# Q 6: Quantum Information (Concepts and Methods) I

Time: Monday 10:30–12:30 Location: K 1.019

**Group Report** Q 6.1 Mon 10:30 K 1.019

**Quantum teleportation via electron-exchange collisions** — •Bernd Lohmann[1,2], Karl Blum[2], and Burkhard Langer[3] — [1]The Hamburg Centre For Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Straße 9, 48149 Münster, Germany — [3]Physikalische Chemie, Freie Universität Berlin, Takustraße 3, 14195 Berlin, Germany

In recent research [1,2], we have shown that strong correlations exist in elastic electron-exchange collisions of light hydrogen-like atoms, violating Bell's inequalities significantly, which allows for generating tunable spin pairs with any desired degree of entanglement. Utilizing our tunable entanglement resource, we will discuss the possibility of performing quantum teleportation with free massive particles applying a twofold elastic electron-exchange scattering. In a first collision, an unpolarized electron will be scattered on an unpolarized atom, generating an entangled electron–atom pair. Subsequently, in a second scattering, an arbitrarily polarized electron will collide with the entangled atom thereby generating interference which allows for teleporting the degree of spin polarization onto the former unpolarized electron. We will demonstrate the feasibility of such experiments.

[1] Blum K., and Lohmann, B., *Phys. Rev. Lett.* **116**, 033201 (2016).
[2] Lohmann, B., Blum, K., and Langer, B., *Phys. Rev. A* **94**, 032331 (2016).

Q 6.2 Mon 11:00 K 1.019

**The Computational Complexity of Multiboson Correlation Interference** — •Simon Laibacher[1] and Vincenzo Tamma[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology ($IQ^{ST}$), Universität Ulm, D-89069 Ulm — [2]Faculty of Science, SEES, University of Portsmouth, Portsmouth PO1 3QL, UK

*Multiboson correlation sampling* was introduced in [1] as a modification of boson sampling [2] in which the photons are detected in a temporally or spectrally resolved manner. Later, it was demonstrated that this problem remains classically hard when nonidentical photons are used, even if they are fully distinguishable in time or frequency at the input [3].

We show that this robustness of the computational complexity persists even if the distinguishability of the photons at the input is random between consecutive runs of the sampling experiment. This feature can be exploited to improve experimental implementations of sampling problems and to significantly simplify the upscaling of such setups to larger photon numbers.

[1] V. Tamma, S. Laibacher, Phys. Rev. Lett. **114**, 243601 (2015).
[2] S. Aaronson, A. Arkhipov, in: *Proceedings of the 43rd annual ACM symposium on Theory of computing* (ACM, 2011) pp. 333–342.
[3] S. Laibacher, V. Tamma, Phys. Rev. Lett. **115**, 243605 (2015).

Q 6.3 Mon 11:15 K 1.019

**Ultra-low vibration closed-cycle cryogenic surface-electrode ion trap setup** — •Sebastian Grondkowski[1], Timko Dubielzig[1], Fabian Ude[1], Giorgio Zarantonello[1,2], Henning Hahn[1,2], Martina Wahnschaffe[2,1], Amado Bautista-Salvador[2,1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig

Operation of ion traps at cryogenic temperatures is highly benefitial to fight the effects of anomalous motional heating, obtain excellent electrical properties of materials and achieve long trap lifetimes [1-3]. When using a closed-cycle cryostat to cool the apparatus, excessive vibrations associated with the mechanical motion of the cooler should be avoided in order not to affect the optical addressing of the ions adversely. We discuss a mechanical suspension for a commercial vibration isolation interface that allows easy alignment and long term stability of the setup. We present an interferometric approach to determine the residual movement of the cold head and find that for suitable temperatures of the cold stage, we can place an upper limit of 8 nm RMS on the vibration level, limited by the performance of the interferometer.

[1] J. Chiaverini and J. M. Sage, PRA 89, 012318 (2014)
[2] S. W. Van Sciver, Helium Cryogenics, 2nd ed., Springer (2012)
[3] D. Gandolfi et al., Rev. Sci. Instr. 83, 084705 (2012)

Q 6.4 Mon 11:30 K 1.019

**Exclusion principles for hard-core bosons** — •Macauley Davy[1], Felix Tennie[1], Vlatko Vedral[1,2], and Christian Schilling[1] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [2]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543

The particle exchange symmetry strongly shapes the behavior of quantum systems even in the one-particle picture: While fermionic occupation numbers obey Pauli's exclusion principle, bosons can multiply occupy any one-particle quantum state $|\varphi\rangle$ and even form a Bose-Einstein condensate. One may therefore wonder how the situation looks like for hard-core bosons, fulfilling mixed commutation relations. We first observe that for arbitrary systems of $N$ hard-core bosons on $d$ lattice sites the maximal possible occupation number is given by $N_{max} = (N/d)(d - N + 1)$ which is smaller than $N$ but larger than 1. $N_{max}$ can only be achieved for states $|\varphi\rangle$ which are maximally unbiased w.r.t. the lattice site basis $\{|j\rangle\}_{j=1}^{d}$ ("momentum states") and when the total system is maximally delocalized. We generalize this result by relating the maximal occupation number $N_{max}^{(\varphi)}$ of a fixed one-particle state $|\varphi\rangle = \sum_{j=1}^{d} c_j |j\rangle$ to the unbiasedness of $|\varphi\rangle$ w.r.t. to the basis of lattice site states.

Q 6.5 Mon 11:45 K 1.019

**Universal extensions of restricted classes of quantum operations - a group theoretic approach** — Michal Oszmaniec[1] and •Zoltán Zimborás[2] — [1]Quantum Information Centre of Gdansk, 81-824 Sopot, Poland — [2]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

For numerous applications of quantum theory it is desirable to be able to apply arbitrary unitary operations on a given quantum system. However, in particular situations only a subset of unitary operations is easily accessible. This raises the question: what additional unitary gates should be added to a given gate-set in order to attain physical universality? In this talk, I will present our recent results on this for three paradigmatic cases: (A) particle-number preserving bosonic linear optics, (B) particle-number preserving fermionic linear optics, and (C) general (not necessarily particle-number preserving) fermionic linear optics. Using recently developed group theoretic tools, we could classify, in each of these scenarios, what sets of gates are generated, if an additional gate is added to the set of allowed transformations [1].

[1] M. Oszmaniec, Z. Zimborás, Phys Rev. Lett. 119, 220502 (2017).

Q 6.6 Mon 12:00 K 1.019

**Reconstructing quantum states from single-party information** — •Christian Schilling[1], Carlos Benavides-Riveros[2], and Peter Vrana[3] — [1]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany — [3]Department of Geometry, Budapest University of Technology and Economics, Budapest, Hungary

The possible compatibility of density matrices for single-party subsystems is described by linear constraints on their respective spectra. Whenever some of those quantum marginal constraints are saturated, the total quantum state has a specific, simplified structure. We prove that these remarkable global implications of extremal local information are stable, i.e. they hold approximately for spectra close to the boundary of the allowed region. Application of this general result to fermionic quantum systems allows us to characterize natural extensions of the Hartree-Fock ansatz and to quantify their accuracy by resorting to one-particle information, only: The fraction of the correlation energy not recovered by such an ansatz can be estimated from above by a simple geometric quantity in the occupation number picture.

Q 6.7 Mon 12:15 K 1.019

**Natural extensions of Hartree-Fock based on extremal one-particle information** — •Carlos L. Benavides-Riveros[1] and Christian Schilling[2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany — [2]Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

One-particle density matrices are compatible with pure N-fermion quantum states whenever their spectra (natural occupation numbers) lie in the polytope defined by the generalized Pauli constraints. We characterize existing and propose novel extensions of the Hartree-Fock ansatz by referring to the different facets of that polytope. Moreover, we derive a quantitative relation between the accuracy of those variational ansatzes and the distance of the exact ground state's occupation number vector to the respective polytope facets. In an extensive numerical study those ansatzes are tested and we explain how a geometrical hierarchy of the polytope allows one to systematically recover all static correlation energy.