Q 63: Matter Wave Optics

Time: Friday 10:30–12:30 Location: Q-H10

Q 63.1 Fri 10:30 Q-H10

Bragg diffraction of large organic molecules — Christian Brand[1,2], Filip Kiałka[1,3], Stephan Troyer[1], Christian Knobloch[1], •Ksenija Simonović[1], Benjamin A. Stickler[3,4], Klaus Hornberger[3], and Markus Arndt[1] — [1]University of Vienna, Faculty of Physics — [2]German Aerospace Center (DLR), Institute of Quantum Technologies — [3]Faculty of Physics, University of Duisburg-Essen — [4]QOLS, Blackett Laboratory, Imperial College London

We present the first experimental realization of Bragg diffraction for polar and non-polar molecules [1]. Using a thick laser grating at 532 nm, we diffract a molecular beam and observe Bragg diffraction in the far-field. We study this effect for the dye molecule phthalocyanine and the antibiotic ciprofloxacin and observe a pronounced angular dependence and asymmetry in the pattern, characteristic for Bragg diffraction. We can thus realize an effective mirror and a large-momentum molecular beamsplitter with a momentum transfer of up to 18 grating photon momenta $\hbar k$. This is an important step towards gaining control over the manipulation of functional, complex molecules.

[1] Brand et al. Phys. Rev. Lett. 125, 033604

Q 63.2 Fri 10:45 Q-H10

Efficient aberration analysis of Bose-Einstein condensates — •Jan Teske and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

Matter-wave interferometry with ultracold atoms is paving the way to a new era of quantum technologies. Recent milestones of space application are space-borne Bose-Einstein condensates [1] and BECs in Earth's orbit on ISS [2]. These achievements require precision modeling of matter-wave optics. In photonic optics, aberrations are efficiently described by Zernike's orthogonal "Kreisflächenpolynome" representing the optical path difference between light waves and a reference wavefront [3].

In this contribution, we present a (3+1)-dimensional aberration analysis for matter-wave optics with Bose-Einstein condensates. Motivated by the intrinsic properties of an interacting condensate, we use a set of orthogonal basis functions to perform a multipole expansion to quantify distortions of the atomic cloud. The resulting aberration coefficients encode the relevant information of the condensate wave function leading to efficient data compression of realistic 3D simulations.

[1] D. Becker et al., Nature 562, 391 (2018)
[2] D. C. Aveline et al., Nature 582, 193 (2020)
[3] F. Zernike, Physica 1, 689 (1934)

Q 63.3 Fri 11:00 Q-H10

Matter-wave Gravimetry Based on Tunneling — •Patrik Schach and Enno Giese — Institut für Angewandte Physik, Technische Universität Darmstadt

One promising candidate for high-precision gravimetry is atom interferometry. In contrast to light in optical interferometers, matter waves consisting of massive particles couple strongly to gravity, making them a tool suitable for gravimetry. In addition to gravity, the motion of atomic wave packets is manipulated by optical potentials that trap, guide or diffract the atoms. Contrary to classical waves, quantum physics allows for tunneling through forbidden regions and thus offers an additional tool to influence the atomic motion.

The combination of quantum tunneling and atom interferometers leads to gravimeters based on an analogue to optical Fabry-Pérot cavities. In this contribution, we theoretically study the transmission spectrum of matter-wave Fabry-Pérot interferometers, present their sensitivity to accelerations and discuss their applicability to gravimetry. Similar to optical Fabry-Pérot cavities that act as monochromators, matter-wave devices introduce a velocity filtering, allowing to select specific momenta of the atomic wave packet. In addition to this effect, we study the preparation of a quantum gas inside the cavity and its asymmetry in tunneling, an effect that has no direct optical analogue.

Q 63.4 Fri 11:15 Q-H10

Chip-based manipulation of guided electrons with autoponderomotvie potentials — •Michael Seidling, Franz Schmidt-Kaler, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Recent advances in free electron beam guiding and beam splitting for electrons from the eV to the keV range are reported [1, 2]. Electron beam guiding and splitting is based on auto-ponderomotive forces generated by the motion of charged particles through electrostatic electron optics on planar substrates. In the co-moving frame of the electron, the electrostatic fields transform into an alternating potential, and thus the electrons are subject to the same transverse restoring forces as in a conventional linear Paul trap driven with oscillating fields. The confinement of electrons in the two directions perpendicular to the direction of motion is determined by the electrodes* layout. In the future coherent electron beam splitting should be feasible using auto-ponderomotive potentials, enabling new coherent charged matter wave experiments. [1] Zimmermann, R., Seidling, M. & Hommelhoff, P. Charged particle guiding and beam splitting with autoponderomotive potentials on a chip. Nat Commun 12, 390 (2021). https://doi.org/10.1038/s41467-020-20592-4 [2] M. Seidling, R. Zimmermann, and P. Hommelhoff, "Chip-based electrostatic beam splitting of guided kiloelectron volt electrons", Appl. Phys. Lett. 118, 034101 (2021) https://doi.org/10.1063/5.0030049

Q 63.5 Fri 11:30 Q-H10

Bragg-Josephson effect in matter-wave beamsplitters — •Oleksandr Marchukov and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

The Josephson effect is one of the few known macroscopic quantum effects. While initially predicted and observed in superconductors, it has been shown in externally trapped Bose-Einstein condensates (BECs), as well as internally prepared superpositions of hyperfine levels [1, 2]. In the QUANTUS collaboration [3] matter-wave Bragg beamsplitters are a central tool. Here we demonstrate the Josephson effect between two macroscopic occupied momentum states $-k_L \to +k_L$ coupled by a Bragg beamsplitter [4] in interacting BECs.

We construct an analytical model and demonstrate how the competition between the Bragg diffraction and mean-field interaction leads to the Josephson-like equations. We compare our analytical calculations with numerical simulations and find good agreement. Finally, we evaluate the experimental parameters that would allow for the observation of the effect, based on the realistic experimental set-ups.

[1] S. Raghavan et al., Phys. Rev. A 59, 620 (1999)
[2] J. Williams et al., Phys. Rev. A 59, R31 (1999)
[3] https://www.zarm.uni-bremen.de/en/research/space-science/experimental-gravitation-and-quantum-optics/projects/quantus-2.html
[4] A. Neumann et al., Phys. Rev. A 103, 043306 (2021)

Q 63.6 Fri 11:45 Q-H10

Atomic diffraction through single-layer graphene — •Christian Brand[1,2], Maxime Debiossac[2], Toma Susi[2], Francois Aguillon[3], Jani Kotakoski[2], Philippe Roncin[3], and Markus Arndt[2] — [1]German Aerospace Center, Institute of Quantum Technologies — [2]University of Vienna, Faculty of Physics — [3]Université Paris Saclay, Institut des Sciences Moléculaires d' Orsay

We discuss the prospect of diffracting fast atomic matter waves through atomically thin membranes, such as graphene. Using hydrogen atoms with a velocity of up to 120'000 m/s, we predict a high probability of coherently diffracting the matter wave through the crystalline grating. As the atom-membrane interaction is encoded in the matter wave, interaction microscopy on the pm-scale might be possible. The natural lattice constant of 246 pm furthermore leads to unusual wide diffraction angles in the regime of mrad, which are interesting for novel applications in atom interferometry.

[1] Brand et al., New J. Phys **21**, 033004 (2019)

Q 63.7 Fri 12:00 Q-H10

Double Bragg atom interferometry with BECs in microgravity — •Julia Pahl[1], Merle Cornelius[2], Peter Stromberger[3], Laura Pätzold[2], Waldemar Herr[4,5], Sven Herrmann[3], Patrick Windpassinger[3], Christian Schubert[5], Ernst M. Rasel[4], Markus Krutzik[1,6], and The QUANTUS Team[1,2,3,4,7,8] — [1]HU

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QUANTUS-2 is a high-flux Bose-Einstein condensate (BEC) experiment operating in microgravity at the ZARM drop tower in Bremen. Its functionality is extended with a rubidium atom interferometry setup based on double Bragg diffraction. We present our latest results on the performance of open interferometer archtictures (Ramsey-type and Mach-Zehnder) in free fall. In combination with a magnetic lens, we are able to enhance the atomic signal on longer time scales. By studying the resulting fringe pattern, we can further spatially resolve the velocity distribution of the ensembles.

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Q 63.8 Fri 12:15 Q-H10

Quantum state engineering of quantum gases in orbit —
•Annie Pichery[1], Matthias Meister[2], Nicholas P. Bigelow[3], Naceur Gaaloul[1], and the CUAS Team[1] — [1]Institut für Quantenoptik, Leibniz University Hannover, Hannover, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [3]The Institute of Optics, University of Rochester, New York, USA

Ensembles of cold atoms behave as matter-waves and are routinely used for quantum sensing experiments. Space provides an environment where atoms can float for extended times, but the free expansion and the inherent atomic density drop make the signal detection difficult. By analogy with light, it is possible to collimate the clouds with atomic lenses, using the delta-kick collimation technique. In this contribution, we present a protocol for controlling the expansion of condensed Rb clouds applied to experiments in the NASA Cold Atom Laboratory (CAL) on board of the International Space Station that led to expansion energies at the tens of picokelvin level. This is made possible thanks to an accurate quantum state preparation of the atomic source that makes it compatible with the most stringent requirements of precision atom interferometry experiments.

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