1 Electron Correlations in Metals and Superconductors

Project description

The undergraduate curriculum in quantum mechanics consists mostly of studies of particles interacting with external potentials. I have in mind a number of projects, generally involving particles (electrons) interacting with one another; this leads to novel states of matter, like superconductivity, magnetism, etc. There are various theoretical approaches, spanning the simplest (quantum mechanics) to the more sophisticated (several many-body formalisms), and projects utilizing either of those will be available. A simple example is a periodic potential with spin-orbit coupling. The presence of spin-orbit coupling in certain lattice types results in exotic phenomena like topological insulators and topological superconductivity. This project will equip a student to understand some of these phenomena in a simple way. Another example is the phenomenon of Anderson Localization due to the presence of defects.

Contact

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2 Superconducting Tc as a function of coupling strength and electron density

Project description

A relatively accurate description of superconductivity exists — the so-called BCS-Eliashberg framework. While some limits exist where analytical work can be performed, most of the relevant parameter space requires numerical calculations. This project will proceed first with the simpler BCS theory; we will compute superconducting Tc as a function of electron density, with particular attention focused on the band edges. Work will be done in both two and three dimensions, since a number of known superconductors are layered. If time permits we will also tackle the more numerically intensive Eliashberg treatment, where retardation effects are explicitly taken into account. The student will begin by examining the current literature. He/she will start with reproducing some known results, both analytically and numerically. Students should be proficient with a computing language (e.g. MatLab, Python, C++, or even Fortran).

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3 Experiments Modelling Particle Transport by River Outflows

Project description

Rivers that flow into the ocean carry with them clay and other suspended particles. Though important for the offshore oil industry, marine biologists and sedimentary geologists, little is known about how the particles eventually rain out onto the seafloor. Recent laboratory experiments ( ) have shown that even in idealized circumstances the dynamics are remarkably complex. As the particles settle into the salty ocean, they carry some fresh water down with them, sometimes collecting into plumes as they do so. This depletes the outflow of buoyancy and also contributes to the formation of a bottom-propagating particulate flow (an underwater avalanche). So far experiments have been performed through an impulsive release of particles. The proposed experiments involve two parallel studies. In one, millimeter-sized particles released in viscous fluid will be used to examine the development of collective settling. In the other, micrometer-sized particles in fresh water will be constantly injected into a tank filled with salt water, thus better representing the constant outflow of a river into the ocean. The set-up and analysis methods (using MatLab) are already in place and it is anticipated that the data collected in the course of the summer will be sufficient for a published research article for each of the two proposed experiments.

Contact

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4 Studies of transition paths in the folding of single biological molecules

Project description

Biomolecules like proteins 'fold' into complex structures. Transition paths are the part of the folding reaction where all the interesting changes in structure take place, but they've never been directly observed before our work last year. In this project, the student will explore questions about the physics underlying folding reactions by looking at the properties of transition paths for single DNA hairpins, measured while they fold under tension when held by laser tweezers. The project will involve a combination of analysis of experimental data and Brownian dynamics simulations of transitions under various conditions. Several different topics are available for study. If successful, the work will lead to authorship on a publication.

Contact

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5 Studies of misfolding in the protein SOD1 linked to ALS

Project description

SOD1 is an antioxidant protein that misfolds in the neurodegenerative disease ALS. We use laser tweezers to pull single SOD1 molecules apart and let their structure re-form, studying the mechanisms for correct folding and misfolding. In this project, the student will help analyse single-molecule pulling data from SOD1 and learn to perform pulling measurements, looking at a mutant of SOD1 that leads to inherited ALS to understand how it can propagate misfolding. If successful, the work will contribute to a planned publication.

Contact

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6 Search for black holes and string balls with the Large Hadron Collider at the CERN Laboratory in Geneva

Project description

The student will be part of the ATLAS group in the Centre for Particle Physics at the University of Alberta. The group consists of two professors, two postdoctoral fellows, two graduate students and an estimated three summer students. Our group is helping to analyse data recorded by the ATLAS experiment at the Large Hadron Collider near Geneva. My group is studying the possibility of the experiment being sensitive to higher-dimensional space beyond our common three dimensions. String theory is one possible theory that requires higher-dimensional space. For many years, string theory has guided the direction of the "theory of everything". One drawback is that it is extremely difficult to find a unique prediction of the theory that can be testable in current or future experiments. Low-scale gravity and string models based on intersecting D-branes have recently allowed a connection to be made between the theory and experiment. The student will develop the phenomenology of this theory in the context of the ATLAS experiment at the Large Hadron Collider by searching for black holes and highly-excited string states.

The student will perform the computer simulations, analyse and plot data, and present the results. She/he will also document the project and describe the significance of the results. In particular, the student will create an algorithm for searching for evidence of black holes and highly-excited string states at the Large Hadron Collider.

Contact

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7 Benford's and Seismic Data Processing

Project description

Benford's law appears everywhere in the natural sciences. It predicts the distribution of first digits of real-world observations. This result has been used to detect fraud and to check the quality of different datasets. I would like to find a student interested in reviewing the application of Benford's law to different databases and to examine the possibility of adopting it as an indicator of excessive amount of "preconditioning" in seismic data processing flows.

Requirements: Programming in Matlab or Julia or Python. Interested in statistics, data analysis, and data analytics. Supervisor: M D Sacchi There could be industrial funding for future grad work if the project if successful.

Contact

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