texts (Provisional)

Supplementary reading

Aims
1. To provide an overview of the advantages and properties of reducing the size of particles on the nanoscale.
2. To understand different physical and chemical processes for the production of particles and films.
3. To understand production of nanoparticles by templating, colloidal, and chemical vapour deposition routes.

Learning Outcomes
On completion of the course, students will be able to:
1. Know the differences in the physical properties of nano and bulk materials.
2. Relate materials chemistry to nanoparticle production.

Syllabus (provisional)
The lectures will cover the following topics:
- Introduction to nanoparticles, including dimensionality and general properties. (e.g. surface energy’s role in reactivity and crystal structure, optical properties and electronic structure) (3 hours).
- Production routes for nanoparticles and nanomaterials (colloidal, templating, chemical vapour deposition) (3 hours).
Part 3: Electron Microscopy and Electrical Measurements

Tutors: Dr. T Burnett, Prof. T. Thomson

Prerequisites: Nanoscience Core Modules; students will be required to do some reading before lectures, depending on their background.

Classes: 12 lectures in semester 2 (months 4-6)

Assessment: Data analysis coursework of example images and spectra Course work on signal processing

Recommended texts
- Nanotechnology measurement handbook, Keithley Instruments

Supplementary reading

Aims
1. To understand the basic principles, operation and image contrast formation in an electron microscope.
2. To understand elemental analysis within an electron microscope.
3. To understand the principals of low noise electrical measurements
4. To be familiar with lock-in amplifier techniques

Learning Outcomes
On completion of the course, students will be able to:
1. Be able to interpret image, diffraction and elemental data obtained from an electron microscope.
2. Be able to interpret images and to evaluate diffraction patterns and analytical data obtained from an electron microscope.
3. Understand techniques to measure small electrical signals and be familiar with sources of noise
4. Have a working knowledge of the basic theory of lock-in measurement techniques

Syllabus
The lectures will cover the following topics:
- Scanning electron microscopy (SEM) – operation and imaging modes (e.g. secondary electron, back scattered electron and current) (2 lectures)
- Transmission electron microscopy - operation and imaging modes (e.g. bright field, dark field, diffraction, HREM and STEM) (2 lectures)
- Elemental analysis techniques (e.g. EDX and EELs) (2 lectures)
- Sensor to number – measuring the real world (1 lecture)
- Measuring small electrical signals (1 lecture)
- Noise in electrical measurements (1 lecture)
- Estimating measurement uncertainties (1 lecture)
- Electrical measurement instruments (1 lecture)
- The lock-in amplifier (1 lecture)
Option Modules
Pick Option Module 1 or 2 for Second Semester

Option Module 1: Fundamentals of Nanoelectronics and Properties of 2D Materials
Course Code PHYS60652 (15 credits)

Tutor: Prof V Falko
Prerequisites: CDT core
Classes: 28 lectures in semester 2 (months 4-6)
Assessment: Continuous assessment – course work

Recommended text

Supplementary reading
• Course handouts

Aims
1. To provide a broad overview of electronic properties of nanostructures made from semiconductors, metals, ferromagnetic materials.
2. To introduce students to the main concepts of quantum transport effects in electronic material and nanostructures.
3. To introduce students to the main concept of Coulomb effects in nanostructures.
4. To overview the recent progress in new low dimensional materials, such as graphene, silicene, hexagonal boron nitride, and transition metal dichalcogenides, and indium selenide.

Learning Outcomes
On completion of the course, students will be able to:
1. Be aware of the features of electronic properties of two-dimensional (2D) materials.
2. Understand basic ideas of quantum transport in low-dimensional systems and 2D materials.
3. Make estimations for the characteristic scale of quantum effects in nanoelectronic systems
4. Orient themselves in specialized literature (such as journal publications) on mesoscopic physics and 2D materials.

Syllabus
28 lectures will cover the following topics:
• Quantum wells, wires, dots. Ideas of quantum transport, the conductance quantum e²/h, and the Buttiker-Landauer conductance formula. Metallic point contacts and atomic break-junctions.
• Universal conductance fluctuations in small phase coherent conductors. Quantum chaos in quantum dots. The Aharonov-Bohm effect in small (‘mesoscopic’) metallic/semiconductor rings.
• Interference and the enhanced backscattering of waves in disordered media. Localisation (weak and strong) in two- and one-dimensional electron systems.
• Hall effect. Skipping orbits, caustics, and transverse electron focusing. Landau levels and edge states. The quantum Hall effect and the quantum resistance standard.
• The resonance tunneling phenomenon. The Coulomb blockade phenomenon and a single-electron transistor. Parity effect in superconductor quantum dots. Spin states of few electron quantum dots. Quantum dot ‘spin qubits’ and point contact ‘readout’.
• Electronic properties of graphene. Van der Waals heterostructures of graphene with other hexagonal crystals.
• Two-dimensional materials beyond graphene.
• Nanotubes (carbon nanotubes, nanotubes of other materials).

The lectures will be complemented by discussion seminars.
Option Module 2: Fundamentals of Molecular Modelling
Course Code PHYS60653 (15 credits)

Tutor: Dr. Paola Carbone
Prerequisites: None
Classes: Lectures (10 hours) plus 18 hours of practical work and 8 hours of independent study
Assessment: Written essay (3000 words ca.)

Recommended texts
- Molecular Modelling: Principles and Applications (2nd Edition) by Andrew R. Leach
- Understanding Molecular Simulation, Second Edition: From Algorithms to Application (Computational Science) by Daan Frenkel and Berend Smit

Aims
Introduce the modelling techniques used in the physical sciences with emphasis on Molecular Dynamics and Monte Carlo.

Learning outcomes
On completion of the course, students will be able to:
- Have a basic understanding of the computational methods available and their capabilities.
- Identification of relevant scientific problems solvable with the aid of molecular simulations
- Evaluation of the relevance of computational methods to the problem of interest
- Use of molecular dynamics package to solve a specific experimental problem
- Understand the scientific literature
- Perform and critically analyse simulations

Syllabus
- Introduction of statistical mechanics and definition of thermodynamic variables
- Computer simulations their advantages compared with running wet experiments and limitations
- Fundamentals of molecular dynamics (ergodic principle, ensembles, algorithm, force fields, periodic boundary conditions, choice of input parameters)
- Examples of use of molecular dynamics in nanoscience (CNT, graphene, self-assembly process of amphiphilic molecules)
- Advanced simulation techniques (development of coarse-grained models)
- Overview of recent literature and introduction to the tutorial
Enquiry-Based Learning

EBL projects will be done in groups of 3 - 4. Each student will complete two projects chosen from the list below (one in October-December and one in January-March). The following topics will be offered in the academic year 2017-2018 (6 in each semester):

1. Future Technologies for Neuromorphic Computing (Dr Christoforos Moutafis): How has the study of biological nano-structure advanced in the 53 years since Richard Feynman’s “room at the bottom” lecture?

2. Beyond flatland: 3D Biological Microscopy (Dr Michael Sherratt): How and why do some nano- and meso-scale systems prefer organization over disorder.

3. Self-assembly in a Chaotic World (Dr Aravind Vijayaraghavan): How does the study of biological nano-structure advanced in the 53 years since Richard Feynman’s “room at the bottom” lecture?

4. Spin based electronics: The future! (Prof Tom Thomson): The generation, propagation and use of spin will be explored as a new way of creating nanoelectronic devices and sensors.

5. What Can You Do with Graphene? (Prof Irina Grigorieva): Exploring the various existing and potential applications of graphene and their impact on modern technology.

6. Investigating 2D materials, one atoms at a time, with electron microscopy techniques (Dr Eric Prestat): Exploring the nature and the structure of 2D materials with atomic precision is essential to understand their unique properties. How to achieve it? What are the challenges, limitations and the potentials?

7. Nanoscale Modelling: How Hard Can It Be? (Dr Jim Miles): What are the limits of modelling the nanoscale, and can it rival experiment?

8. Carbon Nanomaterials in Electrochemical Energy Storage - why and how? (Dr Rob Dryfe): Nanostructured materials are essential to energy conversion. The EBL topic should research the current use and future developments in electrochemical energy storage/conversion, specifically in (lithium ion) batteries, supercapacitors and fuel cells.

9. The good, the bad and the ugly nanocarbons for medicine (Prof Kostas Kostarelos): A student-driven investigative exploration of the types of carbon-based nanomaterials and the way they are developed for biology and medicine.

10. Injecting spins in graphene: are there alternatives to charge currents and magnetic materials? (Dr Ivan Vera-Marun): Explore and compare different approaches to create spin currents in graphene, which are key to enable spintronics in novel 2D materials.

Plus 2 further projects - titles to be confirmed
Group Lab Projects

Semester 1
Dr. S Chakraborty

CDT Lab unit
Part of CDT

Studying Graphene Plasmonics with THz Quantum Cascade Lasers

Prerequisites: CDT core course modules
Classes: Twelve days laboratory work including planning, characterisation, electromagnetic modeling, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts

Aims
Experimental characterization and modeling of graphene controlled tunable THz quantum cascade lasers (QCLs).

Learning outcomes
On completion, successful students will have:

1. Familiarity with terahertz photonics laboratory protocols and procedures
2. Familiarity with low temperature (<10K) optoelectronic measurements
3. Familiarity with state-of-the-art electromagnetic simulation software
4. A basic understanding of characterization techniques for terahertz photonic devices
5. A basic understanding of the role Graphene plays in controlling optoelectronic devices

Structure
The overall objective will be to design graphene modified surface-plasmon photonic-bandgap waveguides for controlling QCL radiation on sub-wavelength scales with high accuracy. Subsequent experimental measurements will then be made of the effective refractive indices and losses in micro-structured THz QCLs. A comprehensive range of experimental facilities will be available to the student to pursue the planned research project. These include the Bruker Vertex 80 Fourier transform infra-red step-scan spectrometer, helium-cooled silicon bolometer and a continuous flow optical access cryostat.
Creating Domain Walls in Magnetic Nanowires

Prerequisites: CDT core course modules
Classes: Twelve days laboratory work including planning, fabrication, characterisation, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
  - Laboratory notebook 60% (individual marks)
  - Project summary – 40% (Joint short journal-style paper)

Recommended texts
- "Discrete Domain Wall Positioning Due to Pinning in Current Driven Motion along Nanowires" Xin Jiang, Luc Thomas, Rai Moriya, and Stuart S. P. Parkin, Nano. Lett. 11 (2011) 96

Aims
Create a magnetic nanowire device and observe domain wall motion in a nanowire using the magneto-optic Kerr effect and/or magnetic force microscopy and/or electrical detection.

Learning outcomes
On completion, successful students will have:
1. Familiarity with cleanroom protocols and procedures
2. Familiarity with nanoscale fabrication techniques for top-down processing
3. Deposition of metal layers with nanometre thickness
4. Characterisation techniques for magnetic and electrical properties in nanodevices

Structure
This laboratory project involves the design, fabrication and characterisation of a nanoscale magnetic domain wall device such as might be used for nanoscale magnetic logic or data storage. It is designed to introduce students to the important stages in creating physical devices using the processing techniques found in the semiconductor or hard disk industry. The student will first have to design a device and assist in its fabrication (some stages of fabrication, mainly e-beam lithography, will be outside the students’ competencies’ and will be done in collaboration with a SEO). The group will also have to design and fabricate probes suitable for measuring the device and finally undertaken a range of electrical and magnetic characterisation.
Investigating the interactions of cells with 2D materials using confocal Raman imaging and bioassays

**Prerequisites:** CDT core course modules

**Classes:** Twelve days laboratory work including planning, executing tests, analysing results, reporting

**Assessment:** Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

**Recommended text**

**Aims**
- Evaluate the biological responses of cell line models to graphene or other 2D materials exposure using bioassays
- Compare the biological outcome between materials
- Assess the internalisation of 2D materials using confocal Raman imaging
- Critically evaluate whether internalisation can be correlated with biological outcome

**Learning outcomes:**

On completion, successful students will have:
1. Familiarity with working in a sterile environment using aseptic techniques
2. A basic understanding of the rules (good practices) in place in a cell culture facility
3. Familiarity with cell culture assay design (e.g. serial dilution), protocols, procedures and time requirements
4. A basic understanding of how Raman spectroscopy can be used for the chemical imaging of cellular internalisation of 2D materials
5. A basic understanding of how toxicity of nanomaterials is generally assessed in vitro and the limitations with conventional methods for toxicity assessment of nanomaterials

**Structure**

The overall objective is to complete in vitro tests of toxicity and Raman imaging following the exposure of cell lines to aqueous suspensions of 2D materials.

The students will first master basic cell culture techniques and prepare 2D materials aqueous suspensions following aseptic procedures. They will then perform one bioassay of interest after exposure of cells to nanomaterials (for various periods of time). Finally, the students will perform confocal Raman imaging of the exposed cells to assess the level of internalisation.

Students will have access to state-of-the art facilities for doing cell culture and preparing the nanomaterial suspension (safety cabinets, CO2 incubators, reagents, cells, microscopes). They will learn how to operate a plate reader to measure the outcome of cytotoxicity assays performed, how to operate a Raman microscope to perform 2D materials imaging, learn how to report data and keeping a lab book up-to-date, and finally learn how to work both individually and as a team in this environment.
Semester 1
Prof. Ian Kinloch

Synthesis and Characterisation of Carbon nanomaterials

Prerequisites: CDT Core
Classes: Twelve days laboratory work including planning, fabrication, characterisation, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts

Aims
Produce and characterise low dimensional carbon structures (single-walled nanotubes, multi-walled nanotubes and graphene).

Learning outcomes
On completion, successful students will have:

1. Knowledge on the growth of carbon nanotubes by catalytic vapour deposition (CVD).
2. Knowledge on the production of graphene.
3. Familiarity with transmission electron microscopy (TEM) and scanning electron microscopy (SEM).
4. Be able to identify low dimensional carbon structures by Raman spectroscopy through the relationship of the spectra to the phonon-electron properties of carbon.

Structure
This laboratory project involves the production and characterisation of carbon particles which possess a low dimensionality. Carbon nanotubes will be produced by using catalytic vapour deposition techniques. Aligned mats of multi-walled carbon nanotubes (MWNTs) will be produced by the pyrolysis of ferrocene and toluene. Single-walled carbon nanotubes (SWNTs) will be produced by the cracking of methane over a nickel catalyst held on a silica substrate. The growth steps of the SWNTs will be analysed as a function of growth parameters. Raman spectroscopy will be used to indentify the structures produced, taking advantage of the unique electron-phonon coupling in each graphene based material. Finally, the students will work with Dr. Bangert to study the structures produced using state-of-the-art electron microscopy.
Semester 1
Dr. O. Kolosov, Dr. B. Robinson

Lancaster University - CDT Lab unit
Part of CDT

Nanomechanical Properties of Graphene and 2D Nanostructures

Prerequisites: CDT Core
Classes: Twelve days laboratory work including planning, sample preparations, measurements, characterization, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts

Aims
1. Become accustomed with Atomic Force Microscopy (AFM) as a tool for imaging nanomaterials.
2. Familiarize with approaches for nanomechanical testing of two-dimensional materials and sample preparations and handling (graphene, MoS2).
3. Derive quantitative nanomechanical information from AFM and related data.

Learning outcomes
On completion, successful students will have developed an understanding of:

1. AFM in various imaging modes - intermittent contact (tapping) mode for topographical imaging and adhesion related contrast;
2. Two-dimensional materials sample preparation via exfoliation and transfer on test substrates;
3. Contact mode AFM for topographical, friction and nanoindentation based nanomechanical probing;
4. The basics of Force Modulation Microscopy, Force Spectroscopy and Ultrasonic Force Microscopy for mapping and measurements of local mechanical properties;
5. The planning, execution, analytical models and statistical analysis required to study materials nanomechanics in AFM.

Structure
This laboratory project takes place in a dedicated environment (Lancaster Physics SPM lab) in the Physics Building of Lancaster University. It is designed to give the students a theoretical and practical background in the use of atomic force microscopy for the visualisation and nanomechanical characterization of solid state materials. The module is delivered via a series of linked experiments designed to cover a number of aspects of the use of AFM in condensed matter physics using several related nanomechanics methods:

1) Tapping mode AFM – topography and phase contrast;
2) Contact mode AFM – topography, friction force contrast and nanoindentation;
3) Force Modulation and Ultrasonic Force microscopy for nanomechanical mapping; as well as aspects of
4) Preparation of 2D materials (graphene, MoS2, etc.) on dedicated substrates that allow studying nanomechanics of supported and suspended films and nano-flakes, as well as
5) Analysis of nanoscale layers deformation – plate and membrane models.

Students will utilise instruments within the Lancaster SPM Facility, clean room for sample preparation and subsequently analyse their captured data. The module culminates with a dedicate project where the students are expected to use skills acquired during the course to explore and solve, with minimal supervision, a problem of mapping dynamic nanomechanical properties, giving specific attention and interpretation to measured parameters, statistical comparison and data presentation.

Note: This lab will be based in Lancaster
Semester 1  
Prof. Rahul Raveendran Nair  
CDT Lab unit  
Part of CDT  

**Molecular permeation through 2D materials based membranes**

**Prerequisites:** CDT core course modules  
**Classes:** Twelve days laboratory work including planning, characterisation, analysis and reporting  
**Assessment:** Each group will be marked collectively and as individuals:  
- Laboratory notebook 60% (individual marks)  
- Project summary – 40% (Joint short journal-style paper)

**Recommended texts**  

**Aims**  
Study molecular permeation through 2D materials-based membranes

**Learning outcomes**  
On completion, successful students will have gained the following skills:  
1. Graphene oxide membrane preparation and characterization  
2. Operation of various characterization techniques  
3. Operation of gravimetric technique to study vapor permeation

**Structure**  
In this experimental project, you’ll learn to fabricate and characterize 2D materials based membranes and will study water and gas permeation properties. The primary objective of this project is to teach you the basic skills required to study the mass transport properties of 2D materials based membranes and study the behavior of molecules at atomic scale confinement.
Atomic Force Microscopy for Imaging Biological Samples

Prerequisites: CDT Core
Classes: Twelve days laboratory work including planning, measurements, characterisation, analysis and reporting
Assessment: Each group will be marked as individuals:
  • Laboratory notebook 60% (individual marks)
  • Project summary – 40% (Joint short journal-style paper)

Recommended texts
  • Atomic Force Microscopy for Biologists - VJ Morris, AR Kirby & AP Gunning

Aims
1. Become accustomed with Atomic Force Microscopy (AFM) as a tool for imaging soft/biological samples.
2. Derive quantitative information from AFM data.

Learning outcomes
On completion, successful students will have developed an understanding of:

1. AFM in intermittent contact (tapping) mode for imaging soft/biological samples in air;
2. Peak-force tapping mode AFM for imaging samples in a liquid environment;
3. The use of AFM-based nanoindentation to measure mechanical properties;
4. The planning, execution and statistical analysis required to employ quantitative AFM in a graphene-related biological project.

Structure
This laboratory project takes place in a dedicated environment (The BioAFM Facility) in the Stopford Building. It is designed to give the students a theoretical and practical grounding in the use of atomic force microscopy for the visualisation and quantitation of soft/biological materials. The module is delivered via a series of individual experiments designed to cover a number of aspects of AFM (including the derivation of nanomechanical information) by imaging a wide range of materials, from nanoparticles and macromolecular structures through to cells. Students utilise three instruments within the BioAFM Facility (which differ in mode of operation and capabilities) and subsequently analyse their captured data using in-house applications in parallel with both propriety and open-source software packages. The module culminates with a “mini-project” where the students are expected to use skills acquired during the course to address, with minimal supervision, a given graphene-related biological problem, giving specific attention to population size, appropriate morphological parameters, statistical comparison and data presentation.

Students are supplied with a CD containing relevant background literature, seminar presentations and analysis programs.
Applications of Graphene and Two-Dimensional Materials in Energy Storage Devices

Prerequisites: CDT Core
Classes: Twelve days laboratory work including planning, characterisation, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts

Aims
Fabricate and characterize batteries and supercapacitors based on graphene and other two-dimensional materials.

Learning outcomes
On completion, successful students will have gained the following skills:

4. Large-scale preparation of graphene, activated carbon and MXenes
5. Understanding of the principles of operation of different types of batteries and supercapacitors
6. Fabrication of electrochemical test cells
7. Operation of a potentiostat and understanding of key electrochemical measurements

These will be combined to:

1. Study batteries and supercapacitors with different electrode compositions
2. Investigate the potential for graphene and other two-dimensional materials to improve the properties of energy storage devices

Structure
In this experimental project, you’ll first learn the basic principles of batteries and supercapacitors, how they differ, and how they can be used in different applications. You will then learn the preparation techniques for making large (lab- or factory-scale) quantities of graphene and MXenes, and then use these materials to fabricate electrodes. Electrode materials will be characterized using X-ray diffraction, scanning electron microscopy and atomic force microscopy to see the microstructural differences between different forms of carbon. Your electrodes will then be used to assemble working battery and supercapacitor devices, which you will characterize to determine properties such as capacity, internal resistance and power capabilities – all of which are crucial parameters for energy storage devices used in real-world applications. Using the information obtained from this study, you will be able to identify key parameters and properties that are important to optimize the performance of the energy storage device.

*Note: This lab will be based in Lancaster*
Fabrication and characterisation of graphene transparent conducting films

Prerequisites: CDT core course modules
Classes: Twelve days laboratory work including planning, fabrication, characterisation, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts

Aims
Fabricate a carbon nanotube and graphene network transistor and observe the field-effect switching of such devices and its variation with respect to network composition.

Learning outcomes
On completion, successful students will have:

1. Familiarity with cleanroom protocols and procedures.
2. Familiarity with microelectronics fabrication technologies.
3. Ability to deposit networks of aligned carbon nanotubes and graphene.
4. Familiarity with electronic transport measurements of field-effect transistors.

Structure
In this project, carbon nanotubes and graphene will be deposited in a well-controlled manner on a silicon/silicon dioxide substrate. Samples with differences in composition of metallic and semiconducting CNTs or graphene flakes will be produced. Atomic force and scanning-electron microscopy will be used to characterize network density and uniformity. Standard microelectronic nanofabrication in the clean room will be used to produce network field-effect transistors. Subsequently, the switching behaviour of such FETs under three-terminal bias conditions will be evaluated as a function of network composition. In this project, students will be exposed to fabrication and characterization facilities essential to CNT and graphene research. Students will also gain an insight into the potential for application of CNT and graphite in transparent and flexible electronics.
Graphene/2D-material based field-effect devices and optoelectronics

Prerequisites: CDT core course modules
Classes: Twelve days including device fabrication, and electrical and optical characterization.
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts

Aims
Fabrication of graphene/2D-material based field-effect devices/photodetectors and their subsequent electrical and optical characterization.

Learning outcomes
On completion, successful students will have:

1. Familiarity with cleanroom protocols and procedures and work in a lab environment
2. Familiarity with microscale fabrication techniques for top-down processing
3. Familiarity with scanning probe and optical techniques for material characterization
4. Familiarity with combined electrical and optical techniques for device characterization
5. Understanding the influence of the electronic properties of materials on the device characteristics

Structure
This laboratory project involves the design, fabrication and electro-optical characterization of graphene and 2D-material based field-effect devices/photodetectors. In the first part of the project, devices will be designed and subsequently fabricated employing various top-down microfabrication and characterization techniques. In the second part, the fabricated devices will be characterized by electrical, optical and combined electro-optical techniques.
Influence of substrate on physical properties of various 2D materials

Prerequisites: CDT core course modules
Classes: Twelve days laboratory work including planning, characterization, analysis and reporting
Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts
- Probing the Intrinsic Properties of Exfoliated Graphene: Raman Spectroscopy of Free-Standing Monolayers
- Electromechanical Resonators from Graphene Sheets
  http://www.sciencemag.org/content/315/5811/490.full
- Probing excitonic states in suspended two-dimensional semiconductors by photocurrent spectroscopy
  http://www.nature.com/srep/2014/141016/srep06608/pdf/srep06608.pdf

Aims
Use high-resolution scanning probe and optical techniques to characterise and assess the optoelectronic potential of 2D materials with and without substrate

Learning outcomes
On completion, successful students will have gained the following skills:

1. Sample preparation: free standing atomically thin crystals
2. Studying sample morphology and mechanical properties using atomic force microscope
3. Studying sample uniformity and using Raman microscopy

Structure
In this experimental project, you’ll learn to fabricate atomically thin crystals suspended over a trench etched in an underlying substrate. You will then study these devices using atomic force microscopy and Raman spectroscopy to assess their electronic and mechanical properties. The primary aim is to teach you the skills required to fabricate free hanging atomically thin materials and understand how they are influenced by the proximity of a supporting substrate and contamination.
Optical properties and mapping of exfoliated 2D materials

Prerequisites: CDT core course modules

Classes: Twelve days laboratory work including planning, characterisation, analysis and reporting

Assessment: Each group will be marked collectively and as individuals:
- Laboratory notebook 60% (individual marks)
- Project summary – 40% (Joint short journal-style paper)

Recommended texts
- Wu et al. “Imaging Spectroscopy of Two-Dimensional Excitons in a Narrow GaAsAlGaAs Quantum Well”, PRL 83, 2652 (1999) - goo.gl/3djS53

Aims
Use high-resolution optical techniques to characterise and assess the optoelectronic potential of 2D materials

Learning outcomes
On completion, successful students will have gained the following skills:

1. Sample preparation for optical characterisation
2. Operation of low-temperature and high-vacuum systems, and pulsed laser excitation
3. Micro-photoluminescence spectroscopy
4. Picosecond-resolution time resolved optical detection

These will be combined to:

1. Study the emission characteristics of 2D samples you have fabricated, mapping defects and the use of optical techniques in assessing fabrication quality
2. Investigate the potential of developing devices, using these materials as light sources

Structure
In this experimental project, you’ll learn to fabricate samples containing 2D materials and assess their optical properties in a state-of-the-art quantum electro-optics laboratory. The primary aim is to teach you the skills required to perform such measurements, and highlight the value of optical characterisation. You’ll employ these techniques both for high-resolution (temporal and spatial) assessment, but also as a means for exploring the role of these materials in applications ranging from classical light sources to information security.

Note: This lab will be based in Lancaster
Lab Book Protocol

Maintaining a comprehensive and accurate laboratory notebook is a key requirement for any research scientist whether experimental or theoretical. As a student of the Graphene NOWNANO CDT you will be required to maintain a lab book for the practical sessions, which will then be used to assess that part of the course. The lab book is maintained by the student and should meet the following requirements:

- Lab books are hardbound books where pages cannot be added or taken away
- Pages are numbered
- The date is entered at the start of a new day
- If the books cannot be taken into a particular area such as a cleanroom, then cleanroom paper should be used and then stuck into the lab book on the same day
- Lab books are not works of art! but contemporary records of the experiment which should contain information about the planning, execution and preliminary conclusions of the work.

If you are unsure of what your project supervisor expects from you or have further queries where your lab book is concerned, please contact your supervisor to discuss further.

Helpful Reading

You will note in the Handbook that recommended reading suggestions are made for each individual module. In addition to these, you may find the following basic texts helpful, particularly if you do not have a background in one of the subjects. As I am sure you can imagine, with a multi-disciplinary programme such as ours, the academic backgrounds of our student cohorts are varied. We provide extra help and assistance wherever possible to avoid this causing any mishaps. The module tutors, and the advisors that you are assigned to are all incorporated into the programme to facilitate your learning. Please use these resources well.

Chemistry - advanced A-level:
- G.F. Liptrot “Modern Inorganic Chemistry” Bell & Hayman
- R.O.C. Norman & D.J. Waddington “Modern Organic Chemistry” Bell & Hayman

Maths - lots of worked examples:
- K.A. Stroud “Engineering Mathematics” MacMillan
- K.A. Stroud “Further Engineering Mathematics” MacMillan

Physics - 1st year UG level:
- R. Eisberg & R. Resnick “Quantum Physics”. Note: these authors have also individually produced a number of other UG texts which might be helpful.

Nanoscience:
- Stuart Lindsay, Introduction to nanoscience, Oxford University Press 2010; (7 books currently in the library)

Biology – UG level:
- Introduction to Biology, D. L. Wilson; Blackwell, 2010 (ebook)
Public Engagement and Outreach

Public engagement and school outreach describe the myriad of ways in which the activity and benefits of higher education and research can be shared with the public or pupils. Engagement is by definition a two-way process of communication, involving interaction and listening, with the goal of generating mutual benefit. While the audience will learn more on cutting-edge research and get the chance to handle research kits, CDT students will learn to present their research in lay terms and experience the perception of research by the society.

The main purpose of these activities is to go out of the ivory tower to “generate public awareness; communicate research outcomes and benefits to society; encourage public engagement and dialogue with scientists toward an open science practice; and disseminate knowledge and how science & research are contributing to daily life and improving the future”. For the CDT students, it is also a way to develop effective communication skills in an informal environment. Those transferable skills are a key part of the training to develop as a well-rounded scientific expert.

Types of activities:
- School outreach (table top demonstration and discussion with pupils and teachers)
- Blog, instant messaging and skype discussion with school class
- Participation in Science festivals at the University, museums, and special venues (town hall, shopping centre, Jodrell Bank, etc.)
- The Nano Masterclass, a one-day event for sixth form students and their teachers, run at the University of Manchester.
- Pint of Science: sharing about science in a pub
- STEM (science, technology, engineering, math) fair
- Career days
- University open days for prospective candidates
- Community open days
- Creation of table top activities, poster and communication tools
- Maintenance of the CDT social media tools and web presence of CDT activities.

Media training will be provided to prepare students for interviews in blogs (Home of graphene website and CDT website), online videos, local news magazine.

Beginners will be teamed with CDT students from previous years who have experience with delivering engagement activities

Expected commitment
Equivalent to 4 full days over the 4 years of the programme and starting after a STEM ambassador training and induction session in collaboration with curators from the Museum of Science and Industry, Manchester (after April of year 1). Public engagement/outreach activities are mandatory for all students and coordinated by a team made of CDT students and academics with experience in public engagement.
Registration and Induction

All students will be initially registered at the University of Manchester where all teaching will be taking place during the first six months. If a student chooses to do their PhD research project at Lancaster, he/she will transfer their registration to Lancaster while retaining a visiting status at Manchester.

Registration

Details of how the registration process operates at the two institutions can be found at the links below:

University of Manchester (all students initially)
http://www.welcome.manchester.ac.uk/

Please note: if you do not register by the last day of September you will be liable for a late payment charge of £50.

University of Lancaster (for students that choose Lancaster PhD project after 6 months)
www.lancs.ac.uk/sbs/registry/postgrads/

If you have any queries about registration please contact the respective institutions at:

University of Manchester Registration Helpline (Student Services Centre)
Tel: 0161 275 5000 (option 4) Email: ssc@manchester.ac.uk

University of Lancaster (Postgraduate Studies Office)
Tel: 01524 592140
Email: pgso@lancaster.ac.uk

Collection of Student Cards

University Student Cards are issued to all students registered at Manchester as well as Lancaster, for those students who transfer their registration after the six month taught period. The cards are used for security purposes and where access control or other automated systems are in use. It also serves to identify those entitled to use University facilities and services.

Collecting your student card from Manchester

Once registered online, students will be able to collect their swipecard from various points across the University of Manchester. Details of this will be included in the Crucial Guide which will be given to you at your first induction event of Welcome Week.

Collecting your student card from Lancaster

Once registered please contact Deborah Dunne or Barbara Waites (Postgraduate Coordinators in Physics), who will provide instructions on how to obtain your swipecard.

Email: py-pgcoordinator@lancaster.ac.uk, Tel: 01524 592067
**Supervision Arrangements**

**Year 1; months 1-6**

Each student will be assigned a personal tutor and an academic advisor: the tutor will deal with pastoral issues and the academic advisor will be available weekly for a set period of time (1-2 hours) to help students who have difficulties with a specific topic or part of their course.

**Year 1; months 7-12 and Years 2-4**

Students will start working on their PhD projects in this period, so the PhD main supervisor and a new advisor (appointed by the School where the student is registered), will take over the supervision and pastoral care in the normal manner of a PhD project. (An advisor is normally appointed for all University of Manchester PhD students in addition to the main supervisor and co-supervisor(s). The advisor is a non-technical role.) PhD projects will often be interdisciplinary and the supervisory team always includes one or more co-supervisors to ensure that technical supervision is available in all appropriate disciplines.
Progression and Assessment

Students’ work will be assessed throughout the taught element of the programme (months 1-6) and achievement of a minimum of 60% overall will be required for progression to the research stage. Furthermore a mark of no less than 50% is required in each part of a Core course (for example, Part (i) of Core 1, Part (iii) of Core 3, etc., see course descriptions for details of the structure for each course).

The table below outlines all the milestones and possible progression paths.

**Years 1-4**

| Semester 1 | Core 1: Fundamentals of Graphene and Nanomaterials |
| Semester 1 | Core 2: Introduction to Nanoengineering |
| Semester 1 | Enquiry Based Learning (EBL) Projects |
| Semester 1 | Group Lab Projects |
| Semester 2 | Core 3: Techniques in Nanotechnology |
| Semester 2 | Option Module |
| Semester 2 | Enquiry Based Learning Assignments |
| Semester 2 | Group Lab Projects |

The Management Committee will meet between Semester 1 and Semester 2 to review the progress of students and the success of modules. There will be no formal action taken in consequence but, in cases of concern, CDT Director will meet such students and advise them of their performance to date and the possible outcomes at the end of semester 2.

<p>| Months 7-11 | Normal research project commences as for year 1 of a ‘standard’ 3.5 year PhD. Skills Audit: Development Needs Analysis | PG Diploma (exit route) |
| Months 12-17 | PhD research continues. Weekly meetings with supervisors, periodic meetings with advisor, completion of any generic skills training or technical education identified as necessary in the skills audit. Quarterly progress review meetings with supervisory team (main supervisor and all co-supervisors). | |
| 18 | End of 1st year report and Viva Voce conducted by a panel of examiners. Decision is taken on PhD progression (whether to continue PhD or to exit with MPhil). Poster presentation at the CDT conference. | |
| 19-29 | Normal thesis research as for year 2 of a standard PhD. | |
| 20 | For students exiting with MPhil, Notice of Submission for MPhil | |
| 22 | For students exiting with MPhil, submit Thesis for MPhil Examination | |</p>
<table>
<thead>
<tr>
<th>Period</th>
<th>Description</th>
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<tr>
<td>During 24-33</td>
<td>Bespoke course ‘Innovation and Commercialisation of Research’ delivered by the Manchester Science and Enterprise Centre (MSEC);</td>
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<tr>
<td>30</td>
<td>End of 2nd year PhD assessment: normally a written report. Exact form of assessment at this stage may be somewhat different in different Schools (follows the established procedure in each School of registration)</td>
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<tr>
<td>30-41</td>
<td>Normal thesis research. Weekly meetings with supervisors, periodic meetings with advisor, completion of any generic skills training or technical education identified as necessary in the skills audit. Progress review meeting with the supervisory team in month 36.</td>
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<tr>
<td>During 12-42</td>
<td>Training in preparation of research publications and research presentations; attendance and presentation at national/international conferences in relevant research areas; participation in outreach activities.</td>
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<tr>
<td>42-45</td>
<td>End of year 3 assessment: oral presentation at a CDT conference and a standard assessment at the School of registration, if applicable. In addition, the students produce a thesis plan which is assessed by the supervisory team.</td>
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<tr>
<td>During 12-45</td>
<td>Presentations to international advisory board meeting</td>
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<tr>
<td>43-48</td>
<td>Completion of the research project and writing thesis.</td>
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<tr>
<td>48</td>
<td>Submit Thesis for PhD Examination</td>
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## Assessment Methods

<table>
<thead>
<tr>
<th>Graphene NOWNANO CDT Modules</th>
<th>Method of Assessment</th>
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<tr>
<td><strong>SEMESTER ONE</strong></td>
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### CORE 1: Fundamentals of Graphene and Nanomaterials

- **Part 1:** Key aspects of the biological and medical applications of (nano)materials: 20 minute presentation
- **Part 2:** 2D materials from a solid state physics perspective
  - Worksheet 1
  - Worksheet 2
  - Worksheet 3
  - Worksheet 4
- **Part 3:** Characterisation of nanomaterials
  - Worksheet (Cinzia Casiraghi)
  - Worksheet (Andrew Thomas)

### CORE 2: Introduction to Nanoengineering

- **Part 1:** Microfabrication Techniques
  - 30 minute group presentation
- **Part 2:** Building 3D architectures with 2D materials
  - Worksheet (Suelen Barg)
  - Worksheet (Will Williams/Nigel Hodson)
- **Part 3:** Applications of 2D materials
  - Worksheet 1
  - Worksheet 2

### Lab Work

- **EBL work**
  - Group presentation (30%)
  - 3000-5000 word report (70%)

### SEMESTER TWO

### CORE 3: Techniques in Nanotechnology

- **Device Fabrication**
  - Problem sheet (Artem Mischchenko)
  - Poster presentation (Guillaume De Bo)
- **Nanoparticles, Nanomaterials and Routes to their Preparation**
  - Question sheet
- **Electron Microscopy and Electrical Measurements**
  - Worksheet (Tom Thomson)
  - Worksheet (Tim Burnett)

### Optional Modules

- **Optional Module 1:** Fundamentals of Nanoelectronics
  - Worksheet 1
  - Worksheet 2
  - Worksheet 3
  - Worksheet 4
- **Optional Module 2:** Fundamentals of Molecular Modelling
  - Written Essay (3000 words ca.)

### Lab Work

- **EBL work**
  - Group presentation (30%)
  - 3000-5000 word report (70%)
eProg

Please note University of Manchester based student are added to the eProg system in April of Year 1 when you move to your research phase. eProg is a University-wide system for postgraduate researchers to record and monitor progression throughout their programme and manage skills training activities. The eProg system offers an online platform for academic staff and their PGR students to record and track key milestones throughout the student’s programme, from the point of registration to thesis examination. The system also provides access to an extensive catalogue of skills training activities across the University.

Accessing eProg

eProg can be accessed via My Manchester Portal my.manchester.ac.uk or directly www.eprog.manchester.ac.uk

Components of eProg

eProg is made up of the following components:

- **Personal timelines:** Each student has a personalised bespoke timeline which provides a visual representation of forthcoming key milestones and information that make up your programme of study.
- **Progression:** Each student has their own progression area which provides a detailed list of milestones and skills training activities with the dates or deadlines attached.
- **Online forms:** Students will be required to complete online progression forms which are tied to individual milestones. These forms provide a formal record of meetings or discussions between you, your supervisor and your advisor. It also provides an opportunity for any issues or problems to be raised. All forms and the deadlines by which they must be completed can be found on your eProg progression page. You can access, complete and save information at any time prior to these meetings and we recommend that you do this so that information is available to review before each meeting takes place. At the meeting, your supervisor or advisor will complete the remainder of the form with their comments and feedback. This provides us with a record that you are making satisfactory progress.
- **Skills training:** A skills training area where students can search training events across the University, book onto any courses of interest events and view courses they are registered for or have attended
- **Help and support:** Help and advice on how to use eProg and useful links to online training (in Blackboard)

Student responsibilities

Your responsibilities as a student are:
- to meet with your supervisors and advisor to review progress and to complete the appropriate online forms
- to attend/comlete all mandatory skills training components

Supervisor and advisor responsibilities

The supervisor’s and advisor’s responsibilities are:
- to meet or liaise with their students in a timely manner to discuss student’s progress and to submit the appropriate online progression forms
- to encourage attendance of their students at all required skills training events

Contacts

For queries relating to eProg please contact eprog@manchester.ac.uk.
Transferable Skills Training

CDT Provision

Given the specialist nature of the research, primary technical training will be provided by the supervisor and co-supervisor and senior members of his/her research group. Students will also undertake safety training provided by the relevant schools of study. A bespoke course ‘Innovation and commercialization of research’ will also be offered as part of the programme, as well as training in preparation of research publications and research presentations, media training and careers training.

Generic skills training will be provided via the FSE Graduate Development Programme. This offers an initial induction and short ‘Introduction to Research’ workshop and an academic writing workshop, followed by an online skills audit, during which the students identify any further generic skills training that they require for their PhD.

The Graduate Development Programme offers a range of training and opportunities that students can choose to engage with as and when needed. Built around individual personal development plans and self-reflection, the face-to-face and online training enables students to successfully complete their research degree and maximise future employability.

The Programme is based around seven core skills:

- Research skills and techniques
- Understanding the research environment
- Research management and information literacy
- Professional effectiveness
- Communication skills
- Networking and team working
- Career management and lifelong development

The Programme's aim is to help students gain and enhance those skills that best meet individual, personal and professional needs. This is achieved through personal development planning – a four step cycle including:

- Conducting a skills audit through the online Development Needs Analysis – compare your existing skills with the skills needed to be a successful researcher and identify areas of strength and areas where you could benefit from further development.
- Developing new skills through workshops or other means of development (e.g. seminars, presentations, publications, public engagement, outreach activities, etc).
- Reviewing achievements and reflecting on future needs – this includes periodically revisit your skills audit.

For further details, please visit;
http://www.researchsupport.eps.manchester.ac.uk/postgraduate_home/index.php

University of Lancaster

Postgraduate training takes place at University, Faculty and Departmental levels. A good place to initially find out about what opportunities are available is the Doctoral Academy website in Lancaster.
http://www.lancaster.ac.uk/research/doctoral-academy/ Here students will find information on the centrally provided programmes such as the Thesis in Progress sessions and links to the Faculty research training programmes. There are also links to a variety of resources and tools such as MyPGR that will help students throughout their time at Lancaster. Students should also ask their supervisor or departmental postgraduate tutor for further information on the Research Training Programme opportunities available.
Research Thesis

Thesis Advice

Student’s PhD thesis must be presented in accordance with the regulations of the registering institution;

University of Manchester  
http://documents.manchester.ac.uk/display.aspx?DocID=7420

University of Lancaster  

It is important that students and their supervisor come to agreement on the style and content of the thesis as soon as possible so that a well-defined work programme can be established with this deadline in mind.

Students should be aware that all PhD theses must be submitted within 4 years of registration. If you exceed the 4 year limit you will have to apply to the Board of Postgraduate Studies for an extension - this is unlikely to be granted except for illness or other extenuating circumstances and you could fail to graduate.

The thesis will be read by an external examiner, appointed by the CDT Management Board on the recommendation of the supervisor, and by an internal examiner who will be a member of academic staff, but not your supervisor. The examiners will read your thesis and then give you an oral examination (a viva) before making their recommendation about the award of a PhD.

Plagiarism

Plagiarism is the unreferenced use of other authors’ material in your assignments and thesis. If you reference other people’s work it must be acknowledged clearly.

The Universities regulations state very clearly that plagiarism is a serious academic offence and the consequences of committing such an offence are severe.

All students should read the guidance notes on plagiarism and academic malpractice for their registering institution which are available at:

University of Manchester  

University of Lancaster  
https://gap.lancs.ac.uk/ASQ/Policies/Documents/Plagiarism-Framework.pdf

If you are in any doubt you must seek guidance from your supervisor.
Student Responsibilities

Personal Details

University of Manchester
Students are responsible for updating their personal details in the student system by going to their student portal. If you have problems logging in please contact 0161 275 5000 or email selfservice@manchester.ac.uk

University of Lancaster
Students who need to change any personal details should contact the Postgraduate Student Office on 01524 592143 or email PGSO@lancaster.ac.uk

Attendance

CDT 2017 Cohort teaching dates 2017-18

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<tr>
<th></th>
<th>Date Range</th>
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<tr>
<td>Induction Week</td>
<td>Monday 18th September 2017 – Friday 22nd September 2017</td>
</tr>
<tr>
<td>Semester 1</td>
<td>Monday 25th September 2017 – Friday 12th December 2017</td>
</tr>
<tr>
<td>Semester 2</td>
<td>Monday 8th January 2018 – Thursday 29th March 2018</td>
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It is crucial that you complete all parts of the CDT taught programme and maintain a continuous dialogue with your supervisors when you start PhD research. Any holidays that you need to take should be previously authorised by the CDT office (during the taught period) or your supervisor (during your research).

Attendance is compulsory for ALL parts of the CDT taught programme in order for you to obtain the required number of credits to pass the 1st year. If you are or need to be absent for any reason you must inform the CDT office by email or telephone – preferably in advance. You must complete an absence form within 5 days of your return. Medical certificates (lodged with the CDT Office) will be accepted as a legitimate reason for lack of attendance.

You are also expected (and may be required) to attend School/Department and group seminars and workshops that are relevant to your research interests. You are encouraged to attend other seminars as part of your general scientific education, and attendance at CDT specific events is mandatory throughout the four years of the programme.

A register may be taken in lectures and practical classes. If you consistently miss lectures or practical classes you will be required to explain the reasons to the CDT Director.

Failure to do this, or further absence from classes, will lead to a formal warning from the CDT Management Board. Continued absence will result in referral to the CDT Management Board, in accordance with standard University procedures, and will become a disciplinary matter.
Absence/Illness

If you are unable to attend the CDT due to illness or unforeseen circumstances, it is essential that you contact the CDT administrator on Andrea.Haworth@manchester.ac.uk or 0161-275-1886 as soon as possible. You can do this by phone or email.

If you miss classes through illness, you should provide either:

- a Student Medical Self Certificate (for absences of up to 7 days)
- a doctor’s note (for absences of more than 7 days)

These forms should be returned to the CDT Office.

We have a duty of care for you so we really do need to know about your whereabouts if you aren’t here during the working week.

Further information relating to holiday entitlement and sick leave can be found at: http://documents.manchester.ac.uk/display.aspx?DocID=8162
Student Support and Guidance

Support

University of Manchester - Student Services Centre (SSC)
This is the place students can go with any administrative queries. The main site is on Burlington Street on the way to the library and a smaller satellite centre is located at Sackville Street on the ground floor of the Staff House building. The SSC can sort out questions concerning registration, swicards, tuition fees assessment or payment, Council Tax exemption, and all sorts of documentation such as academic transcripts or student loans, grants and awards. They can also help with queries about examinations, graduation ceremonies, degree certificates and numerous other general enquiries. Enquiries can be made over a student enquiry phone, by email, letter or fax, or alternatively students can make requests and carry out certain tasks themselves using the Student Portal – log on at http://my.manchester.ac.uk/tab/home using their university username and password and click on ‘My Services’. The walk-in service and student phone line are both available five days a week from 10am - 4pm.

Contact Details
The Student Services Centre
Burlington Street Manchester,
M13 9RL

The Student Services Satellite Centre Staff
House
Sackville Street Site
Manchester, M16 1QD

Tel: +44 (0)161 275 5000
Fax: +44 (0)161 275 7860
Email: ssc@manchester.ac.uk

University of Lancaster Postgraduate Studies Office
The Postgraduate Studies Office (PGSO) office is responsible for creating and maintaining the University's central postgraduate student record system (computerised and paper), student registration and enrolment, statistics and management information, academic progress and discipline, tuition fee invoices, the administration of examinations, assessment and awards, and reviews and appeals. It also gives advice to students and academic departments about all the above.

Students with any problems regarding their studies or student status which cannot be resolved through their Tutors or Department should contact the PGSO where advice and help can be given in confidence.

The Postgraduate Studies Office is located within Student Registry on A Floor, University House, Alexandra Square, the opening hours are Monday – Friday 9:30am – 5pm.
**Student Feedback and Representation**

Feedback surveys are circulated in both semesters of year 1.

Students are also encouraged to discuss matters of concern with their supervisors, advisors or with any of the CDT coordinating staff. Comments made by students via course questionnaires or directly through supervisors, advisors or the pastoral care scheme will be considered by the CDT Management Board and CDT Director in consultation with relevant people.

**The role of the Supervisor**

The Universities Code/Policies can only be a guideline whose detailed application depends on circumstances. The most important general requirements are that the supervisor is approachable and accessible, and that when advice or recommendations are given, you feel that they are constructive and fair. In addition to guiding your research, an important part of the supervisor's responsibility is in helping to plan deadlines, for example, in connection with the various reports that you must complete. This implies that frequent and adequate consultation between you and your supervisor takes place. A reasonable guide to this is a minimum contact time of an hour each week once a supervisor has been appointed. Supervisors are expected to make suitable arrangements for supervision in the event of their absence.

Further information on supervision can be obtained at the following;

*University of Manchester*
http://documents.manchester.ac.uk/display.aspx?DocID=615

*University of Lancaster*
https://gap.lancs.ac.uk/ASQ/Policies/Pages/PGRCode.aspx

**The role of the Student**

The Universities Code/Policy requirements for students can be summarised in three words: communication, application and motivation. As far as communication is concerned, even experienced supervisors may not be aware of some particular problems and you should take the initiative to make sure that these are communicated to the supervisor. Application and motivation are largely up to the individual but even here, supervisors can help considerably by providing an appropriate working environment. Approachability and accessibility are, of course, an important ingredient for success in research for both you and your supervisor. You should consult with your supervisor if you need to be away from the university for any period in excess of a couple of days. Illness must also be reported to your supervisor, and you should take particular care that you comply with the regulations of your funding body in the event of protracted absence due to illness or any other reason.

Further information on the role of the student can be obtained at the following;

*University of Manchester*
http://documents.manchester.ac.uk/display.aspx?DocID=615

*University of Lancaster*
http://www.lancs.ac.uk/student/charter/index.htm
Nine top tips for new research students

1. Discuss your expectations with your supervisor and discuss their expectations of you. Being a research student will be a very different experience to being a taught student, or working, and all supervisors work in different ways.

2. Agree with your supervisor the frequency of your formal supervisory progress meetings. Not the everyday chats, but the meetings at which you will discuss your progress, the problems you have faced, and set the objectives to have reached before the next meeting.

3. Agree with your supervisor who will complete the record of your formal supervisory progress meetings, you or them. It is recommended that you do it and provide your supervisor with a copy. This will ensure no misunderstandings have occurred.

4. Agree during your induction a target date for you to go through your MPhil to PhD upgrade (if appropriate) and a target date for the submission of your thesis. If you ever feel like your deadlines are slipping, speak to your supervisor immediately. Timely submission of your thesis is very important.

5. Expect the unexpected. It is very rare that research runs smoothly and produces the exact results expected. Have a flexible approach.

6. Ask questions and ask for support when you need it. Never feel like you are on your own.

7. Keep your publications to hand, especially the Code of Practice for Research Degree Programmes. This will provide you with vital information as you progress.

8. Help us to keep spreading good practice and making improvements wherever possible. Tell us about your experiences, complete questionnaires and take part in focus groups.

9. Enjoy the ride... it’s a little like a roller coaster with highs and lows, but the achievement at the end is well worth the hard work.

Student Appeals and Complaints

The CDT and the Universities take the well-being of their students very seriously. Where difficulties arise, it is important to seek to address these as early as possible. Many difficulties can be resolved at an early stage by talking informally with the individual(s) most concerned with the issue at a local level. Briefly, students should initially raise any complaints with their supervisor. If they cannot be resolved, they must report the complaint to the CDT Manager/Director(s) initially, and, if appropriate, the Faculty. The University’s must ensure that complaints procedures are operational and effective. However, as noted above, it is the responsibility of students to ensure that any problems are raised at the appropriate level and at the earliest opportunity.

Alternatively, students registered at the University of Manchester may seek advice from the Academic Advisory Service (tel: 0161 275 3033; email: cass@manchester.ac.uk) or the Students’ Union Advice Centre (0161 306 4009 or 0161 275 2930; http://manchesterstudentsunion.com/adviseservice). Students registered at the University of Lancaster can also seek advice from the Complaints Coordinator, Gayle Bentley (tel: 01524 592166 email: g.bentley@lancs.ac.uk).
In the event that such difficulties cannot be resolved informally, both Universities have formal procedures for making complaints, whether about the delivery and quality of services received (i.e. non-academic matters), or about the delivery or quality of research supervision or any other matters relating to the programme of study.

**University of Manchester**
Information about the processes and procedures involved can be obtained from: http://documents.manchester.ac.uk/DocuInfo.aspx?DocID=1893

**University of Lancaster**
The complaints procedure contained within the Students’ Charter has been expanded upon and full details can be found on the Student Registry website at: http://www.lancaster.ac.uk/complaints-procedure/

**Academic Appeals**
While it is not possible for you to contest the academic judgment of the examiners and their decisions in relation to your academic status or progression, the universities are committed to safeguarding the interests of all students in relation to the process by which such decisions are reached. Therefore, procedures are in place that may be used by students to appeal against a decision of a board of examiners, or a progress committee or a graduate committee, or equivalent committee in so far as the decision relates to the individual student’s academic status or progress.

General regulations and procedures for Academic Appeals can be found at;

**University of Manchester**

**University of Lancaster**
https://gap.lancs.ac.uk/ASQ/QAE/MARP/Pages/default.aspx

**Research Ethics**
If a student plans to do research involving human participants, whether directly or indirectly - e.g. interviews, questionnaires, focus groups, observations, accessing personal data about individuals, any human biological materials - then the research must be independently ethically reviewed and approved BEFORE the student begins data gathering.

General policy and procedures for ethical approval can be found at;

**University of Manchester**
https://www.manchester.ac.uk/research/environment/governance/ethics/

**University of Lancaster**
https://gap.lancs.ac.uk/ASQ/QAE/MARP/Pages/default.aspx
Administrative Matters

Programme Management

The Management of the programme is divided into three Committees/Boards/Groups who have varying levels of jurisdiction. These are:

- **Management Board** - The CDT Management Board has responsibility for overseeing the activities of Graphene NOWNANO and is responsible for planning the Graphene NOWNANO CDT research and training strategy. Members of the Management Board include the Director, Co-Director, Chair of the Management Board and representatives of all Schools/Departments at Manchester and Lancaster comprising the CDT, as well as co-opted members who shall be occasionally invited by the Board (student representatives for each cohort, elected by all Graphene NOWNANO students, a representative of EPSRC).

- **External Examiner and Examination Board** – The CDT taught programme is developed and overseen by the CDT Management Board who are responsible for the general conduct of the assessment of all the modules. They initially consider and determine the marks/grades for all forms of assessment for each student. The final marks are considered and confirmed by the External Examiner at the annual Exam Board. The External Examiner also provides a formal appraisal of the CDT taught programme.

- **International Advisory Board** - The CDT International Advisory Board are responsible for formally reviewing CDT progress annually to ensure that Graphene NOWNANO CDT remains internationally competitive and provides excellent postgraduate level training to its students. Members of the International Advisory Board include internationally leading researchers (independent advisors), industry representatives and representatives of industrial partners and EPSRC.

Position within the University

The CDT has two coordinating hubs at the University of Manchester and the University of Lancaster. In Year 1 all students will be registered in the Faculty of Science and Engineering at the University of Manchester, and Semester 1 will be undertaken almost exclusively at the University of Manchester. Local health and safety and security guidelines will be applicable when you are present studying at either hub. After successful completion of the taught part of the programme (months 1 to 6 in year 1), registration of each student will be changed to the School/Department of their main supervisor. Accordingly, your academic progression will be subject to the guidelines of your primary institution of registration. Should you elect to change your institution of registration in April of Year 1, the appropriate local and University guidelines will apply – and you should familiarise yourself with these at the appropriate point.

Finance

For students who are awarded full EPSRC studentships, the CDT has responsibility for administering all the finances for the full four years of the course. This includes paying your stipend and fees. Stipend payments are paid monthly starting on the 1st October for those students registered at Manchester and quarterly for those students registered at Lancaster.

For one-off travel claims (e.g. to attend a conference or a research school) you will need to make a standard expenses claim. Your supervisor will help you to make your claim. Attendance of research schools organized by the CDT will be authorized by the CDT Director. All expense claim forms must be accompanied by original receipts for all items and handed into the CDT office for processing (all claims must be signed by the CDT Director).
Code of Practice / Students’ Charter

University of Manchester
The Code of Practice sets out the University of Manchester’s framework in relation to the management and coordination of postgraduate research degrees both full-time and part-time. The University is committed to ensuring the quality of every student’s research experience and as such the code of practice defines minimum requirements to safeguard high standards of postgraduate research degree activity.

The Code of Practice should be read in conjunction with the University’s Ordinances and Regulations and faculty and/or school handbooks as appropriate.

http://www.staffnet.manchester.ac.uk/services/rbess/graduate/code/

University of Lancaster
The purpose of the Students’ Charter is to provide a framework for the mutual rights and responsibilities of students and staff. It aims to cover all aspects of University which you, as a student, are likely to come into contact with, and gives you a yardstick by which to judge them. Codes of practice for specific sections and departments of the University supplement the information contained in the Students’ Charter and give greater details of the University’s commitments and your responsibilities.

The Students’ Charter is not a tablet of stone and relies on the goodwill of all parties involved, but it does aim to set minimum standards for the delivery of all services. You can find the Students’ Charter on the following web-site: http://www.lancs.ac.uk/student/charter/index.htm
Additional Information

Accommodation

The University requires you to reside within a commutable distance from Manchester during your time as a registered student, unless you are on approved fieldwork / a formal placement or are on a period of Submission pending. This is to ensure that you are able to meet attendance expectations and participate in wider research activities within your discipline area and/or school. Should you be unable to do this at any point during your programme, a formal case must be made to the Faculty office, together with the full support of your supervisor(s). The University reserves the right to reject such a request where it is considered that your residency could have a detrimental impact on the progression and engagement of your studies.

University of Manchester
The Accommodation Office
University Place
Oxford Road
Manchester M13
9PL
Tel: +44 (0)161 275 2888
Fax: +44 (0)161 275 3213
Website: www.accommodation.manchester.ac.uk
Email: accommodation@manchester.ac.uk

University of Lancaster
The Graduate College Residence Office
Lancaster
LA2 0PF
Tel: +44 (0)1524 593449
Fax: +44 (0)1524 594621
Website: http://www.lancs.ac.uk/sbs/accommodation/postgraduate.html
Email: gcro@lancaster.ac.uk

Resources

Student Services Centre

University of Manchester
The Student Services Centre (number 57 on the campus map)
Burlington Street
Oxford Road
Manchester M13
9PL

The Student Services Centre (number 13 on the campus map)
Staff House
Sackville Street
Manchester M60
1QD
Tel: +44 (0)161 275 5000
Email: ssc@manchester.ac.uk

http://www.studentnet.manchester.ac.uk/crucial-guide/
University of Lancaster
The Postgraduate Studies Office Student
Registry
A Floor, University House
Alexandra Square Lancaster
Tel: +44 (0)1524 592143
Email: PGSO@lancaster.ac.uk

International Office

University of Manchester
The International Advice Team, located in the Student Services Centre, offers help and advice to all international
students studying at The University of Manchester on issues such as accommodation issues, council tax, immigration and work permits.

Further information can be obtained at: http://www.manchester.ac.uk/study/international/why-manchester/student-support/

Tel: +44 (0)161 275 5000
Email: iat@manchester.ac.uk

University of Lancaster
The International Student Advisory Service is part of Student Services and provides a wide range of services
and support to the international student community at Lancaster. These services include immigration advice,
induction and orientation, meet and greet Scheme and visa extension scheme.

Further information can be found at: http://www.lancs.ac.uk/studentservices/international/

Libraries

University of Manchester

There are many libraries on campus and in the city, all of which are available to you.

The John Rylands University Library

With more than 4 million printed books and manuscripts, over 41,000 electronic journals and 500,000
electronic books, as well as several hundred databases, the John Rylands University Library (JRUL) is one of
the best-resourced academic libraries in the country. See http://www.library.manchester.ac.uk/

The Main Library holds the principal collections for teaching and research in the humanities, education, law,
medicine, science and the social sciences and is located on Burlington Street, off Oxford Road.

Satellite libraries

In addition to the main sites, there are a number of satellite specialist libraries located across the campus:
• Art and Archaeology Site Library
• Braddick Library
• Eddie Davies Library
• John Rylands Library Deansgate
• Joule Library
Computing Facilities and Courses

University of Lancaster
The Library Lancaster
University Bailrigg
Lancaster LA1
4YH
Tel: +44 (0) 1524 592516
Fax: +44 (0) 1524 63806
http://www.lancaster.ac.uk/library/

Email

a) All email messages initiated by staff in the CDT will be sent only to your University email address. All messages sent to you via email distribution lists will include only your University email address.

b) You are required to check your University email account on a regular basis. If you wish to set up auto-forwarding arrangements to a private email account you may do so, but it is your responsibility to ensure, one way or another, that you read with minimal delay all messages sent to your University email address. Failure to read messages delivered to your University e-mail account will not be accepted as a legitimate excuse if you fail to act on information that has been sent to you.
Careers Service

University of Manchester
Your Careers Service is part of the Manchester Leadership Programme, Careers & Employability Division at the University of Manchester. They work closely with graduate recruiters across the globe to develop and manage numerous services, projects, courses and events, all dedicated to equipping you with key skills and knowledge, to help you decide upon, apply for and succeed within your future career.

For information on the Careers Service provisions visit www.manchester.ac.uk/careers

The Careers Service
3rd Floor, Crawford House Crawford House
Booth Street East
Manchester
M13 9QS
Tel: +44 (0)161 275 2828
Email: careers@manchester.ac.uk

University of Lancaster
The Careers Service is part of Student Bases Services at the University of Lancaster. Whether you are thinking about going into work or thinking about further study, make the Careers your first port of call. They have can advise you on career development, help you find jobs, placements and internships as well as offer workshops and events that aim to enhance your skills.

Careers (The Base)
University House
Lancaster University LA1 4YW
Tel: +44 (0) 1524 592767
Email: careers@lancaster.ac.uk

Student Associations

University of Manchester
Students' Union Advice Centre- South Campus
University of Manchester Students' Union: http://manchesterstudentsunion.com/
Oxford Road Manchester
M13 9PR Tel: 0161 275 2930
Fax: 0161 275 2936

University of Lancaster
Lancaster University Students' Union
www.lusu.co.uk
Tel: 01524 593765
Fax: 01527 594029
Email: lusuinfodesk@lancaster.ac.uk
Counseling Service

Students’ well-being is crucial to their overall academic success and enjoyment of university life. Students will have access to professional services where they can get advice and support with issues that might affect their mood and health.

In your school
Each student is allocated an Academic Advisor (sometimes called a Personal Tutor) who will be an academic member of staff based within the discipline area in which you’re studying, and to whom any problems, either personal or academic, can initially be referred.

Academic Advisors will offer advice, support and signposting, as well as monitoring attendance and work in order to identify any problems. If you don’t know who your academic adviser is, ask at your School office.

Many Schools now also offer a Student Support Officer who offers advice and signposting on a number of pastoral issues that might be affecting your work. Again, ask in your School Office if there is someone available to you.

University of Manchester
University’s Counselling Service offers an innovative self-help programme called Being Well, which will help you develop skills and strategies that can enhance your sense of well-being. See http://www.manchester.ac.uk/counselling/

University of Manchester Counselling Service 5th
Floor, Crawford House
Precinct Centre Booth
Street East
Manchester
M13 9QS
Tel: +44 (0) 161 275 2864
Fax: 0161 275 2281
Email: counsel.service@manchester.ac.uk

University of Lancaster
The Student Services Counselling Service is available here for students to discuss any problems which may arise, privately and confidentially with the University Counsellors. They offer one-to-one and group counselling and also run themed groups. The service is free to all students and staff, and is part of Student Based Services.

Counselling Service and Mental Health Service c/o
The Base
A Floor University House
Lancaster University
Lancaster
LA1 4YW
Email: counselling@lancaster.ac.uk
Telephone: +44 (0) 1524 5-92690
Childcare

University of Manchester
There are two nurseries associated with The University of Manchester:

Dryden Street Nursery
Dryden Street Manchester
M13 9SY
Tel: 0161 272 7121

Dryden Street Nursery is a day nursery operated directly by The University of Manchester and The Manchester Metropolitan University for staff and students of both institutions.

Echoes Day Nursery
Echo Street, Off Granby Row
Manchester
M60 1QD
Tel: 0161 306 4979

Echoes Day Nursery is a day nursery open to registered students and staff of The University of Manchester. Both nurseries provide care for children from six months to five years and are staffed with trained and experienced personnel in accordance with the local authority’s requirements. There are often long waiting lists for places at both nurseries, especially for children under two. Try to apply as early as possible.

University of Lancaster
The University has a Pre-School Centre available to students and staff. For information, please see: http://www.lancaster-preschoolcentre.co.uk/ or telephone 01524 594464.

There are a range of schemes available to assist parents with childcare costs. Some of these are specific to students, such as the LEA childcare grant. Others apply regardless of student status, such as tax credits. Some help is restricted to UK nationals and may not be available to international students. However some initiatives, such as the Nursery Education Grant, are open to all parents of children of certain ages.

Medical Care

Being in good health is extremely important to being successful in your studies. Unfortunately, a student lifestyle is not always conducive to perfect health and so we advise that all students should register with a GP close to their accommodation as soon as they get to Manchester or Sheffield.

If you haven’t been able to find a local GP then you check the NHS website on http://www.nhs.uk(servicedirectories/Pages/serviceSearch.aspx) which will give you details of your nearest GPs who are still taking on new patients. You can also find information from the same site on the nearest hospital, dentist and chemist.

University of Manchester
The Student Occupational Health Service also offers advice on issues relating to university life, work and general medical advice at: http://www.studentnet.manchester.ac.uk/occupational-health/ Medical staff based there can assist with emergency cases of sudden illness on campus, vaccinations, medical examinations, health promotion and general nursing procedures. If you are suddenly taken ill on university premises, all buildings will have a first- aider who can assist you.
If you have a dental emergency and cannot make an appointment with your regular dentist, severe cases can be dealt with at the University’s Dental Hospital, which is open to the general public.

**University of Lancaster**
The Bailrigg Health Centre provides a service for students and staff registered with the doctors’ practice on campus who may be seen either at Bailrigg Health Centre or at the central surgery (38 King Street, Lancaster tel. 01524 541651). Students living on campus, in Lancaster or in Morecambe may register. If you live further away, please ask at reception for details of the practice boundaries.

Appointments may be made with the Receptionist who is available between 8:00am and 6:00pm Monday to Friday. If you are too ill to attend the surgeries, contact should be made with the King Street Surgery (01524 541651) and a visit will be arranged.

A full range of services is provided via the Practice and there is access to a Community Psychiatric Nurse service. Visit: [http://www.lancaster.ac.uk/about-us/theuniversity/health-services/](http://www.lancaster.ac.uk/about-us/theuniversity/health-services/) for more information.

**Campus Maps**
Maps and directions to all University campuses can be found here:

University of Manchester: [http://www.manchester.ac.uk/discover/maps/](http://www.manchester.ac.uk/discover/maps/)