Propagation and Stability of Compact Localized Modes in 2D Photonic Flat-band Lattices

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Photonic lattices with flat bands, characterized by the absence of dispersion and slow group velocity, support compact localized modes (CLMs) known as compactons. Light propagation can be controlled by tuning parameters such as waveguide spacing and wave profile. When the light intensity is sufficient, modulation instabilities can emerge, inducing a nonlinear response that alters propagation. Special attention is given to the Aharonov–Bohm effect and the influence of phase shifts and inhomogeneities on light dynamics and mode formation.

The propagation of light through photonic lattices can be modeled by a system of coupled difference-differential equations under the strong coupling approximation, with each waveguide interacting with its nearest neighbors. Assuming ideal conditions (no losses and infinite waveguides), and incorporating Kerr-type nonlinearity while neglecting diffraction and diffusion, this system reduces to a set of discrete nonlinear Schrödinger equations. Unit cells in photonic lattices are defined analogously to those in solid-state systems, enabling simplification of the governing equations.

We examined the existence and stability of both linear and nonlinear localized modes in 2D photonic lattices using three models: octagonal-diamond [1,2], dice [3], and plus-type [4,5]. The sixth-order Runge-Kutta method was applied to solve the governing equations. Analytical solutions were used to obtain eigenvalues of the Hamiltonian and the structure of CLMs. Linear stability analysis (LSA) provided equations for small perturbations, which were numerically solved to evaluate the stability of specific modes. By using analytical and numerical tools we confirmed the existence and behavior of both linear and nonlinear CLMs. While LSA offered useful insight into the stability spectrum of stationary solutions, it proved insufficient for capturing all features of compact modes, particularly in the presence of inhomogeneities. In such cases, direct numerical simulations were essential for verifying stability. These simulations revealed that the presence or absence of an external magnetic flux significantly affects the behavior and robustness of the observed modes.

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