Exerting better control over matter waves

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(PhysOrg.com) -- “The concept of matter waves is at the heart of quantum mechanics,” Oliver Morsch tells *PhysOrg.com*. “At the beginning of the last century, scientists discovered that solid particles could exhibit properties of waves, such as interference and diffraction. Until then, it was assumed that only light behaved as a wave. But in the quantum world everything is basically a wave.”

Morsch is part of a group of scientists, including Alessandro Zenesini, Hans Lignier, Donatella Ciampini and Ennio Arimondo, at the University of Pisa in Italy. The group has discovered a way to more efficiently control matter waves in a setup that simulates a solid state system. “Once you have control over a quantum system,” Morsch explains, “you can learn any number of things, especially from a fundamental point of view. Additionally, it is worth noting that almost all of our modern technology is related in some way to quantum mechanical principles.” The group’s technique is described in *Physical Review Letters:* “Coherent Control of Dressed Matter Waves.”

In order to control the matter waves, Morsch and his colleagues created an optical lattice. “We, in effect, create a light crystal,” Morsch says. “It’s not a true solid, but it mimics the crystal lattice of a solid. It provides us with a sort of model system for solid state applications, allowing us to perform experiments without being bound by the naturally given physical properties of a solid.” Once the lattice is created, using lasers and mirrors, the Pisa University group shook the mirrors - and hence the optical lattice - to create a phenomenon known as dynamic localization.

“It’s very counter-intuitive,” Morsch says of dynamic localization. “Before we shake the lattice, atoms move freely throughout by quantum tunneling. However, once we apply the shaking, they stop moving. For certain values, we can make sure that atoms stay put in one lattice site. We can also create a quantum phase transition so that the system changes its bulk properties when you change a parameter. In our experiment, we create a phase transition by shaking. That is our control over the matter waves.”

Instead of being a top to bottom approach, the Pisa group is interested in starting at the bottom - with individual particles. “Rather than trying to tweak the bulk system,” Morsch explains, “we are trying to tweak the properties of the individual particles to meet our needs. We are controlling the matter wave to shape it to our needs, and then using that to control the larger system.”

Morsch points out that, right now, this process is most interesting from a fundamental point of view. However, he believes that it is likely to develop into greater uses in the future. Morsch thinks that this method has potential applications in quantum control schemes, which could be important in the development of quantum computers and in directed chemical reactions. “If you look at the history of physics and quantum mechanics, you find that each time you develop another handle on the quantum world - somehow learn how to better control the properties of a quantum system - new inventions and technology come about. This method of control is so new that it is impossible to really predict what, if anything, might come out of it.”

“For the most part,” Morsch continues, “this work represents yet another method that will give us more control over the quantum state of single particles. Over the last 15 or 20 years, it has become possible, and increasingly important, to exert control at the single-particle level. Our demonstration is in line with what existing theory shows, and could be another tool for the development of future quantum-based technologies.”

More information: Alessandro Zenesini, Hans Lignier, Donatella Ciampini, Oliver Morsch, and Ennio Arimondo, “Coherent Control of Dressed Matter Waves.” *Physical Review Letters* (2009). Available online: link.aps.org/doi/10.1103/PhysRevLett.102.100403 .