Foundations of Quantum Statistics 2024

Vienna, September 19-20

Venue

Erwin Schrödinger International Institute for Mathematical Physics,

Boltzmanngasse 9A,

1090 Vienna

Program

Thursday, September 19

9:30 — 10:00 *Welcome and Gathering*

10:00 — 11:00 Philip Goyal, *A Reconstructive Approach to Identical Particle Statistics and Entanglement*

11:00 — 11:30 *Coffee Break*

11:30 — 12:30 Borivoje Dakić, *Reconstruction of Quantum Particle Statistics*

12:30 — 14:30 Lunch Break

14:30 — 15:30 Gerardo Adesso, *Work extraction in the quantum regime: correlations versus ignorance*

15:30 — 16:30 Ugo Marzolino, *Quantum thermochemical engines*

16:30 — 17:00 *Coffee Break & Discussion*

18:00 — *Dinner*

Friday, September 20

9:00 — 10:00 Tomasz Bigaj, *The relative character of entanglement for identical particles*

10:00 — 11:00 Gabriel Dufour, *Fourier analysis of the interference of partially distinguishable particles*

11:00 — 11:30 *Coffee Break*

11:30 — 12:30 Paolo Perinotti, *Fermionic Computation Theory Meets Mechanics*

12:30 — 14:30 Lunch Break

14:30 — 15:30 Pablo Arighi, *Fermions are qubit-local*

15:30 — 16:30 Neli Stoilova, *An Algebraic Approach to Quantum Statistics*

16:30 — 17:00 *Concluding Remarks*

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Abstracts

Gerardo Adesso, University of Nottingham

Work extraction in the quantum regime: correlations versus ignorance

We investigate constrained scenarios for work extraction in the resource theory of quantum thermodynamics. On one hand, we consider bipartite scenarios when one party wants to locally distil as much work as possible but is restricted to thermal operations whereas the other party can perform general quantum operations and they are allowed to communicate classically. We demonstrate that this question is intimately related to the distillation of classical/quantum correlations. On the other hand, we consider entropy production upon mixing two gases. Classically, an ignorant observer who cannot distinguish the gases has no way of extracting work by mixing them. Moving the thought experiment into the quantum realm, we find that the ignorant observer can extract as much work as if the gases were fully distinguishable, even without direct access to the gases' intrinsic degrees of freedom: a quantum Gibbs paradox. We discuss the implications of both scenarios for genuinely quantum modifications to thermodynamics.

Pablo Arrighi, Université Paris-Saclay

Fermions are qubit-local

When implementing fermionic creation and annihilation operators on a lattice of qubits, one must enforce their anti-commutation by means of a Jordan-Wigner representation, i.e. a chain of Pauli Z matrices that is not qubit-local. Nevertheless, we demonstrate that the dynamics of the fermions, such as their hopping terms, remains qubit-local. This is well-known in one-dimensional systems, as the chains of adjacent creation and annihilation operators are forced to cancel out. However, this also holds in higher dimensions, provided the gauge field line carried by the fermionic charge is considered.

Still, at the point where fermionic excitations on the qubit lattice intersect, a qubit-local phase is triggered. In the Schrödinger picture, this phase can be interpreted as a Thirring-like interaction. However, switching to the Heisenberg picture reveals that this phase is precisely determined by the requirement that massive particles must not interact with each other.

Reference: https://arxiv.org/abs/2205.03148, Quantum 7, 1179 (2023)

Tomasz Bigaj, University of Warsaw

The relative character of entanglement for identical particles

There is a growing consensus among physicists and philosophers of physics that the concept of quantum entanglement is not absolute but relative. The entanglement of a given quantum state depends on how the system described by this state is decomposed into subsystems. In my talk I will approach the relativization of entanglement with respect to systems of identical (indistinguishable) particles. Using a non-standard characterization of entanglement of identical particles taken from (Ghirardi et al. 2002), I will present simple cases in which one and the same joint state can be interpreted as either entangled in one degree of freedom while non-entangled in another, or as entangled in the second degree and non-entangled in the first. I will pose the question of a possible experimental verification of this surprising effect, and I will discuss its deeper consequences regarding the ontological nature of quantum objects.

Borivoje Dakić, University of Vienna

Reconstruction of Quantum Particle Statistics

Identical quantum particles exhibit only two types of statistics: bosonic and fermionic. Theoretically, this restriction is commonly established through the symmetrization postulate or (anti)commutation constraints imposed on the algebra of creation and annihilation operators. The physical motivation for these axioms remains poorly understood, leading to various generalizations by modifying the mathematical formalism in somewhat arbitrary ways. In this talk, I will take an opposing route and show how to classify quantum particle statistics based on operationally well-motivated assumptions. Specifically, I will consider that a) the standard (complex) unitary dynamics defines the set of single-particle transformations, and b) phase transformations act locally in the space of multi-particle systems. In this way, a complete characterization, which includes bosons and fermions as basic statistics with minimal symmetry is being developed. Interestingly, we have discovered whole families of novel statistics (dubbed transtatistics) accompanied by hidden symmetries, generic degeneracy of ground states, and spontaneous symmetry breaking — effects that are (typically) absent in ordinary statistics.

Reference: N. M. Sánchez and B. Dakić, Reconstruction of Quantum Particle Statistics: Bosons, Fermions, and Transtatistics, arXiv:2306.05919, 2023.

Gabriel Dufour, University of Freiburg

Fourier analysis of the interference of partially distinguishable particles

The concept of partially distinguishable particles—bosons or fermions endowed with internal states which shape the collective interference in their external dynamics—has proved useful from both practical and fundamental perspectives: e.g. as a noise model for photonic quantum computing platforms, as a tool for the systematic investigation of many-particle interference in interacting systems or as a theoretical framework to define wave-particle duality and decoherence at the many-particle level. Here, we apply the Fourier transform over the symmetric group S_N to analyse the interference of N partially distinguishable particles. Fourier analysis over a finite group generalises ordinary Fourier analysis in that it considers non-commutative transformations of a function's domain, in our case permutations of the N particles. The counting statistics of partially distinguishable particles at the output of multimode interferometers is thereby broken down into contributions from irreducible symmetry types, including—but not limited to—the bosonic and fermionic symmetries. As an illustration, we formulate conditions for totally destructive interference to occur for states of a given symmetry type, generalising the Hong-Ou-Mandel scenario to symmetries other than bosonic or fermionic.

Philip Goyal, University at Albany (SUNY)

A Reconstructive Approach to Identical Particle Statistics and Entanglement

TBA

Ugo Marzolino, University of Trieste

Quantum thermochemical engines

Conversion of chemical energy into mechanical work is the fundamental mechanism of several natural phenomena at the nanoscale, like molecular machines and Brownian motors. Quantum mechanical effects are relevant for optimising these processes and to implement them at the atomic scale. This paper focuses on engines that transform chemical work into mechanical work through energy and particle exchanges with thermal sources at different chemical potentials. Irreversibility is introduced by modelling the engine transformations with finite-time dynamics generated by a time-depending quantum master equation. Quantum degenerate gases provide maximum efficiency for reversible engines, whereas the classical limit implies small efficiency. For irreversible engines, both the output power and the efficiency at maximum power are much larger in the quantum regime than in the classical limit. The analysis of ideal homogeneous gases grasps the impact of quantum statistics on the above performances, which persists in the presence of interactions and more general trapping. The performance dependence on different types of Bose-Einstein Condensates (BECs) is also studied.

BECs under considerations are standard BECs with a finite fraction of particles in the ground state, and generalised BECs where eigenstates with parallel momenta, or those with coplanar momenta are macroscopically occupied according to the confinement anisotropy.

Quantum statistics is therefore a resource for enhanced performances of converting chemical into mechanical work.

Paolo Perinotti, Pavia University

Fermionic Computation Theory Meets Mechanics

In this seminar we will introduce Fermionic theory as an Operational Probabilistic Theory, and motivate its use in the fundamental description of physical processes. We will illustrate various aspects of the theory, with particular emphasis on anticommutation relations and the consequent parity superselection. We will then argue that Bosonic systems might be Fermionic in their intimate nature, and emerge as composite systems.

Neli Stoilova, Bulgarian Academy of Sciences

An Algebraic Approach to Quantum Statistics

Inspired by the fact that Bose-Einstein and Fermi-Dirac statistics and their generalizations paraboson and parafermion statistics correspond to Lie (super)algebras or their generalizations of class *B* we define quantum statistics associated with classical Lie algebras, basic classical Lie superalgebras and their $Z_2 \times Z_2$-graded analogues. We discuss microscopic and macroscopic properties of some of these generalized statistics, including parastatistics.