Project: Classical motion in artificial magnetic monopole fields

Background

Berry demonstrated that a general quatum system undergoing adiabatic evolution may pick up a nontrivial phase of purely geometric origin [1]. For a spin in a slowly rotating magnetic field this phase turns out to be proportional to the flux of an artificial magnetic monopole sitting at the energy crossing at the origin (corresponding to vanishing magnetic field). Due to the elusiveness of magnetic charges in standard electromagnetism, this result has triggered numerous studies in adiabatic evolution of spin systems [2].

Real-space realizations of artificial magnetic monopoles have been demonstrated in spin ice [3] and Bose-Einstein condensates [4]. Similarly, Berry artificial monopoles in parameter space can be mapped nontrivially to physical space via a nonuniform magnetic field that drives the adiabatic spin system. This opens up for the experimental study of classical trajectories in the presence of magnetic monopoles.

Project plan

The purpose of the project is to derive classical equations of motion for the centre of mass (CM) of a particle with spin moving in an inhomogeneous magnetic field. A key ingredient is to examine the influence of internal spin-spin interaction on the trajectories of the CM. The spin-spin interactions are known to modify the distribution of artificial monopoles, such as splitting of magnetic charges some of which located at points where the magnetic field is nonzero [5].

The key objectives of the project are:

- to derive and (numerically) simulate classical CM equations of motion of a composite system (such as an atom or molecule) consisting of pairs of interacting spins;
- to estimate parameter ranges needed to see effects of the internal spin-spin interaction on the CM trajectories.

The form of spin-spin interaction is retricted to Ising type. Spin-$\frac{1}{2}$ constituents are considered.

The overall aim is to develop a physical setting that allows for direct experimental studies of artificial magnetic monopoles in real space.

Time plan

The project is carried out during spring 2022. Time plan:

- Literature study, week 2-3
- Deriving equations of motion, construction of model (external magnetic field configuration), week 4-6
- Development of numerical code for classical trajectories, week 7-10

- Numerical simulations and interpretation, week 12-15
- Writing report , week 13-22. Preliminary dates for first draft 20 May and final report 7 June.
- Preparation and presentation, week 20-22. Preliminary date for presentation 30 May.

References

[1] M. V. Berry, Quantal Phase Factors Accompanying Adiabatic Changes, Proc. R. Soc. London Ser. A **392**, 45 (1984).

[2] A. Shapere and F. Wilczek, *Geometric phases in physics* (1989).

[3] C. Castelnovo, R. Moessner, and S. L. Sondhi, Magnetic monopoles in spin ice, Nature (London) **451**, 42 (2008).

[4] M. W. Ray, E. Ruokokoski, K. Tiurev, M. Möttönen, and D. S. Hall, Observation of isolated monopoles in a quantum field, Science **348**, 544 (2015).

[5] A. Eriksson and E. Sjöqvist, Monopole field textures in interacting spin systems, Phys. Rev. A **101**, 050101(R) (2020).