

Quantum topological effects in magnetization dynamics: the Berry phase, the Aharonov–Casher effect and electric field control of spin waves dynamics

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Condensed matter physics is revolutionizing by introducing topology-based concepts that characterize a system's physical states and properties. An example of topological effects in magnetization dynamics is the additional quantum mechanical phase, the so-called Berry phase [1], and the Aharonov–Casher (AC) effect [2], acquired by the quantum orbital motion of chargeless bosonic quasiparticles with magnetic dipole moment – e.g., spin waves (SWs) with magnetic moment $\mu_m = \pm g\mu_B$ – in mesoscopic rings in an external electric (E) field. It manifests itself in a shift of the dispersion and the group velocity direction of SW by the E field. In the linear approximation concerning the electric field, the magnonic AC effect can be considered by adding the Dzyaloshinskii-Moriya-like interaction between neighboring spins. This topological quantum phenomenon has been directly detected experimentally for SWs propagating in the classical magnetic insulator Y₃Fe₅O₁₂ [3,4]. The magnitude of the AC phase was two orders larger than previously estimated theoretically for centrosymmetric ferromagnet insulators. This finding allows for tuning the properties of SWs, an essential ingredient for magnonic devices, by the E-field. Through analytical calculations and micromagnetic simulations, we demonstrated that in ferromagnetic, antiferromagnetic, and ferrimagnetic nanoscale films, it is possible to control the SWs characteristics using an external E-field [5-9]. From the fundamental point of view, the discussed quantum phenomena open a new avenue for quantifying topological effects in magnetization dynamics. The E-field control of SW dynamics in magnetic film can also be helpful for the development and designing of new magnonic nanodevices and could be utilized for quantum technologies.

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