Q 30: Matter Wave Optics

Time: Wednesday 10:30–12:45 Location: S SR 211 Maschb.

Invited Talk Q 30.1 Wed 10:30 S SR 211 Maschb.

Atom transport at the quantum speed limit and its application for atom interferometry — Manolo Rivera[1], Natalie Peter[1], Thorsten Groh[1], Wolfgang Alt[1], Gautam Ramola[1], Richard Winkelman[1], Carsten Robens[1], Antonio Negretti[2], Simone Montangero[3], Tommaso Calarco[3], Dieter Meschede[1], and •Andrea Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg — [3]Institut für komplexe Quantensysteme, Universität Ulm

I will report on the experimental realization of fast, high-fidelity transport of atomic wave packets in deep optical lattices.

The goal here is to transport atoms by one or more lattice sites in the shortest time allowed by quantum mechanics, under the constraint that no motional excitation is created after transport, and the optical lattice depth does not exceed a maximum value given by the available resources (e.g., finite laser power).

To achieve fast atom transport, we use quantum optimal control, which allows several motional excitations to be created during the transport process, and yet refocus them back into the motional ground state with a fidelity $> 99\%$. Optimizing the process for various transport times, we clearly observe a minimum time below which transport operations unavoidably create motional excitations. This time defines the *quantum speed limit* for the transport operation.

Extending fast atom transport to spin-dependent optical lattices, I show that we are able to enhance coherence of atom interferometers and quantum walk experiments.

Q 30.2 Wed 11:00 S SR 211 Maschb.

Optimal control technique for fast excitation-less transport of BECs on an atom chip — •Sirine Amri[1,2], R. Corgier[2,1], D. Sugny[3], E.M Rasel[2], and N. Gaaloul[2] — [1]ISMO, Université Paris-Saclay, Bât.520, 91400 Orsay France — [2]Institute of Quantum Optics, LUH, Welfengarten 1 30167, Germany — [3]ICB, Université de Bourgogne, 20178 Dijon Cedex, France

Recent proposals for testing foundations of physics assume Bose-Einstein condensates (BECs) as sources of atom interferometry sensors. In this context, atom chip devices allow to build transportable BEC machines with high flux and high repetition rates, as demonstrated within the QUANTUS (drop tower) and MAIUS (sounding rocket) [D. Becker et al, Nature, 562, 391 (2018).] micro-gravity experiments. According to the specific atom interferometric sequence considered, the external degrees of freedom of the BEC need to be manipulated after its creation. We present optimal control theory protocols for the fast, excitation-less transport of BECs with atom chips, i.e. engineering transport ramps with durations not exceeding 200 ms with realistic 3D anharmonic traps. This controlled transport is implemented over large distances, typically of the order of 1-2 mm, i.e. of about 1,000 times the size of the atomic cloud. The advantages over shortcut-to-adiabaticity schemes reported by our team [R. Corgier et al. NJP 20, 055002 (2018)] will be discussed.

Q 30.3 Wed 11:15 S SR 211 Maschb.

Diffractive focusing of interacting matter waves — •Patrick Boegel[1], Matthias Meister[1], Jan-Niclas Siemss[2,3], Naceur Gaaloul[3], Maxim Efremov[1], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover,Germany

A common way to control the position and the size of maximal focusing of a matter-wave is to use a lens which imprints a position-dependent phase on the initial wave. However, quantum mechanics allows focusing even without a lens [1,2], based on diffractive focusing, where the initial wave function is a real-valued one. Hence, the optimal focusing relies on a smart choice of this initial wave function [3]. We explore the phenomenon of diffractive focusing of an atomic Bose-Einstein Condensate (BEC) in the regime, where the resonant atom-atom interaction plays a key role.

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[1] Case, W.B. et al. Optics Express 20, 27253 (2012)
[2] Weisman D. et al. Phys. Rev. Lett. 118, 154301 (2017)
[3] Vogel, K. et al., Chem. Phys. 375, 133-143 (2010)

Q 30.4 Wed 11:30 S SR 211 Maschb.

Quantifying partial distinguishability in many-particle systems — •Eric Brunner[1], Gabriel Dufour[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg

Many-particle interference is an essential ingredient in the complex dynamics of quantum systems and a consequence of the particles' indistinguishability. We consider particles whose state space is augmented by an internal degree of freedom, which allows one to adjust their mutual distinguishability. Within this framework we quantify (partial) distinguishability of many-body states and investigate its influence on the expectation values of many-particle observables. These ideas can equally be applied to study correlations at the output of multi-mode interferometers, as well as the dynamics of interacting many-body systems. This paves the way for a generalization of the Hong-Ou-Mandel indistinguishability test to bosonic and fermionic systems of more than two particles.

Q 30.5 Wed 11:45 S SR 211 Maschb.

Many-particle interference to test Born's rule — •Marc-Oliver Pleinert[1,2], Joachim von Zanthier[1,2], and Eric Lutz[3] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91052 Erlangen, Germany — [3]Institute for Theoretical Physics I, University of Stuttgart, D-70550 Stuttgart, Germany

Born's rule, one of the cornerstones of quantum mechanics, relates detection probabilities to the modulus square of the wave function. Single-particle interference is accordingly limited to pairs of quantum paths and higher-order interferences are prohibited. Deviations from Born's law have been quantified via the Sorkin parameter which is proportional to the third-order interference term. We here extend this formalism to many-particle interferences and find that they exhibit a much richer structure. We demonstrate, in particular, that all interference terms of order $(2M + 1)$ and greater vanish for M particles. We further introduce a family of many-particle Sorkin parameters and show that they are exponentially more sensitive to deviations from Born's rule than their single-particle counterpart.

Q 30.6 Wed 12:00 S SR 211 Maschb.

Matter-wave diffraction from a quasicrystalline optical lattice — •Konrad Viebahn[1,2], Matteo Sbroscia[1], Edward Carter[1], Jr-Chiun Yu[1], and Ulrich Schneider[1] — [1]Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, UK — [2]Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich

Quasicrystals are long-range ordered and yet non-periodic. This interplay results in a wealth of intriguing physical phenomena, such as the inheritance of topological properties from higher dimensions, and the presence of non-trivial structure on all scales. Here we report on the first experimental demonstration of an eightfold rotationally symmetric optical lattice, realising a two-dimensional quasicrystalline potential for ultracold atoms. Using matter-wave diffraction we observe the striking self-similarity of the quasicrystalline structure, in close analogy to the very first discovery of quasicrystals using electron diffraction. The diffraction dynamics on short timescales constitutes a continuous-time quantum walk on a homogeneous four-dimensional tight-binding lattice. These measurements pave the way for quantum simulations in fractal structures and higher dimensions.

Q 30.7 Wed 12:15 S SR 211 Maschb.

Spatial properties of multiphoton-photoemitted electron pulses from metallic needle tips — •Stefan Meier, Takuya Higuchi, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Tungsten needle tips represent well-suited electron sources for various applications like electron microscopy or holography. These methods strongly benefit from the spatially highly coherent electron beams that such tip sources, usually operated in DC-field emission, can provide. To equip these techniques with high temporal resolution, one can trigger the electron emission with few-cycle laser pulses, leading to electron pulses emitted on ultrashort timescales. Recent experiments show that pulsed electron beams, emitted by either a single photon photoemission process [1] or a multiphoton photoemission process [2], have similar coherence properties as DC-field emitted beams. We show our current progress on the investigation of the spatial properties of multiphoton photoemitted electron beams. By investigating the interference pattern of the electron beam after a beamsplitter, we can determine an effective source size r_{eff} of an emitter, which is a quantitative measure for spatial coherence. We report on an upper limit of $r_{\text{eff}} \leq (0.65 \pm 0.06)$ nm for multiphoton-photoemitted electrons from tungsten needle tips with a geometrical radius of $r_{\text{geo}} = (6.8 \pm 1.7)$ nm. In combination with the spatial distribution of the emitted electrons we can also access other electron optical parameters, like beam emittance or brightness.

[1] D. Ehberger *et al.*, Phys. Rev. Lett. **114**, 227601 (2015).
[2] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).

Q 30.8 Wed 12:30 S SR 211 Maschb.

Spectroscopic Mueller Matrix Ellipsometry for Advanced Nanoform Metrology — •Tim Käseberg[1], Johannes Dickmann[1], Thomas Siefke[2], Matthias Wurm[1], Stefanie Kroker[1,3], and Bernd Bodermann[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, Albert-Einstein-Straße 15, 07745 Jena, Germany — [3]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology, Pockelsstraße 14, 38106 Braunschweig, Germany

The resolution of many optical imaging techniques is still limited to about half the wavelength of the incident light. To overcome this classical optical resolution limit, we investigate the use of structured illumination or patterned near-field manipulation in spectroscopic Mueller matrix ellipsometry to enhance the resolution of geometric features in off-diagonal Mueller matrix elements. In a first step, we designed resist nanostructures with variing geometries between 50 and 2000 nm on silicon substrate for measurements using a commercial ellipsometer. Additionally, we examine these structures numerically using the finite element tool JCMwave.