Autumn 2020 QI Seminar Speakers

Cavendish Laboratory

18 September – 4 December

*(abstracts listed below)

18 September (11.15am): Nicole Yunger Halpern (ITAMP Harvard) – Noncommuting conserved quantities in quantum many-body thermalization

25 September (11.00am): David Ibberson (Hitachi) – Large dispersive interaction between a CMOS double quantum dot and microwave photons

2 October (11.00am): Irati Alonso Calafell (University of Vienna) – Quantum Computing with Graphene Nanoribbons

9 October (11.00am): Stuart Holmes (UCL) – Suppression of phonon-assisted processes in InGaAs

16 October (11.00am): Jacob Chevalier Drori (DAMTP, Cambridge) – Conditions tighter than non-commutation needed for non-classicality

23 October (11.00am): David Arvidsson-Shukur (Cavendish, Cambridge) – The usefulness of negativity: Quantum advantage in post-selected metrology

30 October (11.20am): Adam Bene Watts (MIT) – Macroscopic Tests of Quantum Mechanics

6 November (11.00am): Zhoe Wenbin (Nagoya University) – General state transitions with exact resource morphisms: a unified resource-theoretic approach

13 November (3.00pm): Edwin Barnes (Virginia Tech) – Noise-resistant quantum control from geometric curves

20 November (11.00am): Chiara Marletto (Oxford) – The Aharonov-Bohm phase is locally acquired, like all other quantum phases

27 November (11.00am): Theodor Lundberg (Hitachi) – A Spin Quintet in a Silicon Double Quantum Dot

4 December: TBA

Noncommuting conserved quantities in quantum many-body thermalization

(Quantum Thermodynamics)

18 September 11.20am
Nicole Yunger Halpern
ITAMP Harvard

In statistical mechanics, a small system exchanges conserved quantities—heat, particles, electric charge, etc.—with a bath. The small system may thermalize to the canonical ensemble, the grand canonical ensemble, etc. The conserved quantities are represented by operators usually assumed to commute with each other. But noncommutation distinguishes quantum physics from classical. What if the operators fail to commute? I will argue, using quantum-information-theoretic thermodynamics, that the small system thermalizes to near a "non-Abelian thermal state." I will present a protocol for realizing this state experimentally, supported with numerical simulations of a spin chain. The protocol is suited to ultracold atoms, trapped ions, quantum dots, and more. This work introduces a nonclassical phenomenon—noncommutation of conserved quantities—into a decades-old thermodynamics problem.

References

1) NYH, Beverland, and Kalev, Phys. Rev. E 101, 042117 (2020) https://dx.doi.org/10.1103/PhysRevE.101.042117.
2) NYH, Faist, Oppenheim, and Winter, Nat. Comms. 7, 12051 (2016) https://www.nature.com/articles/ncomms12051.
3) NYH, J. Phys. A 51, 094001 (2018) https://iopscience.iop.org/article/10.1088/1751-8121/aaa62f/meta.

Large dispersive interaction between a CMOS double quantum dot and microwave photons

(Semiconductor Quantum-Information Processing)

25 September 11.00am
David Ibberson
Hitachi

We report a large coupling rate, $g/2\pi = 183$ MHz, between the charge state of a double quantum dot in a CMOS split-gate silicon nanowire transistor and microwave photons in a lumped-element resonator, which is formed by wire-bonding to a superconducting inductor fabricated on a separate chip. We enhance the coupling by exploiting the large interdot lever arm of an asymmetric split-gate device, $\alpha = 0.72$, and by inductively coupling to the resonator to increase its impedance, $Z = 560\ \Omega$. In the dispersive regime, the large coupling strength at the DQD hybridisation point produces a frequency shift comparable to the resonator linewidth, the optimal setting for maximum state visibility. We exploit this regime to demonstrate rapid gate-based readout of the charge degree of freedom, with an SNR of 3.3 in 50 ns. In the resonant regime, the fast charge decoherence rate precludes reaching the strong coupling regime, but we show a clear route to spin-photon circuit quantum electrodynamics using hybrid CMOS systems.

References
1) https://arxiv.org/abs/2004.00334

Quantum Computing with Graphene Nanoribbons

(Plasmon Quantum Computing)

2 October 11.00am

Irati Alonso Calafell
University of Vienna

Among the various approaches to quantum computing, all-optical architectures are especially promising due to the robustness and mobility of single photons. However, the creation of the two- photon quantum logic gates required for universal quantum computing remains a challenge. Here we propose a universal two-qubit quantum logic gate, where qubits are encoded in surface plasmons in graphene nanostructures, that exploits graphene's strong third-order nonlinearity and long plasmon lifetimes to enable single-photon-level interactions. In particular, we utilize strong two-plasmon absorption in graphene nanoribbons, which can greatly exceed single-plasmon absorption to create a "square-root-of-swap" that is protected by the quantum Zeno effect against evolution into undesired failure modes. Our gate does not require any cryogenic or vacuum technology, has a footprint of a few hundred nanometers, and reaches fidelities and success rates well above the fault-tolerance threshold, suggesting that graphene plasmonics offers a route towards scalable quantum technologies.

References

1) Alonso Calafell, et al. npj Quantum Information 5, 37 (2019),
https://www.nature.com/articles/s41534-019-0150-2

Suppression of phonon-assisted processes in InGaAs

(Semiconductor Physics)

9 October 11.00am
Stuart Holmes
UCL

I discuss the metal-to-insulator transition in disordered InGaAs two-dimensional electron gas devices that are thermally isolated from a temperature reservoir. At high temperatures the devices are diffusion dominated, whilst at low temperatures they show insulating behaviour below conductance (s) ~ e2/h. The device characteristics for a localization behaviour cross-over from 'Mott'-variable range hopping to interaction-dominated, 'Efros-Shklovskii' conditions where a Coulomb gap can be observed are studied. The suppression of phonon-assisted processes in this region of transport can lead to the condition s(T) = 0 at finite temperature T with a breakdown in thermalization. Progress towards this transport regime needed to study Many Body Localization effects are discussed with the importance of this for future technology.

Conditions tighter than non-commutation needed for non-classicality

(Fundamental Quantum Mechanics)

16 October 11.00am
Jacob Chevalier Drori
University of Cambridge

Kirkwood discovered in 1933, and Dirac discovered in 1945, a representation of quantum states that has undergone a renaissance recently. The Kirkwood-Dirac (KD) distribution has been employed to study nonclassicality across quantum physics, from metrology to chaos to the foundations of quantum theory. The KD distribution is a quasiprobability distribution, a quantum generalization of a probability distribution, which can behave nonclassically by having negative or nonreal elements. Negative KD elements signify quantum information scrambling and potential metrological quantum advantages. Nonreal elements encode measurement disturbance and thermodynamic nonclassicality. KD distributions' nonclassicality has been believed to follow necessarily from noncommutation of operators. We show that noncommutation does not suffice. We prove sufficient conditions for the KD distribution to be nonclassical (equivalently, necessary conditions for it to be classical). We also quantify the KD nonclassicality achievable under various conditions. This work resolves long-standing questions about nonclassicality and may be used to engineer quantum advantages.

The usefulness of negativity: Quantum advantage in post-selected metrology

(Quantum Metrology)

23 October 11.00am
David Arvidsson-Shukur
University of Cambridge

In this talk, I will show that post-selection offers a non-classical advantage in metrology. In every parameter-estimation experiment, the final measurement or the post-processing incurs some cost. Post-selection can improve the rate of Fisher information (the average information learned about an unknown parameter from an experimental trial) to cost. This improvement, we will see, stems from the negativity of the Kirkwood-Dirac (KD) quasi-probability distribution, a quantum extension of a probability distribution. In a classical theory, in which all observables commute, the KD distribution can be expressed as real and non-negative. In a quantum-mechanical theory, however, I will show that non-commutation forces the KD distribution to include negative or non-real quasi-probabilities. The distribution's non-classically negative values enable post-selected experiments to outperform even post-selection-free experiments whose input states and final measurements are optimised: Post-selected quantum experiments can yield anomalously large information-cost rates. Finally, I will outline a preparation-and-post-selection procedure that can result in an arbitrarily large Fisher information. In collaboration with Aephraim Steinberg's quantum-optics group, we are currently conducting an experiment to demonstrate this result.

References

1) D. Arvidsson-Shukur *et al.*, *Nature Comms.,* 11, 3775, (2020)
https://www.nature.com/articles/s41467-020-17559-w
2) https://arxiv.org/abs/1903.02563
3) https://www.cam.ac.uk/research/news/quantum-negativity-can-power-ultra-precise-measurements

Macroscopic Tests of Quantum Mechanics

(Foundations of Quantum Mechanics)

30 October 11.20am

Adam Bene Watts
MIT

How precise do measurements need to be to detect quantum mechanical effects? In this talk I will describe a device-independent protocol which tests for entanglement in a macroscopic system using only measurements with macroscopic precision. The test involves measurements of the covariance between macroscopic measurements and assumes independence between the microscopic subsystems making up each macroscopic system. As such, it cannot be used to disprove local hidden variable theories, but can be used to certify nonclassical correlations under reasonable experimental assumptions. Time permitting, I will also describe some possible experimental implementations. This talk is based off of joint work with Aram Harrow and Nicole Yunger Halpern.

References

1) https://arxiv.org/abs/1911.09122

General state transitions with exact resource morphisms: a unified resource-theoretic approach

(Quantum Resource Theories)

6 November 11.00am
Zhou Wenbin
Nagoya University

Given a non-empty closed convex subset F of density matrices, we formulate conditions that guarantee the existence of an F-morphism (namely, a completely positive trace-preserving linear map that maps F into itself) between two arbitrarily chosen density matrices. While we allow errors in the transition, the corresponding map is required to be an exact F-morphism. Our findings, though purely geometrical, are formulated in a resource-theoretic language and provide a common framework that comprises various resource theories, including the resource theories of bipartite and multipartite entanglement, coherence, athermality, and asymmetric distinguishability. We show how, when specialized to some situations of physical interest, our general results are able to unify and extend previous analyses. We also study conditions for the existence of maximally resourceful states, defined here as density matrices from which any other one can be obtained by means of a suitable F-morphism. Moreover, we quantitatively characterize the paradigmatic tasks of optimal resource dilution and distillation, as special transitions in which one of the two endpoints is maximally resourceful.

References
1) https://arxiv.org/abs/2005.09188

Noise-resistant quantum control from geometric curves

(Noise-Robust Quantum Computing)

12 November 3.00pm
Edwin Barnes
Virginia Tech

Future technologies such as quantum computing, sensing and communication demand the ability to control microscopic quantum systems with unprecedented accuracy. This task is particularly daunting due to unwanted and unavoidable interactions with noisy environments that destroy quantum information through decoherence. I will present a new theoretical framework for deriving control waveforms that dynamically combat decoherence by driving qubits in such a way that noise effects destructively interfere and cancel out. This theory exploits a rich geometrical structure hidden within the time-dependent Schrödinger equation in which quantum evolution is mapped to geometric curves. Control waveforms that suppress noise can be obtained by drawing closed curves and computing their curvatures. I will show how this can be done for single- and multi-qubit systems.

References
1) https://arxiv.org/abs/2008.01168

The Aharonov-Bohm phase is locally acquired, like all other quantum phases

(Foundations of Physics)

20 November 11.00am

Chiara Marletto
University of Oxford

In the Aharonov-Bohm (AB) effect, a superposed charge acquires a detectable phase by enclosing an infinite solenoid, in a region where the solenoid's electric and magnetic fields are zero. Its generation seems therefore explainable only by the local action of gauge-dependent potentials, not of gauge-independent fields. This was recently challenged by Vaidman, who explained the phase by the solenoid's current interacting with the electron's field (at the solenoid). Still, his model has a residual nonlocality: it does not explain how the phase, generated at the solenoid, is detectable on the charge. I will explain how to solve this nonlocality by explicitly quantizing the field. In this model, the AB phase is mediated locally by the entanglement between the charge and the photons, like all electromagnetic phases. I will discuss a realistic experiment to measure this phase difference locally, by partial quantum state tomography on the charge, without closing the interference loop.

References

1) https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.125.040401
2) https://arxiv.org/abs/1906.03440

A Spin Quintet in a Silicon Double Quantum Dot

(Semiconductor Quantum-Information Processing)

27 November 11.00am
Theodor Lundberg
Hitachi

Spins in gate-defined silicon quantum dots are promising candidates for implementing large-scale quantum computing. To read the spin state of these qubits, the mechanism that has provided highest fidelity is spin-to-charge conversion via singlet-triplet spin blockade, which can be detected in-situ using gate-based dispersive sensing. In systems with a complex energy spectrum such as silicon quantum dots, accurately identifying when singlet-triplet blockade occurs is therefore critical for scalable qubit readout.

In this work, we present a description of spin blockade physics in a tunnel-coupled silicon double quantum dot defined in the corners of a split-gate transistor. Using gate-based magnetospectroscopy, we report successive steps of spin blockade and spin blockade lifting involving spin states with total spin angular momentum up to $S = 3$. Furthermore, we report the formation of a hybridized spin quintet state and show triplet-quintet and quintet-septet spin blockade. This enables investigation of the quintet relaxation dynamics from which we find a relaxation time of $T_1 \sim 4$ μs. Finally, we develop a quantum capacitance model that is applied generally to reconstruct the energy spectrum of the double quantum dot including the spin-dependent tunnel coupling and the energy splitting between different spin manifolds. Our results open the possibility of using silicon complementary metal-oxide-semiconductor (CMOS) quantum dots as a tuneable platform for studying the interactions and dynamics of high-spin systems.

References
1) https://arxiv.org/abs/1910.10118

TBA

4 December 11.00am