Nonlinear Waves in Honeycomb (graphene-like) Photonic Lattices

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Abstract:

We study the dynamics of waves in honeycomb lattices. Wave dynamics in honeycomb lattices exhibits unique phenomena that cannot be observed in any other periodic system, such as conical diffraction [1] and Klein tunneling. The origin of these intriguing phenomena is the conical intersection between the two bands and the presence of two atoms in each unit cell. These two properties make it possible to describe the dynamics of the Bloch modes by the massless Dirac equation - the same equation describing neutrinos that are massless spin-half particles. It it very well known that when particles (or a wave-packet) incident upon an infinite potential step of height V_0 with energy lower then the step are always reflected. However, Dirac particles (relativistic fermions) have non-zero transmission probability [2]. This remarkable phenomenon is named Klein tunneling, first proposed in 1929. Even more surprising is the scattering of quasi-particles in graphene/carbon nanotubes that behave as massless fermions. The later do not exhibit ordinary Klein tunneling but instead they exhibit unit transmission probability [3, 4].
Here, we study scattering of wave packets from potential steps in deformed honeycomb photonic lattices, and find that below a critical deformation - in which a gap in the spectrum is formed - the wave packet is completely transmitted, i.e., an optical beam exhibits unit transmission [5]. On the other hand, beyond the critical deformation we find total reflection for a wave packet incident upon a step in the deformation direction [5]. Hence, we witness a very sharp transition from unit transmission to total reflection, giving an indication for a possible quantum phase transition.
This remarkable phenomenon occurring only in honeycomb lattices is completely linear. However, it is most interesting to also study the nonlinear dynamics of waves in honeycomb lattices. We study the nonlinear propagation of a circular wave-packet from the Dirac cone, that under linear conditions evolves into two rings with zero intensity in the middle, i.e., conical diffraction [1]. Surprisingly, we find that the same circular wave-packet evolves into "triangular rings" (triangles with slightly curves lines). By projecting the output beam onto the Bloch modes of the system, we find that the nonlinearity is responsible for energy transfer between different Bloch modes, and eventually the wave packet is comprised of Bloch mode that do not reside inside the Dirac cone anymore. Hence, the nonlinearity breaks the Dirac dynamics in honeycomb lattices, giving rise to completely new phenomena.

References:

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