The daily routine

- All meals are included:
  - Breakfast is served each day from 7.30am in *Haldane's Eatery*.
  - Lunch is served each day from 12.30pm in the Stirling Court Hotel, with the exception of Sunday when a packed lunch is provided.
  - Dinner is served each day at 7pm in the Stirling Court Hotel.
- Lectures and tutorials will be in *the Monument Roo*m in the Stirling Court Hotel.
- The welcome reception and poster sessions will be in the Stirling Court Hotel Conservatory.

Schedule of lectures, tutorials and seminars

<table>
<tr><th></th><th>9am</th><th>10am</th><th>11am</th><th>12pm</th><th>1pm</th><th>2pm</th><th>3pm</th><th>4pm</th><th>5pm</th><th>6pm</th><th>7pm</th><th>8pm</th></tr>
<tr><td>Mon 14th</td><td colspan="6"></td><td colspan="4">Arrival</td><td rowspan="11">Dinner (7:00-8:00)</td><td>Welcome</td></tr>
<tr><td>Tue 15th</td><td colspan="2">SCQ</td><td rowspan="5">Break (11:00-11:30)</td><td>STM</td><td rowspan="5">Lunch (12:30-1:30)</td><td>ELS</td><td colspan="2" rowspan="4">Free Time (3:00-5:00)</td><td colspan="2">T-SCQ</td><td>S-1</td></tr>
<tr><td>Wed 16th</td><td colspan="2">STM</td><td>ELS</td><td>SCQ</td><td colspan="2">T-STM</td><td>Poster 1</td></tr>
<tr><td>Thu 17th</td><td colspan="2">ELS</td><td>SCQ</td><td>STM</td><td colspan="2">T-ELS</td><td>Poster 2</td></tr>
<tr><td>Fri 18th</td><td colspan="2">STM</td><td>SCQ</td><td>ELS</td><td colspan="2">T-mix</td><td>S-2</td></tr>
<tr><td>Sat 19th</td><td colspan="2">CQF</td><td>SCQ</td><td colspan="5">Free Time</td><td></td></tr>
<tr><td>Sun 20th</td><td colspan="10">Free Day – pick up packed lunch at breakfast</td><td></td></tr>
<tr><td>Mon 21st</td><td colspan="2">QIM</td><td rowspan="5">Break (11:00-11:30)</td><td>DFT</td><td rowspan="5">Lunch (12:30-1:30)</td><td>TOP</td><td colspan="2" rowspan="4">Free Time (3:00-5:00)</td><td colspan="2">T-QIM+CQF</td><td>S-3</td></tr>
<tr><td>Tue 22nd</td><td colspan="2">DFT</td><td>DFT</td><td>MES</td><td colspan="2">T-MES+TOP</td><td>S-4</td></tr>
<tr><td>Wed 23rd</td><td colspan="2">TOP</td><td>QIM</td><td>CQF</td><td colspan="2">T-mix</td><td>S-5</td></tr>
<tr><td>Thu 24th</td><td colspan="2">CQF</td><td>MES</td><td>QIM</td><td colspan="2">T-mix</td><td>S-6</td></tr>
<tr><td>Fri 25th</td><td colspan="2">MES</td><td>TOP</td><td colspan="7">Departure</td></tr>
</table>

Key to lectures and tutorials

Lecture	Tutorial	Topic
CQF	T-CQF	Correlated Quantum Fluids
ELS	T-ELS	Electrons in Solids
SCQ	T-SCQ	Strongly Correlated Systems
STM	T-STM	Statistical Mechanics
DFT	T-DFT	Density Functional Theory
QIM	T-QIM	Quantum Information for Quantum Matter
MES	T-MES	Mesoscopic Physics
TOP	T-TOP	Topological Phases of Matter

We consider the courses in the first week to be core material, and cover material that one would expect any aspiring theoretical condensed matter physicist to be aware of, even if it is not your specialized topic. The courses in the second week are more specialized, applying the core material from the first week to different subfields of condensed matter theoretical physics. This gives you a breadth of knowledge that you often don't appreciate working on a PhD thesis, as well as illustrating that the same concepts appear again and again in seemingly completely different areas.

While lectures guide you through a subject, you don't really understand anything until you've tried to do questions on it yourself. In the tutorials, the lecturers and tutors will help you with this, as well as discussing with you any topic of physics you wish. While most of the tutorial sessions have been given a topic as a guide, please feel free to work on whichever question sheets interest you the most. Ultimately, there are far more problems than you will possibly have time to answer in two weeks!

Finally, if there is a topic you are interested in that isn't covered, then ask around – if one of the staff knows about this topic and is willing, and enough students are interested, then we can schedule extra optional lectures on rainy days!

Poster Sessions

The evening sessions marked Poster 1 and Poster 2 on the schedule are poster sessions (you probably could have guessed this). As there are too many posters to see in one evening, you will be randomly divided into two groups. At the beginning of the poster session, you will be asked to make a 1-minute introduction to your poster before we go to see the posters and have some drinks. There will be a prize for the best poster.

Key to Seminars

In the evenings when there are no poster sessions, we have research seminars, indicated by S-n (n=1-6) on the schedule.

S-1	Frank Schindler	Crystalline Topological Insulators with and without lattice defects
S-2	Aidan Brown	The Physics of Viruses
S-3	Sarah Croke	An Introduction to Quantum Computing: Algorithms, Simulation, and Quantum Advantage
S-4	Gareth Conduit	Artificial intelligence – a tool for the modern-day blacksmith
S-5	Panel Discussion	The academic journey
S-6	Aitor Garcia-Ruiz	Quantum Oscillations: Butterflies on a superlattice

Core Lecture Courses

CQF: Cold Matter and Quantum Fluids

Course and lecture notes written by Derek Lee (Imperial)
Lectures presented by members of the cast

Quantum fluids are those many-particle systems in whose behaviour the effects of both the quantum mechanics and quantum statistics are important, which occurs at cold temperatures. The most important two examples are superfluids, such as liquid Helium, and superconductors. This lecture course will begin with the phenomenon of Bose condensation in an ideal Bose gas with interactions; explore why this is not a true superfluid, and go on to look at the role of interactions. It then proceeds to explore what is different when the particles are charged, and finally look at the BCS theory of superconductivity where one begins with fermions rather than bosons.

ELS: Electrons in Solids

Niels Walet (Manchester)

A quantitative understanding of bonding in condensed matter systems demands a solution of the many electron problem. This course will show how the many electron problem can be mapped onto single electron problems in an approximate way (Hartree and Hartree Fock approximations) and a formally exact way (density functional theory and the Kohn Sham equations). Further, some of the methodology used to solve the Kohn Sham equations in complex systems will be described. In the last part of the lectures, some examples will be analysed, and we will critically evaluate the strength and weaknesses of DFT and other ab-initio electronic structure methods.

Niels is a professor of theoretical physics at the University of Manchester. His research interests are in the theory of condensed matter and nuclear physics, combining computational and theoretical approaches, using many-body and ab initio techniques. He has a special interest in twistronics and higher-order topological materials. Outside physics, he works as associate Dean for Teaching and Learning in the Faculty of Science and Engineering.

SCQ: Strongly Correlated Quantum Systems

Chris Hooley (St Andrews)

This course deals mainly with the influence of interactions on the electrons in materials. We begin with a review of second quantisation and the Fermi gas theory of metals, and then progress to Landau's Fermi liquid theory and the notion of quasiparticles. The effect of impurities on the Fermi liquid (including the Kondo effect) is discussed, and we then move on to consider how the Fermi liquid gives way to other phases as the interactions are increased, concentrating on the Stoner instability and the Mott insulator. We analyse the magnetism in the Mott insulating phase, developing the concept of spin waves. Finally, we make a survey of some experimental data on strongly correlated crystalline solids, giving basic interpretations in terms of the concepts developed in the course.

Chris is a reader at the University of St Andrews. He works on various topics in the theory of strong correlations, including non-Fermi-liquids, highly frustrated magnets, non-equilibrium atomic fluids, and vortex-mediated phase transitions.

STM: Statistical Mechanics

Richard Blythe (University of Edinburgh)

Statistical Mechanics aims to provide a macroscopic description of a physical system starting from knowledge of its microscopic properties. The methodology and techniques are widely used throughout condensed matter physics and are also today being applied to understand the dynamics of model ecologies, economies and societies. In these lectures, we will revisit the equilibrium properties of matter - such as phase transitions and universality - from the perspective of dynamics (as opposed to statics, as is typically done in undergraduate courses). Then we will examine successively further-from-equilibrium systems, ending with a discussion of fluctuations in driven systems, a subject currently generating considerable excitement in this field.

Richard is a Professor of Complex Systems at the University of Edinburgh. Since his PhD days, he has been researching models and theories for nonequilibrium dynamical systems. Applications of these models include transport in biological systems, traffic flow, population dynamics and language change.

Applications Lecture Courses

DFT: Density Functional Theory

Mohammad Saeed Bahramy (University of Manchester)

This course will give you a practical guide to density functional theory (DFT), including running a series of simulations to model and study quantum phase transition in a crystalline system. Upon completing this course, you should be able to set up a DFT calculation, interpret the output results and post-process them using complementary techniques such as Wannier interpolation.

Saeed is a lecturer in theoretical physics at the University of Manchester. His research is focused on first-principles modelling of topological quantum phase transition, superconductivity and quasiparticle dynamics of strongly correlated electrons in low-dimensional crystalline systems.

MES: Mesoscopic Physics

Edward McCann (University of Lancaster)

Mesoscopic physics is the name given to electronic behaviour in solid state nanostructures that are so small that their size is similar to relevant characteristic length scales. Examples of such length scales include the elastic mean free path (which governs the scale for ballistic transport), the phase coherence length (quantum interference effects), and the electronic wavelength (quantum confinement). The aim of this course is to describe key experimental transport phenomena including weak localisation, universal conductance fluctuations, Aharonov-Bohm oscillations, and conductance quantisation whilst giving an overview of theoretical methods such as the tight binding model, the Landauer-Büttiker formulism, scattering theory, and scaling theory.

Ed works in the condensed matter theory group at Lancaster University. Recently, his research has been focussed on the properties of chiral electrons in graphene and graphene multilayers, looking at their transport and spectroscopic properties.

QIM: Quantum Information for Quantum Matter

Zlatko Papic (University of Leeds)

This lecture series will introduce the use of quantum information techniques for the study of correlated problems in quantum matter. First, the general notion of quantum information and entanglement will be introduced, alongside the notions of matrix product states and tensor networks. The lectures will then go on to give examples of these in topical problems such as dynamics, thermalisation, and many-body localisation.

Zlatko is an Associate Professor in Theoretical Physics at University of Leeds. He obtained his PhD at Université Paris Sud in 2010. He was a postdoctoral researcher at Princeton University (2010-2013), and a joint postdoctoral fellow between Perimeter Institute and Institute for Quantum Computing in Waterloo (2013-2015). His research spans condensed matter theory and quantum information, focusing on topology and dynamics in quantum many-body systems, such as topological phases of matter, the fractional quantum Hall effect, and many-body localisation.

TOP: Topological phases

Sam Carr (University of Kent)

The well-known Landau theory of phase transitions classifies phases of matter according to broken symmetries and local order parameters, such as solids that break translational symmetry, or magnets that break magnetic rotation symmetry. It has been long known that there are phases of matter that defy this classification — the quantum Hall state being the most obvious (but by no means only) example. With the discovery of topological insulators about 10 years ago, interest in this field has exploded, and we now know of many distinct phases of matter with no local order parameter, but instead characterised by a topological invariant. This short lecture course will focus mostly on non-interacting band theory, and introduce topological invariants, boundary states, and the bulk-boundary correspondence necessary to understand the modern topic of topological insulators. Other manifestations of topology in modern condensed matter physics will also be exposed, although not discussed in detail.

Sam works on the theory of strongly correlated systems, specialising in low-dimensional systems both in and out of equilibrium. He has worked in groups in the US, Italy and Germany, and since 2013 has been a lecturer at the University of Kent in Canterbury where he is a founding member of the quantum materials group.

Seminars

1. Crystalline Topological Insulators with and without lattice defects

Frank Schindler, Imperial College London

Quantum materials exhibit exotic states of matter, such as superconductivity or topological phases. These promise to have manifold applications in microelectronics or quantum computing. The simplest “nontrivial" quantum materials are topological band insulators. I will start out my talk by explaining how they can be classified in terms of crystalline inversion symmetry. An exciting example that I'll briefly mention are higher-order topological insulators which host lossless conduction channels on their edges. I will then derive a simple framework for identifying such phases by their response to lattice defects. My talk will be a pedagogical invitation to the field rather than a comprehensive technical review.

Frank recently started as a lecturer in condensed matter theory at Imperial College London, after completing a postdoc in Princeton and a PhD at the University of Zurich. He is mostly interested in topological band theory and its generalisation to interacting, nonlinear, and non-equilibrium condensed matter systems.

2. The Physics of Viruses

Aidan Brown (University of Edinburgh)

Viruses are extremely diverse organisms: their volume and genome length range over four orders of magnitude, they infect every type of organism on Earth, and they may have evolved independently multiple times. Nevertheless, their structure and behaviour appear to be governed by a few simple rules that arise from the tight physical constraints that they are under. I will describe these constraints and work through the implications for their morphology and for their mechanisms of assembly and disassembly.

Aidan is a Lecturer and Chancellors Fellow at the University of Edinburgh, working in the Institute for Condensed Matter and Complex systems.

3. An Introduction to Quantum Computing: Algorithms, Simulation, and Quantum Advantage

Sarah Croke (University of Glasgow)

Quantum computing has been been an active field of research for over 30 years, and has generated some excitement in popular media as well as in the scientific community. The scientific and engineering effort culminated in the last few years in claimed demonstrations of "quantum computational advantage" - that is, experimental evidence of a quantum device performing a calculation that would not be feasible on a classical computer, even the world's most powerful supercomputer. In this talk I will give a flavour of why we think quantum computers will be more powerful than classical computers for some tasks, and discuss some of these first claimed demonstrations of quantum advantage. Time permitting, I'll talk about some of my own research interests in quantum algorithms, making an unlikely connection between quantum computation and gravitational waves.

Sarah is a senior lecturer in the quantum theory group at the University of Glasgow. Her research interests are in quantum information and quantum foundations.

4. Artificial intelligence – a tool for the modern-day blacksmith

Gareth Conduit (University of Cambridge)

We present a machine learning tool, Alchemite, that exploits all available information: experimental data, physical laws, and computer simulations. By combining multiple sources of information, the approach can circumvent sparse experimental data to predict and design materials.

Firstly, we design and experimentally verify a nickel superalloy for direct laser deposition. From a training set of just eight results the machine learning tool combines complementary material properties to circumvent missing data. Secondly, we highlight other uses of the machine learning approach across materials, chemicals, pharmaceuticals, and beyond.

In the final part of the talk we follow the journey from the development of the algorithm at a university through to its commercial exploitation by scale-up Intellegens.

Gareth is a Royal Society University Research Fellow in the theory of condensed matter group at the University of Cambridge, and co-founder & Chief Scientific Officer at scale-up Intellegens.

5. Panel Discussion on The Academic Journey

Members of the cast

Congratulations to all of you who have successfully navigated the first year of your PhD in physics and are now fully immersed in your research projects. As you've invested considerable time in mastering the necessary physics for your work, including attending this school, you may be wondering about the next steps after completing your PhD. What lies ahead for those who wish to pursue research through postdoctoral positions and, perhaps, secure faculty positions in academia? Join us for an engaging panel discussion where our staff will share their own experiences as former PhD students and their subsequent journey in academia. This interactive session offers you the chance to ask any questions you may have and witness the delightful exchange of perspectives among different academics!

The abstract for this event was written by ChatGPT, however none of the contributors to the panel are cyborgs (to the best of my knowledge).

6. Quantum Oscillations: Butterflies on a superlattice

Aitor Garcia-Ruiz (University of Manchester)

Quantum oscillations refers to the periodic behaviour observed in measurements such as resistivity or magnetisation in many materials under the effects of an external magnetic field. Because the period of the oscillations can be related to the area of the Fermi surface perpendicular to the magnetic field, this technique has been widely employed to map Fermi surfaces. In this talk, I will review the textbook theory of quantum oscillations, and develop this for the resistivity of a two-dimensional system: twisted double-bilayer graphene. Here, in addition to the classic quantum oscillatory behaviour of the resistivity with the magnetic fields at very low energies, there is an additional mechanism for quantum oscillations caused by the interference effect of electrons travelling through a Kagome network of trajectories in reciprocal space.

Aitor is a postdoc at the Graphene Centre at the University of Manchester, and a tutor at this school.

Tutor

Aitor Garcia-Ruiz Fuentes

Aitor completed his PhD at the University of Bath under the supervision of M. Mucha-Kruczynski working on optical properties of graphene based systems. After completing this in 2019, he joined the theory group at the National Graphene Institute led by V. Fal'ko where he works as a research associate. He currently works on strongly correlated phases in twistronic graphene. Outside physics, he also holds a piano performance degree and plays competitive chess.

Physics by the Lake / Loch

Physics by the Lake is a national summer school for PhD students in condensed matter theory in the UK. It was held for the first time in 1997, this year will be the 23rd occurrence of the school. Many of the lecturers were themselves students at the school in the past – ask them about it!

The name `Physics by the Lake' comes from the original location of the school, in Ambleside beside Lake Windermere, in which it ran for more than 10 years (aside from one year in Wales – but that is another story entirely). The original location where we held the school however was mothballed in 2010, and the school had to move. After a few itinerant years, the school settled for a while in Cumberland Lodge, which is close to Virgina water - it was quite a challenge to find a location that filled all the usual academic requirements as well as being near a lake! Since 2019 however, we have been at our current location at the University of Stirling, by Airthrey Loch. We think this location works very well for the school – feel free to give us your views though!

Originally, this school was funded by EPSRC. However a number of years back, EPSRC withdrew direct support for the school as their training money is routed through universities and CDTs. We do have support from a number of sponsors however who we would like to thank– CECAM, CCP magnetism, CCP5 and CCP9, and in particular, a number of groups from the Institute of Physics, listed in full on the next page. Finally, we need to thank the Higgs centre for theoretical physics at the University of Edinburgh for underwriting the school, and in particular Thelma Dugdale and Angela Muir for a huge amount of administrative support.

Sam Carr
Richard Blythe

Institute of Physics Groups sponsoring the school this year:

The **IOP Computational Physics Group** is a member-driven community that utilizes computers for physics research and problem-solving. It covers a wide range of areas, including quantum calculations, astrophysics, and industrial applications. With over 2,500 members from various sectors, the group stays informed about developments in microelectronics, computer science, and numerical analysis that impact computational physics.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/computational-physics-group

The **IOP Low Temperature Group** was founded in 1945 and specializes in physics research and industries related to low-temperature physics. Our diverse interests encompass topics like superfluidity, superconductivity, and techniques for producing and maintaining low temperatures, including milli-kelvin and micro-kelvin techniques. We also study the properties of solids and fluids at low temperatures, and focus on systems such as cryopumps, infrared detectors, superconducting magnets, and devices based on the Josephson effect.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/low-temperature-group

The **IOP Magnetism group**, a member-driven forum, actively promotes and supports physics research in magnetism, spintronics, and magnetic materials. Our focus ranges from fundamental theoretical and experimental work to practical applications. We offer support to early career physicists, established researchers in academia, and industrial enterprises of all sizes.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/magnetism-group

The **IOP Semiconductor Physics Group** has a large membership that comes from a broad range of backgrounds that often extend beyond physics to electronics, chemistry, and materials science. The community we represent broadens understanding of solids, at the quantum mechanical level, when electrons are confined in potentials with reduced dimensionality at nano-scale, and the carrier movement is restricted to one or two dimensions. Our group provides an umbrella for device technologists to interact with scientists and to explore fundamental aspects of the field. A forum where ideas can be exchanged is particularly important at this time.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/semiconductor-physics-group

The **IOP Superconductivity Group** is a member-driven group with a keen interest in superconducting materials, from theoretical research to practical applications like magnetic resonance imaging. Established in 1997, we provide a forum for individuals interested in superconductivity and organize scientific meetings, ranging from student-focused gatherings to national conferences.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/superconductivity-group

The **IOP Theory of Condensed Matter Group** is a community-driven group focused on fostering collaboration and a sense of camaraderie among physicists engaged in. Our primary objectives revolve around promoting the exchange of ideas and facilitating collaboration between different UK research groups. We have a special interest in supporting and nurturing the UK condensed matter theory research community, which includes physicists specializing in electronic structure, statistical mechanics of solids and liquids, and correlated systems and many-body theory.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/theory-condensed-matter-group

The **IOP Thin Films and Surfaces Group** (TFSG) aims to provide a forum for members to stimulate interest and advance the science and technology of thin films and materials surfaces and interfaces. Our research field is vibrant and is closely linked to applications such as energy storage, catalysis, optoelectronics, and the semiconductor industry. Established in 1969, the group organises conferences and workshops at which scientists from both academic and industrial environments come together to collaborate.
For further information about the group and how to become a member, please go to our IOP website: https://www.iop.org/physics-community/special-interest-groups/thin-films-surfaces-group