Q 21: Matter Wave Optics

Time: Tuesday 14:30–16:30 Location: a310

Q 21.1 Tue 14:30 a310

Impact of retro–reflective geometries on atomic Bragg diffraction — •Alexander Friedrich[1], Enno Giese[1], Wolfgang P. Schleich[1], and Ernst M. Rasel[2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology ($\mathrm{IQ}^{\mathrm{ST}}$), Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Light–pulse based atom interferometry has become a valuable tool for high precision measurements of inertial forces, fundamental constants and tests of the weak equivalence principle. Most light–pulse interferometers rely on either Bragg or Raman diffraction. In both cases wave–front distortions and the effects of mirror vibrations can be reduced by retroreflective setups with two counterpropagating laser pairs from a common optical fibre. This approach comes at the cost of introducing off–resonant transitions into the diffraction process which contribute to the phase of the matter wave and thereby the interferometer phase. In case of Raman diffraction this so called two–photon light shift is well understood.[1,2] We present an analogue analysis as well as analytic expressions for the two–photon light shift in Bragg diffraction. Furthermore we demonstrate that this behaviour can be significantly improved by appropriately shaping the pulse envelopes.

[1] A. Gauguet et al., Phys. Rev. A **78**, 043616 (2008)
[2] T. Lévèque et al., Phys. Rev. Lett. **103**, 080405 (2009)

Q 21.2 Tue 14:45 a310

Modeling molecular diffraction at ultra-thin gratings — •Christian Brand[1], Johannes Fiedler[2], Thomas Juffmann[1,3], Michele Sclafani[1,4], Christian Knobloch[1], Stefan Scheel[2], Yigal Lilach[5], Ori Cheshnovsky[5], and Markus Arndt[1] — [1]University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria — [2]University of Rostock, Institute of Physics, Albert-Einstein-Straße 23, 18055 Rostock — [3]Stanford University, Physics Department, 382 Via Pueblo Mall, Stanford, USA — [4]ICFO - Institut de Ciènces Fotòniques, 08860 Castelldefels (Barcelona), Spain — [5]School of Chemistry, Tel-Aviv University, Tel Aviv 69978, Israel

For quantum diffraction experiments with molecular matter-waves material gratings have the advantage that they are independent of the particles' internal properties. However, this universality is limited by the attractive Casimir-Polder interaction which might remove molecules from the beam and thereby prevents them from traversing the gratings. Here we compare three different theoretical models to describe the attractive interaction between a molecular matter-wave and a material grating at different scales of complexity. While even simple approximations lead to reliable results and give significant physical insights, simulations based on quantum electrodynamics point to the influence of an additional attractive contribution in the experiments. These are identified as originating from charges in the grating material, implanted during the fabrication process. The consequences for matter-wave diffraction of complex particles are discussed.

Q 21.3 Tue 15:00 a310

Matter-wave interferometry and its application to molecular spectroscopy — •Johannes Fiedler and Stefan Scheel — Institute of Physics, University of Rostock, Rostock, Germany

The wave-particle duality provides a wide range of interesting effects on microscopic objects such as atoms, molecules or clusters. One of them is the possibility to create interferences by diffraction on a periodic structure, e.g. standing-wave laser fields or material gratings. Current experiments investigate the influence of the particle mass on their interference capability. At present, the wave nature of particles has been demonstrated for masses up to 10,000 a.m.u. [1]. Of particular interest is the interference of particles at material diffraction gratings. During the diffraction process, the particles achieve very small distances to the grating bars. Hence, the Casimir-Polder interaction of the particles with the object becomes important [2]. To a good approximation the interaction can be described by a phase shift. Consequently, this phase shift is engraved in the interference pattern. We will present a possible measurement set-up to fully reconstruct a matter wave by using a combination of measuring the amplitude of the interference pattern and the phase of the wave with an adapted Hartmann-Shack sensor. With the knowledge of the wave front, together with the geometry of the interferometer, we will present an algorithm for the estimation of the Casimir-Polder potential and the polarisabilty of the involved particle.

[1] S. Eibenberger, S. Gerlich et al., Phys. Chem. Chem. Phys. 15, 14696 (2013). [2] C. Brand, J. Fiedler et al., Ann. Phys. (Berlin) 527, 580 (2015).

Q 21.4 Tue 15:15 a310

Quantum reflection and Liouville transformations — •Gabriel Dufour[1,2], Romain Guérout[2], Astrid Lambrecht[2], and Serge Reynaud[2] — [1]Institute of Physics, Albert-Ludwigs University, Freiburg, Germany — [2]Laboratoire Kastler Brossel, UPMC-Sorbonne Universités, Paris, France

Collisions of ultracold atoms with surfaces are governed by quantum reflection of the atomic matter wave from the attractive Casimir-Polder potential. While no reflection is expected classically, the quantum reflection probability goes to one for slow atoms and weak atom-surface interactions. These counterintuitive results are best understood by performing a Liouville transformation of the Schrödinger equation, which preserves the scattering amplitudes while changing the potential landscape. We discuss the properties of these transformations and introduce a special choice of coordinate which allows one to map the problem of quantum reflection on the Casimir-Polder potential well onto that of reflection on a repulsive wall [1]. Within this new approach, we identify the parameters which determine the reflection probability. These results have implications for the GBAR project at CERN, which aims to measure the acceleration of gravity for a cold antihydrogen atom [2].

[1] G. Dufour, R. Guérout, A. Lambrecht, and S. Reynaud, EPL 110, 30007 (2015), J. Phys. B: At. Mol. Opt. Phys. 48, 155002 (2015).
[2] G. Dufour, D. B. Cassidy, P. Crivelli, P. Debu, A. Lambrecht, V. V. Nesvizhevsky, S. Reynaud, A. Y. Voronin, and T. E. Wall, Advances in High Energy Physics 2015, 379642 (2015).

Q 21.5 Tue 15:30 a310

Atomic quantum superpostion at the half-meter scale — Tim Kovachy, •Peter Asenbaum, Chris Overstreet, Christine Donnelly, Susannah Dickerson, Alex Sugarbaker, Jason Hogan, and Mark Kasevich — Stanford University, Stanford, US

In matter wave interferometers, large wave packet separation is impeded by the need for long interaction times and large momentum beam splitters, which cause susceptibility to decoherence and dephasing. We use light-pulse atom interferometry to realize quantum interference with wave packets separated by up to 54 cm on the time scale of one second. Large superposition states are vital to exploring gravity with atom interferometers in greater detail, e.g. tests of the equivalence principle.

Q 21.6 Tue 15:45 a310

QUANTUS-2 - towards a dual species matter wave interferometer in free fall — •Christian Deppner[1], Ernst Maria Rasel[1], and THE QUANTUS Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Physik, Humboldt Universität zu Berlin — [3]ZARM, Universität Bremen — [4]Institut für Physik, Johannes Gutenberg Universität Mainz — [5]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [6]Institut für Quantenphysik, Universität Ulm — [7]Institut für angewandte Physik, TU Darmstadt

QUANTUS-2 is a mobile high-flux Rb BEC source used for experiments in microgravity in the Bremen drop tower. To further decrease the residual expansion rate of the BEC, magnetic lensing - also known as delta-kick cooling - is crucial for observations after long evolution times in the range of seconds. Here we present our results of a lens, which leads to an observability of the BEC of up to 2.7 s after free expansion, only limited by the microgravity-duration in the drop tower. Anharmonicities of the magnetic lensing potential can introduce distortions of the BEC's shape. We discuss the neccessary steps towards harmonic lensing and report our results. This will - in the future - allow us to demonstrate atom interferometry with unprecedented sensitivity on time scales on the order of seconds.

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Q 21.7 Tue 16:00 a310

Circumventing Heisenberg's uncertainty principle in atom interferometry tests of the equivalence principle — •Albert Roura and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

Atom interferometry tests of universality of free fall based on the differential measurement of two different atomic species provide a useful complement [1] to those based on macroscopic masses. However, gravity gradients pose a serious challenge. In order to achieve very high sensitivities, the relative initial position and velocity for the two species need to be controlled with extremely high accuracy, which can be rather demanding in practice and whose verification may require rather long integration times. Furthermore, gravity gradients lead to a drastic loss of contrast. These difficulties can be mitigated by employing wave packets with narrower position and momentum widths, but this is ultimately limited by Heisenberg's uncertainty principle. We present a novel scheme that simultaneously overcomes the loss of contrast and the initial co-location problem [2]. In doing so, it circumvents the fundamental limitations due to Heisenberg's uncertainty principle and eases the experimental realization by relaxing the requirements on initial co-location by several orders of magnitude.

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556.

[1] D. Schlippert *et al.*, Phys. Rev. Lett. **112**, 203002 (2014)
[2] A. Roura, `arXiv:1509.08098`

Q 21.8 Tue 16:15 a310

Multiparticle correlations in complex scattering: birthday paradox and Hong-Ou-Mandel profiles in mesoscopic systems — •Juan-Diego Urbina[1], Jack Kuipers[1], Klaus Richter[1], Quirin Hummel[1], and Sho Matsumoto[2] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Graduate School of Science and Engineering, Kagoshima University, 1-21-35, Korimoto, Kagoshima, Japan

In this presentation we generalize the Hong-Ou-Mandel effect to the mesoscopic regime of complex scattering and to macroscopically occupied incoming wavepackets. This is aachieved by a complete enumeration of all processes in terms of interfering many-body paths that allow us to study universal effects due to the interplay between instability of the single-particle classical motion and quantum indistinguishability.

We show how, in the limit of large particle number, one finds a mesoscopic version of the bosonic birthday paradox responsible for a sharp quantum-classical transition. Furthermore, under a scaling that defines the classical-quantum boundary we predict a macroscopic, experimentally accessible Hong-Ou-Mandel profile. Our methods can be extended to the quantum optics domain, and point towards a mesoscopic implementation of the boson sampling problem.