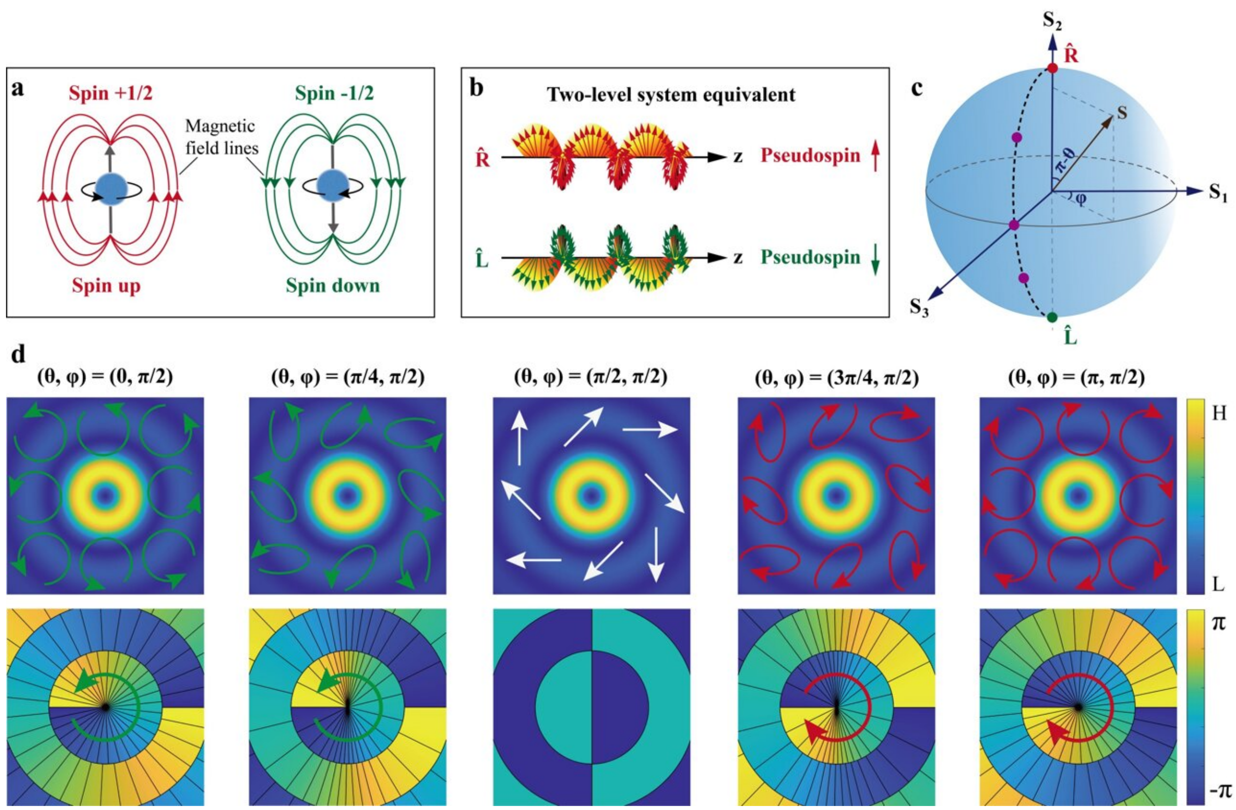
Uncovering the secrets of spin-orbit optical Rabi oscillations

October 12 2023



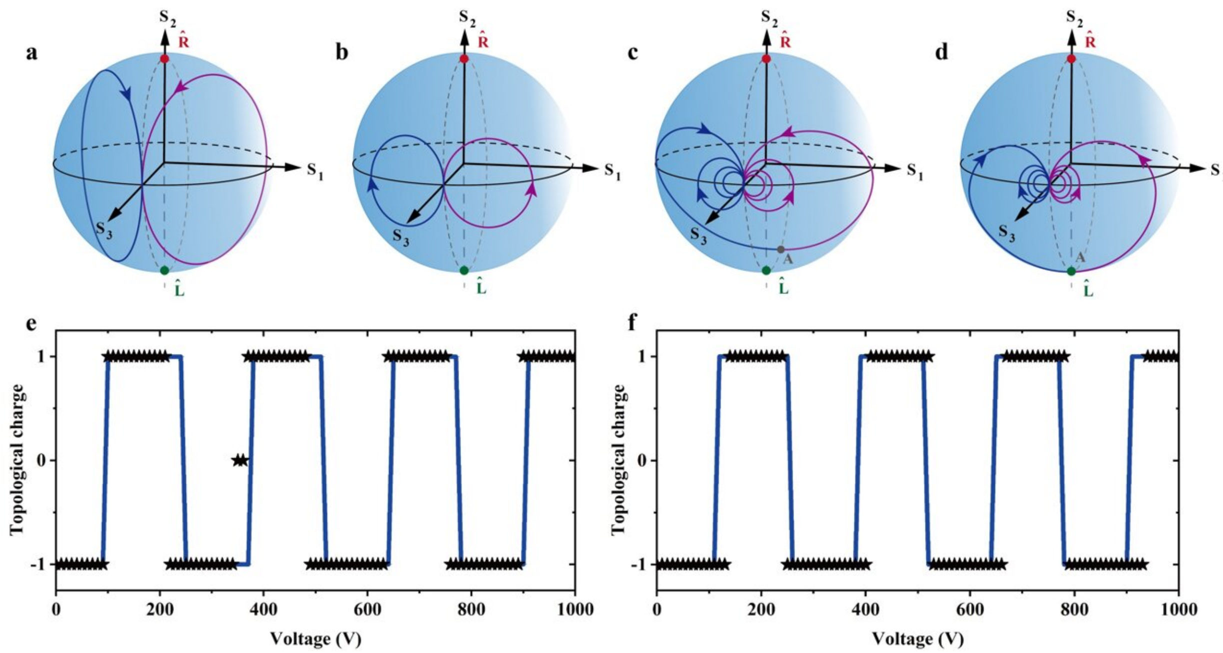
a, The original spin-1/2 setting describing spinnings of a quantum particle in a driven magnetic field, where the spin up and spin down constitute the two-level eigenstates. b, In the presented setting, the eigenstates R and L simultaneously coupling with the SAM and OAM are defined as the spin up and spin down equivalents, respectively. These pseudo spin up and spin down states are coupled by a synthetic magnetic field. c, The higher-order Poincaré sphere is introduced to represent the spin-orbit states, with two poles denoting the eigenstates. d, Typical states mapped on the sphere (marked points in c) showing spatial variations of polarization (upper panels) and phase (bottom panels) distributions with polar angle. The arrows in the upper panels denote polarizations; while the black lines in the bottom panels represent the phase contours. Credit: Guohua Liu, Xiliang Zhang, Xin Zhang, Yanwen Hu, Zhen Li, Zhenqiang Chen, and Shenhe Fu

The Rabi oscillation has been proven to be one of the cornerstones of quantum mechanics, triggering substantial investigations in different disciplines including atomic and molecular physics, acoustics, and optics. Various important applications have been demonstrated, ranging from nuclear magnetic resonance imaging and spectroscopy to quantum information processing.

So far only two independent classes of wave states in the Rabi oscillations have been revealed as spin waves and orbital waves, while a Rabi wave state simultaneously merging the spin and orbital angular momentum has remained elusive.

In a new paper published in *Light: Science & Applications*, a team of scientists, led by Professor Zhen Li and Shenhe Fu from Department of Optoelectronic Engineering, Jinan University, China, and co-workers have reported a new form of Rabi oscillation, exhibiting both spin and orbital angular momentum.

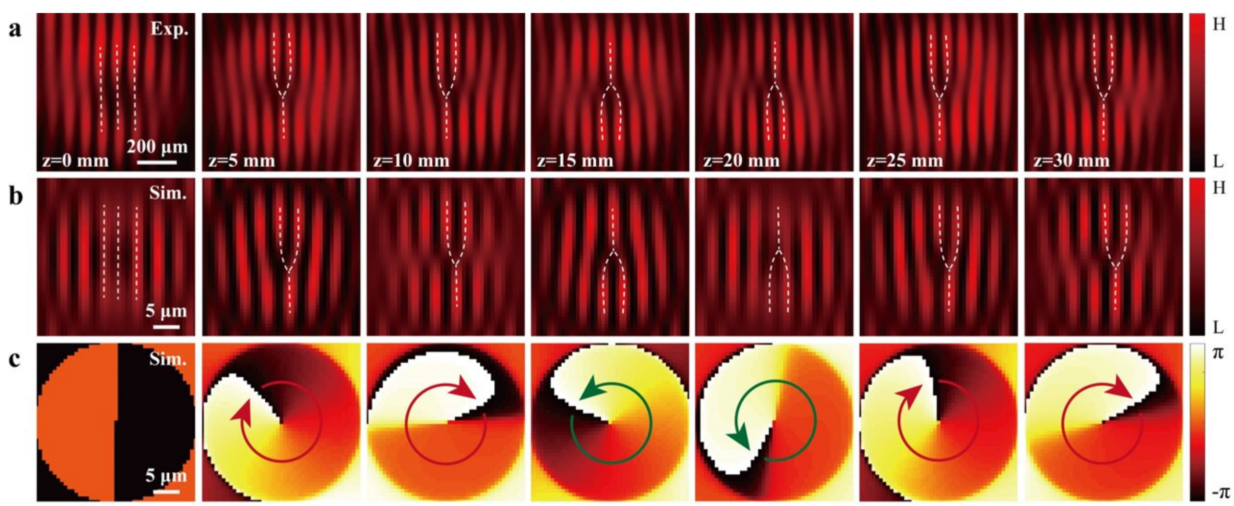
To reveal this fundamental phenomenon, they constituted a pseudo spin-1/2 formalism and optically synthesized a controllable magnetic field in the light-crystal interaction process. Based on this formulism, they observed simultaneous oscillations of the spin and orbital angular momentum in weak and strong coupling regimes, driven by the beam-dependent synthetic magnetic field.



a, b, The electrically tunable synthetic magnetic field allows Rabi transition between different oscillatory modes: a, V = ±50 V (trajectories in blue and purple); b, V = ±200 V (trajectories in blue and purple). c, The spinor moves slowly from point A to its initial position by gradually sweeping the voltage from 0 to 1000 V, see blue curve; while altering the voltage sign producing a symmetric trajectory (purple line). d, The same as described in c but in a different case of beam width. e, f, The emitted topological charge as a function of voltage after a coupling length z =30 mm, in two different cases of beam widths. Credit: Guohua Liu, Xiliang Zhang, Xin Zhang, Yanwen Hu, Zhen Li, Zhenqiang Chen, and Shenhe Fu

Furthermore, they introduced an electrically tunable platform, allowing a fine control of transition between different Rabi oscillatory modes, resulting in an emission of orbital-angular-momentum beams with tunable topological structures. Their results constitute a general framework to explore spin-orbit couplings in the higher-order regime, offering routes to manipulating the spin and orbital angular momentum of light in three and four dimensions. The reported method and technique will find potential applications both in classical and quantum optics.

The observed spin-orbit-coupled Rabi oscillation is manifested by simultaneous oscillations of spin and orbital angular momentum with the coupling length, in the presence of the optically synthesized magnetic fields.



The Rabi oscillation is manifested partially by the separated orbital-angular-momentum oscillation along with the coupling length. a, b, The interferograms recorded at different coupling lengths: a, experiments; b, simulations. c, Simulated phase distributions of light fields at the corresponding coupling lengths. Credit: Guohua Liu, Xiliang Zhang, Xin Zhang, Yanwen Hu, Zhen Li, Zhenqiang Chen, and Shenhe Fu

"We constitute a pseudospin-1/2 formalism in an analogy to Pauli equation describing the spinning of a quantum particle and optically synthesize a magnetic field through light-crystal interaction. In the system, we define the right- and left-handed circularly polarized vortex beams as the spin-up and spin-down equivalents coupled by the synthesized magnetic fields, which can be fully controlled by either structuring the light beam or engineering the crystal."

"Structured light comprising a superposition of spin and orbital angular momentum states has drawn considerable interest since it holds a promise for multidimensional high-capacity data multiplexing. Our platform allows spatiotemporal modulations of the synthesized magnetic fields, enabling to manipulate the structured light beams in three- and four-dimensional configurations," the scientists say.

"Since the setting is equivalent to those described by the Pauli equations such as in quantum mechanics and nonlinear optics, our results open new possibilities for spinor manipulation in the higher-order regime."

More information: Guohua Liu et al, Spin-orbit Rabi oscillations in optically synthesized magnetic fields, *Light: Science & Applications* (2023). DOI: 10.1038/s41377-023-01238-8

Provided by Chinese Academy of Sciences

Citation: Uncovering the secrets of spin-orbit optical Rabi oscillations (2023, October 12) retrieved 29 April 2024 from https://phys.org/news/2023-10-uncovering-secrets-spin-orbit-optical-rabi.html