Q 58: Matter Wave Optics

Time: Thursday 16:30–18:30 Location: P

Q 58.1 Thu 16:30 P

Coulomb-induced loss of spatial coherence of femtosecond laser-triggered electrons from needle tips — •Jonas Heimerl, Stefan Meier, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

In the past, tungsten needle tips have been a playground to study a plethora of effects around non-linear electron photoemission. The emitted electrons from such tips are strongly localized to nanometer length and femtosecond time scales when using few-cycle laser pulses. Because of the spatial localization, the electrons possess a high spatial coherence, which can be probed by matter wave interference experiments [1]. In this contribution, we show how Coulomb interactions in the multi-electron regime reduce the spatial coherence, well supported by numerical simulations. In a further step, we use these results to make estimations towards the correlation between two electron wavepackets.

[1] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).

Q 58.2 Thu 16:30 P

Using interferometers to measure molecular properties — •Philipp Rieser, Armin Shayeghi, and Markus Arndt — University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), , Boltzmanngasse 5, A-1090 Vienna, Austria

The wave nature of molecules is a perfect example of the peculiarities of quantum physics. Molecular quantum optics deals with phenomena related to this wave nature, particularly the interaction of molecules with light.

The working principle of molecule interferometers, namely generating nanoscale fringes in the density distribution of molecular beams, makes them sensitive to external perturbations at nanometre scale. This high sensitivity to beam shifts and dephasing effects can be used to extract a variety of intrinsic molecular electronic properties[1].

Molecular matter-wave experiments have the potential of opening a wide field of research at the interface between quantum optics and chemical physics. Complex many-body systems have a vast variety of electric, magnetic and optical properties that make controlled perturbations an interesting and possibly useful tool for future applications[2].

References

[1] S. Eibenberger et al., Phys. Rev. Lett. 112, 250402 (2014).

[2] J. Rodewald, et al., Appl. Phys. B 123,3 (2017).

Q 58.3 Thu 16:30 P

Towards diffracting atoms through graphene — •Jakob Bühler and Christian Brand — German Aerospace Center (DLR), Institute of Quantum Technologies

Modifying graphene by introducing foreign atoms and defects is a commonly used approach to augment its properties [1]. While often beams of fast atoms are used, the interaction process is only partly understood. To resolve this issue, we plan to diffract atomic hydrogen with a velocity of up to 120 000 m/s through the 246 pm lattice of graphene [2]. Thereby, we aim to directly probe the atom-graphene interaction during transmission, using the diffraction pattern as the read out. Using fast atoms will also provide new opportunities for fundamental tests of physics, such as quantum friction [3]. [1] Wang and Shi, Phys. Chem. Chem. Phys. **17**, 28484 (2015) [2] Brand et al. New J. Phys. **21**, 033004 (2019) [3] Silveirinha, New J. Phys. **16** 063011 (2014)

Q 58.4 Thu 16:30 P

Femtosecond laser-triggered electron emission from cooled needle tips — •Manuel Knauft, Norbert Schönenberger, Stefan Meier, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Dielectric laser acceleration offers a miniaturized framework of creating high-energy beams of charged particles, enabling applications where large-scale accelerators are unfeasible. The nanometric dimensions of these require electron sources with utmost beam quality. Similarly, in the context of microscopy and fundamental research coherent electron sources are of high specific interest. It is well known that reducing the operating temperature of the tip emitter positively influences coherence. In this contribution, we present initial experimental results from cooled needle emitters triggered with femtosecond laser pulses.

Q 58.5 Thu 16:30 P

Creating auto-ponderomotive potentials with planar, chip-based electrodes for electron beam manipulation — •Franz Schmidt-Kaler, Michael Seidling, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Advances in complex free electron beam manipulation are shown to be possible based on planar electrodes and electrostatic fields. In the frame of the moving electrons these static fields transform into an alternating auto-ponderomotive potential. This confining pseudopotential resembles the one of a radiofrequency-driven Paul trap. Well-designed electrode layouts enable electron beam splitting and curved guiding, which we demonstrated. The applied electron energies range from a few eV to 1.7 keV (splitting) and 9.5 keV (guiding) permitting integration into standard scanning electron microscopes to allow entirely new electron control.

Q 58.6 Thu 16:30 P

The logarithmic phase singularity in the inverted harmonic oscillator — •Freyja Ullinger[1,2], Matthias Zimmermann[2], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89081 Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), 89081 Ulm, Germany

Relevant phenomena in quantum field theory, such as Hawking radiation and acceleration radiation [1,2], are based on a logarithmic phase singularity and the presence of an event horizon in spacetime.

In this poster, we show that related effects emerge in the simple quantum system of a one-dimensional inverted harmonic oscillator. In fact, the Wigner function corresponding to an energy eigenfunction of this system [3,4] clearly displays a horizon in phase space. Although usually hidden, even a logarithmic phase singularity in combination with an amplitude singularity emerges with the help of a suitable coordinate transformation.

Our insights into this simple quantum system lay the foundation for future applications in the field of matter wave optics.

[1] S. W. Hawking, Nature **248**, 30 (1974)

[2] M. O. Scully, S. Fulling, D. M. Lee, D. N. Page, W. P. Schleich, and A. A. Svidzinsky, Proc. Natl. Acad. Sci. U.S.A. **115**, 8131 (2018)

[3] N. L. Balazs and A. Voros, Ann. Phys. (N. Y.) **199**, 123 (1990)

[4] D. M. Heim, W. P. Schleich, P. M. Alsing, J. P. Dahl, and S. Varro, Phys. Lett. A **377**, 1822 (2013)

Q 58.7 Thu 16:30 P

QUANTUS 2 - Towards dual species atom interferometry in microgravity — •Laura Pätzold[1], Merle Cornelius[1], Julia Pahl[2], Peter Stromberger[3], Waldemar Herr[4,5], Sven Herrmann[1], Markus Krutzik[2,6], Patrick Windpassinger[3], Christian Schubert[5], Ernst M. Rasel[4], and The QUANTUS Team[1,2,3,4,6,7,8] — [1]U Bremen — [2]HU Berlin — [3]JGU Mainz — [4]LU Hannover — [5]DLR-SI — [6]FBH Berlin — [7]U Ulm — [8]TU Darmstadt

Matter wave interferometry allows for quantum sensors with a wide range of applications, e.g. in geodesy or tests of fundamental physics. As a testbed for future space missions, the QUANTUS-2 experiment enables rapid BEC production of Rb-87 atoms with 10^5 atoms and performs atom interferometry in free fall at the ZARM drop tower in Bremen. In combination with a magnetic lens, we are able to reduce the total internal kinetic energy to 38 pK in three dimensions [1]. Here, we present the latest results on our single species interferometry experiments and an outlook on the integration of a potassium laser system, which will open up the possibility to study and manipulate quantum gas mixtures, as well as to perform dual species atom interferometry in microgravity. This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers DLR 50WM1952-1957.

[1] C. Deppner et al., Phys. Rev. Lett. **127**, 100401 (2021)

Q 58.8 Thu 16:30 P

Second-order correlations of scattering electrons — •Florian Fleischmann[1], Mona Bukenberger[2], Raul Corrêa[3], Simon Mährlein[1], Anton Classen[4], Marc-Oliver Pleinert[1], and Joachim von Zanthier[1] — [1]Department Physik, Universität Erlangen-Nürnberg — [2]Department of Environmental Systems Science, ETH Zürich — [3]Departamento de Física, Federal University of Minas Gerais, Brazil — [4]Institute for Quantum Science and Engineering, Texas A&M University, USA

We investigate the spatial second-order correlation function of two scattering electrons in the far field. We first estimate semi-classically how the Pauli exclusion principle and the Coulomb repulsion affect the expected correlation pattern. We then treat the problem fully quantum-mechanically. To that aim, in analogy to the solution of the hydrogen atom, the system is separated into center-of-mass and relative coordinates. In the relative system, we solve the Coulomb scattering problem while the center of mass system can be described in a plane wave ansatz. After incorporating the time evolution, the function is evaluated in the far field. The formal solutions of the problem are shown and the current state of the numerical investigation is discussed.

Q 58.9 Thu 16:30 P

Ray Tracing for Matter Wave Optics — •Maurice Bardel and Reinhold Walser — Institute of Applied Physics, Technical University Darmstadt, Germany

Ray tracing is an effective method for the semi-classical simulation of the dynamics of thermal clouds [1]. It is based on the idea of studying the dynamics of quantum gases in phase space. For this purpose, the cold thermal clouds ($T > T_{BEC}$) are described in the Wigner representation. By applying the truncated Wigner approximation (semi-classical limit), the time evolution expressed by the quantum Liouville-von-Neumann equation corresponds to the classical transport equation. This allows us to consider the solutions of the associated Hamilton's equations to obtain the evolution of the Wigner distribution function.

We simulate the optical guiding of a thermal cloud inside a laser beam (optical dipole potential) and delta kick collimation with magnetic lense [2, 3]. This is helpful for testing and optimising matter wave optics, as needed for matter wave interferometers [1].

References:

[1] Mathias Schneider, *Semi-classical description of matter wave interferometers and hybrid quantum systems*, Doktorarbeit, Technische Universität Darmstadt (2014)

[2] Hubert Ammann and Nelson Christensen, *Delta Kick Cooling: A New Method for Cooling Atoms*, Phys. Rev. Lett. 78, 2088 (1997)

[3] H. Müntinga et al., *Interferometry with Bose-Einstein Condensates in Microgravity*, Phys. Rev. Lett. 110, 093602 (2013)

Q 58.10 Thu 16:30 P

Time-averaged potentials for optical matter-wave lensing — •Simon Kanthak[1,2], Gilad Kaplan[1], Martina Gebbe[3], Ekim Hanimeli[3], Matthias Gersemann[4], Mikhail Cheredinov[4], Sven Abend[4], Ernst M. Rasel[4], Markus Krutzik[1,2], and the QUANTUS team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Quantenoptik, LU Hannover

Residual expansion and size of Bose-Einstein condensates, determined by the features of the release trap and repulsive atom-atom interactions, become the limiting factors for signal extraction in atom interferometry on long timescales. Attempts to overcome these limitations include precisely shaping the expansion of the atomic ensembles after the release via matter-wave lensing.

Optical potentials allow for the flexible creation of matter-wave lenses of different shapes and refractive powers [1]. Here, we report on the realization of and results with our dipole trap setup, which features an acousto-optical deflector to tailor potentials in multiple dimensions. With this setup, versatile optical lens systems can be engineered in pulsed schemes for ground-based sensors, which open the opportunity to compensate the center-of-mass motion of the atoms or to counteract anharmonicities of the release traps.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

[1] S. Kanthak et al., 2021, *New J. Phys.* 23, 093002