QUANTUM TRANSPORT, MAJORANA FERMIONS AND OTHER EXOTIC EXCITATIONS IN CONDENSED MATTER SYSTEMS (QUAMFEE)

One-day Symposium, Department of Physics, University of Warwick

Tuesday, 18th 2019

Organisers:

A. Chakrabarti (Presidency University, Kolkata), R.A. Römer (Warwick), S. Das (IISER Kolkata), N. Wilson (Warwick)

Background and Purpose

Transport of quasi-particle excitations in the quantum coherent regime is full of surprises even in the simplest models of non-interacting systems. The lattice structure, interplay of spin and orbital degrees of freedom, its composition and deviation, if any, from perfect periodicity, determines whether the material is an insulator or a metal, or a semi-metal, a Weyl metal or a Dirac metal. This is of course foremost due to the quantum, and hence wave-like, nature of such excitations. When long range entanglement induced by many-body interactions are taken into account, similar surprises in the form of exotic collective excitations can arise, given birth to phenomena such as exotic superconductivity and magnetism hosting excitation with fractional quantum numbers (like fraction charges) and fraction/non-abelian statistics (like Majorana fermions). In this workshop, we want to bring together some of the practitioners of various fields of quantum transport, ranging from the non-interacting approaches in non-standard environments to the Majorana and many-body approaches. The aim of the workshop is to understand each other's approaches and strategies, be these analytical, numerical or experimental.

Organisation, Resources

The symposium will start at 09:30 a.m. on Tuesday, June 18th, 2019, at the University of Warwick. Note that the university is located at the outskirts of Coventry and not in Warwick. See http://www2.warwick.ac.uk/about/visiting/ for travel details and http://www2.warwick.ac.uk/about/visiting/maps/ for maps of the central campus. In case you come by car, parking is available for delegates at car park 15.

Programme

Time	Title	Speaker
Tuesday, June 18th, 2019		
09:00-10:00	Registration and Morning Coffee	
Morning Chair: Rudolf A Römer		
10:00-10:45	Transport signatures of spin Berry phase in helical edge states	Sourin Das
10:45-11:30	Heat transfer from topologically protected dynamics of Majorana zero modes	Alessandro Romito
11:30-12:15	Delocalization of electronic states in decorated lattices: a few strange cases	Arunava Chakrabarti
12:15-14:00	Lunch Break	
Afternoon Chair 1: Neil Wilson		
14:00-14:45	Nanowire-based superconducting quantum devices	Jesper Nygard
14:45-15:10	Quantum Transport on Topologically Protected Flat Bands of ABC-stacked Multilayer Graphene	Servet Ozdemir
15:10-15:45	Tea Break	
Afternoon Chair 2: Arunava Chakrabarti		
15:45-16:30	Majorana and Andreev bound states in superconducting circuits	Eran Ginossar
16:30-17:15	Spectral properties of aperiodically ordered structures	Uwe Grimm
18:00-	something to eat	
19:00-	farewell	

Confirmed Participants

Data should be correct up to 13/06/2019. This is all the data we hold, so if things appear wrong, contact the organizers at R.Roemer@warwick.ac.uk

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ABSTRACTS

1. **Delocalization of electronic states in decorated lattices: a few strange cases**

Arunava Chakrabarti, Presidency University, Kolkata

We shall look back at the physics of non-interacting spinless fermions in a class of decorated lattices. Using a simple tight binding Hamiltonian we shall demonstrate that, even in the absence of any long range translational order, such systems can sustain perfectly transmitting, extended single particle states supported on absolutely continuous spectra. This is unusual, and is observed if the numerical values of nearest neighbor hopping integrals in the Hamiltonian bear certain correlations between them. The role of an external magnetic field in the shape of a trapped Aharonov-Bohm flux will be discussed. The lattice structures are recently proposed as potential candidates for the design of spin filters for arbitrary spins.

2. **Transport signatures of spin Berry phase in helical edge states**

Sourin Das, IISER Kolkata

Effects due to Berry phase in a Sz non-conserving helical edge state of quantum spin Hall effect is studied theoretically. We discuss in details the minimal configuration of spin orbit coupling needed to result in effects owing to spin Berry phase in transport across the such Helical edge states. We present a transfer matrix calculation to develop a geometric visualization of the spin Berry phase on the Bloch sphere. We show that the two-terminal conductance with spin polarized lead across a closed helical edge leads results in an Fano type anti- resonance where the position of the anti-resonance as a function of energy (of the incident electron) develops a shift owing to spin Berry phase. This shift is shown to be independent of the overall envelop of the interference pattern which repeats itself as we vary energy though the shape of the envelope itself depends on the shift. An understanding of the line shape of anti-resonance is presented in terms of zeros and poles of transmission ampli- tude in complex energy plane. Finally we also discuss transport signatures of Berry Phase for spin unpolarized leads.

3. **Majorana and Andreev bound states in superconducting circuits**

Eran Ginossar, University of Surrey

Combining superconducting qubits with mesoscopic devices that carry topological states of matter may lead to compact and improved qubit devices with properties useful for fault-tolerant quantum computation. We recently introduced [1] a charge qubit device based on a topological superconductor circuit and show that signatures of Majorana fermions could be detected. This device stores quantum information in coherent superpositions of fermion parity states originating from the Majorana fermions, generating a highly isolated qubit whose coherence time could be greatly enhanced. We study the effect of the Majorana fermions on the quantum electrodynamics of the device embedded within an optical cavity

and develop protocols to initialise, control and measure the parity states. We show that, remarkably, the parity eigenvalue is revealed via dispersive shifts of the optical cavity in the strong coupling regime and its state can be coherently manipulated via a second order sideband transition [2]. As an important implementation, we investigate the low-energy theory of a topological insulator nanowire threaded with magnetic flux and coupled in proximity to a finite capacitance Josephson junction [3]. Both Andreev and Majorana bound states are generated in the weak-link, and the hybridization between the two types of localized excitations has a significant effect on the charge transfer along the junction and the resulting dipole. This behaviour is encoded in a few key spectroscopic patterns, where in conjunction with a high-Q resonator, can be used to detect and differentiate Majorana from Andreev bound states.

REFERENCES:

[1] MICROWAVE TRANSITIONS AS A SIGNATURE OF COHERENT PARITY MIXING EFFECTS IN THE MAJORANA-TRANSMON QUBIT, ERAN GINOSSAR AND EYTAN GROSFELD, NATURE COMMUNICATIONS 5, 4772 (2014)

[2] FERMION PARITY MEASUREMENT AND CONTROL IN MAJORANA CIRCUIT QUANTUM ELECTRODYNAMICS, KONSTANTIN YAVILBERG, ERAN GINOSSAR, EYTAN GROSFELD, PHYS. REV. B 92, 075143 (2015)

[3] DIFFERENTIATING MAJORANA FROM ANDREEV BOUND STATES IN A SUPERCONDUCTING CIRCUIT, KONSTANTIN YAVILBERG, ERAN GINOSSAR, EYTAN GROSFELD, ARXIV:1902.07229.

4. **Nanowire-based superconducting quantum devices**

Jesper Nygard, Center for Quantum Devices, Niels Bohr Institute, Copenhagen

Quantum wires equipped with superconducting electrodes is a versatile model system for hybrid devices and has attracting particular attention due to the prospects for topologically protected quantum qubits based on Majorana modes. Indeed, several recent experiments have shown signatures of topological superconductivity and Majorana bound states in transport spectroscopy.

Progress in materials science has brought this research to a new level by introducing hybrids where high quality III-V semiconductors are interfaced epitaxially with superconducting thin films. This has led to improved devices with cleaner transport characteristics. Moreover, in-situ fabrication techniques and new superconductors expand the accessible range of device parameters. We will survey recent developments in hybrid materials grown by Molecular Beam Epitaxy, Majorana mode spectroscopy as well as experiments on superconductivity and bound states in coupled quantum dot systems.

5. **Quantum Transport on Topologically Protected Flat Bands of ABC-stacked Multilayer Graphene**

Servet Ozdemir, University of Manchester

6. **Heat transfer from topologically protected dynamics of Majorana zero modes**

Alessandro Romito, University of Lancaster

Majorana zero modes are topologically protected excitations emerging at the interface of certain superconductors. Their non-abelian exchange statistics make them of interest both as fundamental excitations and as a platform to implement protected unitary operations for quantum information

processing. A number of experiments have reported signatures of Majorana zero modes in engineered superconducting nanostructures to date, with a current focus on controlling and detecting their topologically protected dynamics.

In this talk, after reviewing the general properties of Majorana zero modes in superconductors, I will discuss the energetics associated with the topological protected dynamics, specifically a Majorana zero-modes braiding. With reference to a minimal model device, I will show that the braiding operation is able to pump energy (heat) between two external reservoirs, as opposed to a vanishing pumped charge. The differential pumped heat per energy is quantised to a universal coefficient that reflects the system protected dynamics. I will finally discuss the thermodynamic implications of the findings, in particular with the identification of a topologically protected correction of some fluctuation theorems.

7. Spectral properties of aperiodically ordered structures

Uwe Grimm, The Open University, Milton Keynes

Aperiodically ordered materials such as quasicrystals display particular physical properties, due to their long-range order and lack of periodicity. This talk presents an introduction to aperiodic order and a brief discussion of two types of spectra, diffraction spectra on the one hand and spectra of Schrödinger operators on the other hand. Both spectra show characteristic features that originate from the aperiodic order.