Cavity soliton Bloch oscillations in a synthetic dimension:
When fiber optics shed light on solid-state physics phenomena

Research - publication

Publication in Nature-Physics: researchers from two laboratories at ULB have realized a synthetic dimension for light using a fiber optical ring. This ingenious system allows to simulate the periodic motion of a particle in a crystal and to study its behavior in the presence of interactions and dissipation. By creating a soliton, the researchers demonstrated the existence of permanent oscillations, despite the detrimental effects of dissipation. This discovery offers a strong potential for the study and modeling of complex phenomena inspired from solid-state physics, which are difficult to access in their natural environment.

The formation of periodic structures such as optical lattices gives access to the investigation of various complex phenomena in solid-state physics, condensed matter, and photonics, among others. In particular, extending these systems beyond their natural geometrical dimensionality is a growing field of research through the implementation of "synthetic dimensions." Such a synthetic space can be realized by exploiting the system's discrete degree of freedom of the system, which, associated with a coupling mechanism, mimics the motion of a particle moving within a crystal lattice. An original
way to create a synthetic dimension in photonics is to implement it in the frequency domain (wavelengths of light) through an optical resonator. The periodicity imposed by the cavity roundtrip time acts as an optical rule. One can then form the artificial lattice by coupling these frequency modes using an intracavity phase modulator.

The resulting synthetic dimension is very similar to that formed by a one-dimensional crystal, where atoms are coupled to their nearest neighbor. Therefore, we expect to observe phenomena from solid-state physics. Among others, synthetic dimensions have been exploited to observe Bloch oscillations - the motion described by particles confined in a periodic potential when subjected to a constant force. This phenomenon - worthy of the 1952 Nobel Prize in Physics - is known to disappear when the system is dissipative or in the presence of interactions. In fact, they are not observed in solids.

In this context, researchers from two ULB laboratories, the Laboratoire interdisciplinaire Carnot de Bourgogne (Dijon), and the University of Auckland (NZ) have implemented a synthetic dimension with dissipation, dispersion and nonlinearity to study the fate of these oscillations. Thanks to the system's nonlinearity, they were able to form a peculiar light pulse called "cavity soliton" and observe permanent Bloch oscillations despite the dissipation. In addition to being the first experimental demonstration of Bloch oscillations in that framework, the intrinsic properties of the cavity soliton allow, on the one hand, to extend the synthetic dimension far beyond previous realizations thanks to the formation of a frequency comb and, on the other hand, to probe the reciprocal space by virtue of its ultrashort temporal duration.

This discovery holds great potential for studying and modeling complex phenomena from condensed matter physics that are difficult to investigate in their natural environment. These results also pave the way for new applications, notably in topological photonics and for the generation of optical frequency combs.

This work carried out in the framework of an international collaboration between two ULB laboratories (OPERA-Photonics and the Center for Nonlinear Phenomena and Complex Systems) as well as France and New Zealand, has been published in the prestigious scientific journal Nature Physics.

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