Q 55: Matter Wave Optics

Time: Friday 11:00–13:00 Location: a310

Q 55.1 Fri 11:00 a310

Quantum-Assisted Metrology in a Long-Baseline Matter-Wave Interferometer — •Sebastian Pedalino, Yaakov Fein, Philipp Geyer, Filip Kiałka, Stefan Gerlich, and Markus Arndt — Faculty of Physics, University of Vienna, Austria

Molecule interferometry is an intriguing tool to probe the foundations of quantum physics and it provides a useful platform for quantum assisted molecular measurements, where the interference fringes on the nanoscale can be shifted and detected with nanometer accuracy. Here we present an upgraded technique to measure molecular properties, using the Long-Baseline Universal Matter-wave Interferometer (LUMI), a near-field interferometer designed for complex massive particles. Using LUMI we have recently demonstrated quantum superposition of molecules with masses exceeding 25 kDa and consisting of up to 2000 atoms [1]. The interferometer is able to probe the quantum nature of matter with de Broglie wavelengths down to 35 fm and it has an inertial force sensitivity of 10^{-26} N. The introduction of external fields allows us to explore the electronic, optical, magnetic and structural properties of a wide range of particles. We demonstrate these capabilities by measuring the static scalar polarizability of the fullerenes C_{60} and C_{70} [2] with improved precision. We have also measured for the first time the ground state diamagnetism of isolated barium and strontium in an atomic beam.

[1] Fein, Y.Y. et al. Nat. Phys. (2019) doi:10.1038/s41567-019-0663-9
[2] Fein, Y.Y. et al. Phys. Rev. Research (2019) doi: 10.1103/PhysRevResearch.00.003000

Q 55.2 Fri 11:15 a310

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

Micro-gravity experiments open new opportunities for quantum sensing technologies using cold atoms. In particular, the sensitivity of atom interferometers with Bose-Einstein condensates as a coherent atomic source benefit from long expansion times [1,2]. However, imperfections need to be considered carefully to avoid contrast loss in matter-wave interferometry.

For this purpose, we characterize the possible aberrations of an interacting condensate with optimal 3D basis functions, analogous to the wavefront decomposition in terms of Zernike polynomials in classical optics. We obtain analytical expressions for the hydrodynamic modes of an expanding Bose-Einstein condensate in the Thomas-Fermi limit [3,4] and compare them with numerical results.

[1] T. van Zoest *et al.*, Science **328**, 1540, (2010)
[2] D. Becker *et al.*, Nature **562**, 391 (2018)
[3] S. Stringari, PRL **77**, 2360 (1996)
[4] M. Fliesser *et al.*, PRA **56**, R2533(R)

Q 55.3 Fri 11:30 a310

Novel techniques for simplified cold atomic gravimeters — •Julia Pahl[1], Benjamin Wiegand[1], Bastian Leykauf[1], Klaus Döringshoff[1], Y Durvasa Gupta[1], Merle Cornelius[3], Peter Stromberger[5], Achim Peters[1,2], Markus Krutzik[1,2], and THE QUANTUS Team[1,3,4,5,6,7] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz — [6]U Ulm — [7]TU Darmstadt

Cold atom experiments performed in practical instruments outside the lab need to satisfy strict demands on the SWaP budget (size, weight and power). In this talk, we present a technique for magneto-optical cooling and trapping of neutral Rb atoms with just a single laser [1]. Here, an agile light source, based on a micro-integrated extended cavity diode laser, is used to sequentially switch between cooling and repumping transition frequencies. We present the characterization of this alternating-frequency MOT (AF-MOT) and further discuss a simple method to determine the local gravitational acceleration by repetitive levitation of a Rb BEC with a single-frequency laser beam. Together, these techniques may be used to reduce the complexity of the laser system architecture required for cold atomic gravity sensors. This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1552-1557 and 50WP1432.

[1] Wiegand et al., *A single-laser alternating-frequency magneto-optical trap*, Rev. Sci. Instrum. **90, 1032202** (2019)

Q 55.4 Fri 11:45 a310

Diffraction of atomic matter-waves through crystalline materials — •Christian Brand[1], Maxime Debiossac[1], Toma Susi[1], Francois Aguillon[2], Jani Kotakoski[1], Philippe Roncin[2], and Markus Arndt[1] — [1]Universität Wien, Fakultät für Physik, A-1090 Wien, Austria — [2]Université Paris-Saclay, Institut des Sciences Moléculaires d'Orsay, F-91405 Orsay, France

In modern atom interferometers clouds of ultra-cold atoms are diffracted at laser gratings, allowing for high precision force sensing [1]. Here we discuss the complementary approach of diffracting atomic hydrogen with a velocity of up to 120.000 m/s through crystalline membranes [2]. Our analysis describes the interaction of the atomic matter-wave with the grating using TDDFT/MD simulations. Even though the simulations predict sizable coupling of the atom to the electronic system of graphene, we find a surprisingly high chance of coherent diffraction through roughly a sixth of the hexagon's area. As the grating period is 400 times smaller than in state-of-the-art nanomachined gratings [3], we predict unusual wide diffraction angles in the 10 mrad regime.

We envision this technique to give new insights into velocity-dependent effects, such as quantum friction, and for gravitational wave detection.

[1] G. M. Tino and M. A. Kasevich, Atom Interferometry (2014)
[2] C. Brand *et al.*, New J. Phys. **21** 033004 (2019)
[3] C. Brand *et al.*, Nat. Nanotechnol. **10** 845 (2015)

Q 55.5 Fri 12:00 a310

Bragg diffraction of polyatomic molecules — Christian Brand[1], Filip Kiałka[1], Stephan Troyer[1], Christian Knobloch[1], •Ksenija Simonović[1], Benjamin A. Stickler[2,3], Klaus Hornberger[2], and Markus Arndt[1] — [1]Universität Wien, Fakultät für Physik, Austria — [2]Faculty of Physics, University of Duisburg-Essen, Germany — [3]QOLS, Blackett Laboratory, Imperial College London, United Kingdom

Bragg diffraction is a widely used technique to manipulate atomic matter-waves in state-of-the art interferometers [1,2]. Here we present the first experimental realization of Bragg diffraction for complex molecules [3]. Using a thick laser grating at 532 nm, we diffract a well-collimated molecular beam and observe Bragg diffraction 0.7 m further downstream. We study this effect for the dye molecule phthalocyanine as well as for the antibiotic ciprofloxacin. The molecules are hot and may additionally absorb several photons during their passage through the laser grating. Nevertheless, we observe a pronounced angle-dependence and asymmetry in the pattern, characteristic for Bragg diffraction, illustrating the universality and robustness of the process. We can thus realize an effective mirror and large-momentum beam splitter for molecules with a momentum transfer of up to 14 $\hbar k_L$. This is an important step towards gaining control over the manipulation of functional, complex molecules.

[1] P. J. Martin *et al.*, Phys. Rev. Lett. **60** 515 (1988) [2] G. M. Tino and M. A. Kasevich, ed. *Atom Interferometry* (2014) [3] C. Brand *et al.*, submitted for publication

Q 55.6 Fri 12:15 a310

An atom interferometer testing the gravitational redshift — •Christian Ufrecht[1], Fabio Di Pumpo[1], Alexander Friedrich[1], Albert Roura[2], Christian Schubert[3], Dennis Schlippert[3], Ernst M. Rasel[3], Wolfgang P. Schleich[1,2], and Enno Giese[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm — [3]Institut für Quantenoptik, Leibniz Universität Hannover

Light-pulse atom interferometers are based on delocalized spatial superpositions and the combination with internal-state transitions directly links them to atomic clocks. This property leads to the question whether such interferometer are sensitive to the gravitational redshift. We present a specific geometry exploiting state transitions during the interferometer sequence which provides us with this sensitivity. In contrast to Ref. [1], the proposed scheme does not rely on a superposition of internal states, but merely on transitions between them, and therefore generalizes the concept of physical atomic clocks and quantum-clock interferometry.

[1] Roura, A., Gravitational redshift in quantum-clock interferometry, ArXiv:1810.06744 (2018)

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Q 55.7 Fri 12:30 a310

Atomic Raman vs. Bragg diffraction in microgravity — •Sabrina Hartmann[1], Jens Jenewein[1], Enno Giese[1], Albert Roura[2], Wolfgang P. Schleich[1,2], and the QUANTUS team[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt

The design of future atom-interferometric space missions requires making a decision about the main diffraction mechanism, Bragg [1] or Raman, at an early stage. With this goal in mind, we present a comprehensive study of Raman and Bragg diffraction in a retro-reflective geometry. This setup allows to couple to one (single diffraction) or two counter-propagating light gratings (double diffraction) [2,3] and to observe the transition from one case to the other through a change of the Doppler detuning.

We show that single Raman diffraction reaches high efficiencies for a broad parameter regime, but double Raman diffraction can only be performed efficiently in a Bragg-type regime due to additional off-resonant couplings. Moreover, broad momentum distributions experience appreciable losses in a double-diffraction scheme during a mirror pulse [4].

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

[1] *NJP* **14**, 023009 (2012).
[2] *PRA* **88**, 053608 (2013).
[3] *PRL* **116**, 173601 (2016).
[4] *arXiv*: 1911.12169 (2019).

Q 55.8 Fri 12:45 a310

Non-perturbative treatment of quasi-Bragg diffraction phases for atom interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[2], Sven Abend[2], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Bragg diffraction is a cornerstone of light-pulse atom interferometry. High-fidelity Bragg pulses for atomic sources with a finite velocity distribution typically operate in the quasi-Bragg regime. While enabling an efficient population transfer, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of the interferometer.

In our work, we formulate Bragg diffraction in terms of scattering theory. We provide an intuitive understanding of the Bragg condition and derive a unitary scattering matrix in case of adiabatic driving with Gaussian pulses. We find, that perturbations of the adiabatic solution are well described by Landau-Zener physics. Furthermore, we include the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

As an illustration, with our comprehensive microscopic model we study diffraction phase shift fluctuations caused by laser intensity noise affecting the sensitivity of a Mach-Zehnder atom interferometer.

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