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Magnons as uncharged carriers for quantum communication between nanomagnets

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Recent experimental studies have shown that magnonics—an independent branch of spintronics—can realize its potential in nanotechnology applications involving magnetophotonics, thermal nanoconversion, magnonic capacitors, magnonic transistors, and other fields. Magnons are very good candidates for use in quantum communication. This is because the transport of magnons as uncharged quasiparticles can occur without the generation of Joule heat, and, just as with charged carriers, this transport can be controlled using magnetic and electric fields. We propose a physical mechanism whereby a localized spin excitation (Kittel magnon) generated in one microwave cavity can be resonantly transferred to another cavity via a ferromagnetic chain connecting the nanomagnets embedded in the cavities. It is shown that long-range magnon transfer can be achieved via coherent one-step tunneling of magnons between nanomagnets. Our theoretical study is based on a model in which, for fixed nanomagnet spin values, the states are determined by macrospin projections, and the ferromagnetic chain acts as a mediating scattering center. The coupling between spin excitations in the “nanomagnet A - ferromagnetic chain - nanomagnet B” hybrid structure (AFB structure) is mediated by the Heisenberg exchange interaction between the spins of adjacent paramagnetic units of the structure. Based on this model, analytical formulas were derived that made it possible to understand the physics of controlling magnon flow using magnetic fields; these fields tune the Kittel magnon frequency to the frequencies of delocalized magnons in the AFB structure. The main results of the study include the following. Analytical expressions for the magnon transport rate and magnon flow are obtained and key parameters controlling off-resonant and resonant magnon tunneling regimes are indicated. Physical conditions are determined under which peak values of the rate characterizing the process of resonant transmission of the Kittel magnon arise both at a fixed tunneling energy with an arbitrary number of units in the ferromagnetic chain or at a fixed number of chain units with a changing tunneling energy. A mechanism of coherent transfer is proposed, based on the premise that the spin states of a bridge, containing magnetically ordered paramagnetic units, play a virtual role. This facilitates a specific quantum exchange of magnons both within the bridge and between its terminal units and the adjacent nanomagnets. As a result, a long-range superexchange coupling arises between magnetostatic spin excitations, which ensures a tunnel regime of magnon transport between nanomagnets. It was also shown that due to the strong photon-magnon coupling in the microwave cavity, at a certain magnetic field, the tunneling flow of magnons can reach an additional peak value, which reflects the process of resonant photon-to-magnon conversion [1]. The obtained results indicate the potential for using magnons for quantum communication in hybrid structures where the transduction of one type of quasiparticle into another (in our case, photons and magnons) is possible.

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[1] E. G. Petrov, S. M. Tunyk, V.V. Gorbach, Phys. Rev. Appl., 25, 024072 (2026).

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