Universal spin-momentum locking of light

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We show the existence of an inherent handedness (spin) of evanescent-electromagnetic-waves which is fundamentally locked to the direction of propagation (momentum). It is universal and accompanies evanescent waves in total internal reflection, waveguides/fibers and surface-states. The hallmark of the recently discovered quantum spin hall (QSH) state of matter is the existence of electronic surface states which are robust to disorder (non-magnetic impurities) . This property arises since the spin of the electron is intrinsically locked to the direction of propagation (momentum) and the electrons cannot backscatter unless there is a spin-flip. Recent work on topological photonics has shed light on electromagnetic surface states which are immune to disorder and show similar effects as the electrons. However, the presence of spin-orbit coupling has been considered fundamental to the origin of this spin-momentum locking effect in both electronics and photonics.

In this paper, we show that such spin-momentum locking is universal behavior for evanescent electromagnetic waves where an intrinsic handedness (spin) of an evanescent wave is locked to the direction of propagation (momentum). We trace the ultimate origin of this phenomenon to complex dispersion and causality requirements on evanescent waves. We demonstrate that every case of evanescent waves in total internal reflection, surface states and optical fibers/waveguides possesses this intrinsic spin-momentum locking. We derive the Stokes parameters for evanescent waves which reveal an intriguing result - every fast decaying evanescent wave is inherently circularly polarized with its handedness tied to the direction of propagation. Our work leads to a unified understanding of this spin-momentum locking in various nanophotonic structures and sheds light on the electromagnetic analogy with the quantum spin hall state for electrons. Our work also conclusively explains why polarization dependent unidirectional propagation of light has been recently observed in various nanophotonic structures.