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Time-domain matter-wave interferometry with clusters and large molecules

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ABSTRACT

Over the last decades, research on matter waves has become a thriving field for studying fundamental physical phenomena. This research is based on the superposition principle, which allows quantum systems to be in coherent superpositions of mutually-excluded states. It is one of the most basic principles in quantum physics, even though it appears counterintuitive. Matter-wave interferometry allows to probe the linearity of quantum mechanics for ever more macroscopic objects and, thus, to test models that suggest modifications of standard quantum mechanics for massive nanoparticles. This thesis discusses the efforts and challenges towards quantum interference with macroscopic particles, which requires the development of suitable particle sources and interferometric schemes.

This work presents the implementation of an optical matter-wave interferometer for clusters and large molecules. In this experiment, we use pulsed absorptive light gratings in combination with Talbot - Lau interferometry in the time domain. Neutral particles fly alongside a mirror, which reflects three UV lasers pulses in equal time intervals. The generated standing waves act as transmission masks by removing particles from their anti-nodes upon single-photon absorption. In contrast to material masks, light gratings can be operated in a pulsed mode, which renders the longitudinal velocity of the particles less important for interferometry and, thus, promises gain in measurement precision.

I discuss the characteristics of this experiment with interference data of clusters of various organic molecules in a mass range up to 3000 u. We exploit photo-ionization and photo-fragmentation as depletion processes in the laser gratings, which render the interferometer suitable for a large class of nanoparticles. It may act on atoms, molecules but also giant clusters and is, thus, a promising tool to test the validity of quantum theory for particles with masses potentially up to 10^6 u. I present our efforts towards and possible scenarios for breaking mass records in nanoparticle interferometry. The demonstrated technology will enable future tests of the quantum superposition principle in so far unexplored mass regimes.