Unveiling the complexity of resonant spin-wave modes in ferromagnetic nanowires

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The theory of the spin-wave phenomena in basic magnetic systems, such as ferromagnetic films [1] or ferromagnetic nanowires [2], was already solved many decades ago and many more complex structures have also been described theoretically. Therefore, it seems unlikely that new effects will be discovered in such simple systems.

In our study, we developed a rigorous analytical model of the resonant spin-wave modes in ferromagnetic nanowires and confirmed it using numerical simulations. This enabled us to uncover several new and interesting properties of this simple system. An important feature of these resonant modes is their rotating character. Unlike in magnetic vortices, modes rotating in opposite directions in uniformly magnetized ferromagnetic nanowires are not degenerate. This breaking of the symmetry is directly connected to the chirality of the spin precession and its effect on the dipolar interactions. It also affects the shape of the modes. Depending on the sense of rotation, they can have a surface or volume character. This further has an impact on the created stray magnetic field, influencing the possibility of the coupling between these modes with other spin-wave excitations. Another important feature of the resonant modes in the ferromagnetic nanowires is the presence of the spins precessing with the anti-Larmor sense of rotation. This effect naturally occurs in some modes and can even span a large area of the nanowire cross-section. Interestingly, the spin precession is unequivocally connected with the orbital angular momentum (OAM) of the modes, which makes for its unexpected behavior. Anti-Larmor precession leads to the lifting of the OAM quantization. Moreover, the OAM can be controlled by an external magnetic field, even creating the possibility of quantizing or dequantizing the rotating modes.

Our work reveals the interesting and unexpected phenomena behind a seemingly simple problem: resonant spin-wave modes in a ferromagnetic nanowire. It uncovers basic features, broadening the knowledge and understanding of the magnetic excitations, which can lead to new findings and applications.

References:

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