Study of topological structures in bidimensional magnetic systems

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Abstract

In the present work, we study the topological phases produced in a ferromagnetic 2D square lattice with the Dzyaloshinskii-Moriya (DMI) interaction in the presence of an external magnetic field. Using the Hybrid Monte Carlo method (HMC)[2], we show the formation and growth of spiral and skyrmion lattice phases depending on the strength of the external magnetic field . Also, with the method proposed in[1], we are controlling the position and movement of an individual magnetic skyrmion.

Model

We used the lattice Hamiltonian, consisting of the Heisenberg exchange H_J , DMI interaction H_D terms for the microscopic description of chiral helimagnet , and magnetic field interactions[1]:

$$H_J = -J \sum_{<ij>} \vec{S}_i \cdot \vec{S}_J \quad (1)$$

$$H_D = \sum_{<ij>} \vec{D}_{<ij>} \cdot \vec{S}_i \times \vec{S}_j \quad (2)$$

$$H_{magneticfield} = -\vec{h} \cdot \sum_i \vec{S}_i \quad (3)$$

$$H = H_J + H_D + H_{magneticfield} \quad (4)$$

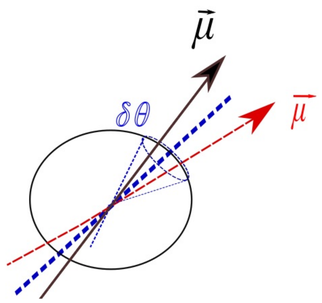

Figure 1:Classical Heisenberg Spin Model

System

In the frame of our computational model the magnetic system is a 2D ferromagnetic square lattice with size $N = LxL(L = 40)$, in which nodes all the Heisenberg spins has been placed, where each spin has four nearest neighbours with periodic conditions.In all the calculations the temperature is given by $T = 0.01$

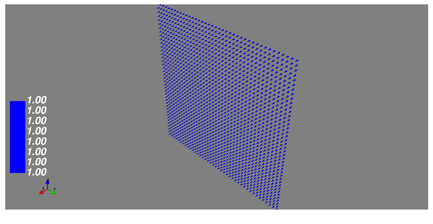

Figure 2:2D square lattice with direct exchange interaction and DMI interaction , size = 1600

Method

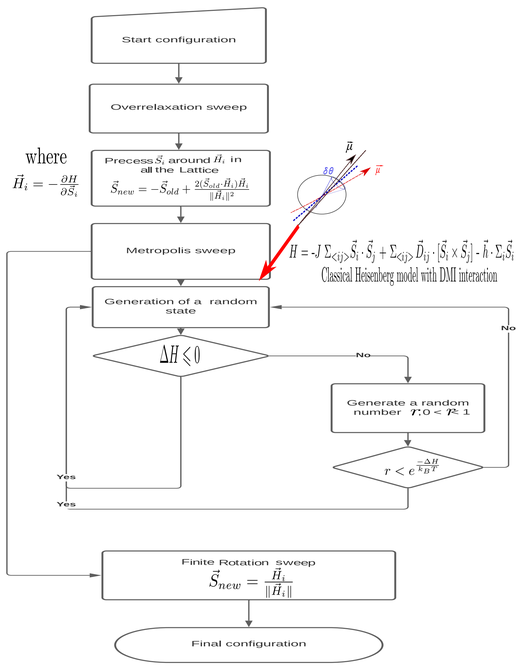

Figure 10:Hybrid Monte Carlo Method

Topological Phases 1

D=0.6

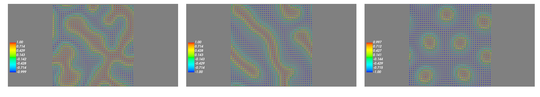

Figure 3:H=0 Figure 4:H=0.1 Figure 5:H=0.2

D=0.7

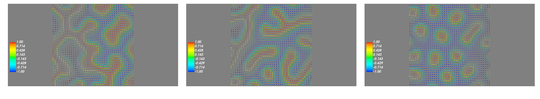

Figure 6:H=0 Figure 7:H=0.1 Figure 8:H=0.2

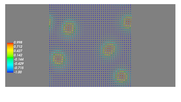

Figure 9:H=0.3

Pushing a Skyrmion

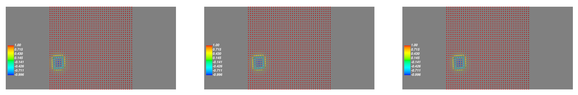

Figure 11:1 Figure 12:2. Figure 13:3.

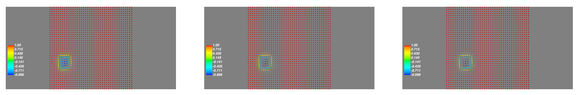

Figure 14:4 Figure 15:5 Figure 16:6

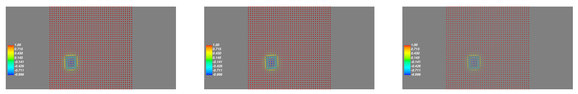

Figure 17:7 Figure 18:8 Figure 19:9

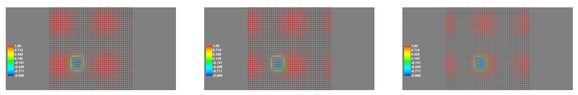

Figure 20:10 Figure 21:11 Figure 22:12

We used two fields with opposite direction ($H_{in} = 0.5$ in the nucleation point,and $H_{out} = 1$ in the rest of the lattice)in order to make and move an single magnetic skyrmion as in [1].

Topological Phases 2

D= 1

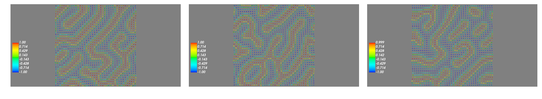

Figure 23:H=0 Figure 24:H=0.1 Figure 25:H=0.2

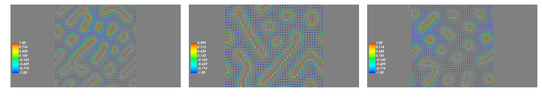

Figure 26:H=0.3 Figure 27:H=0.4 Figure 28:H=0.5

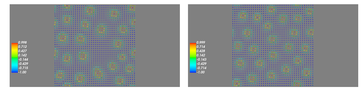

Figure 29:H=0.6 Figure 30:H=0.7

The increase in intensity of the magnetic field perpendicular to the plane of the ferromagnetic square lattice favours the emergence and growth of the Skyrmion lattice phase, but to intensities too much greater (for D=0.6 is H=0.3, and D=1 is H=0.8)this phase is vanished.

Conclusion

1. The increase of the relative intensity of D increase the value of H for the which the skyrmion lattice is vanished as is expected.
2. The DMI interaction leads to the fact that spins deviate from the parallel orientation.The DMI interaction direct to the spins perpendicular each other as is expected.
3. The method proposed in [1] is very successul for the manipulation of single skyrmion proof the concept of the applications of skyrmions in spintronics.

References

1.Kapitan, Vitalii,Vasiliev, Egor, Perzhu, Alexander. (2019). Computer Simulation of Magnetic Skyrmions.

2.Mohylna, M. Žukovič, Milan. (2020). Emergence of a Skyrmion Phase in a Frustrated Heisenberg