Novel Phenomena in Arrays of Magnetic Particles and Josephson Junctions

Michael Forrester

Aim: The analysis of arrays of magnetic particles was to be made with the aim of developing new logic and memory devices. We decided to look at the most basic of designs – a stack of two magnetic particles with disc shaped geometries. Our goal was to see if our theories would lead us to new ways of looking at such systems and to pave the way for more advanced analyses at a later date.

Main results of the collaboration

The analysis of two magnetic particles is made. The energy of the system can be described by the Hamiltonian

$$E = -2J\cos(\varphi_1 - \varphi_2) + \frac{K}{2}\left(\sin^2\varphi_1 + \sin^2\varphi_2\right) - H\left(\cos(\varphi_1 - \beta) + \cos(\varphi_2 - \beta)\right)$$

where the magnetisation direction of particle i is given by φ_i, J is the strength of the nearest neighbour interactions, K is the uniaxial anisotropy strength and H is a uniform magnetic field applied at an angle β to the particles main axes**.** An analysis of this Hamiltonian has been performed that looks at all the stable, unstable and metastable states in the system. As a result a picture of all the possible states of the system emerges. This consists of antiferromagnetic (AF), Ferromagnetic (F) and canted (C) states. An example of a state phase diagram is given below for various levels of anisotropy and magnetic field.

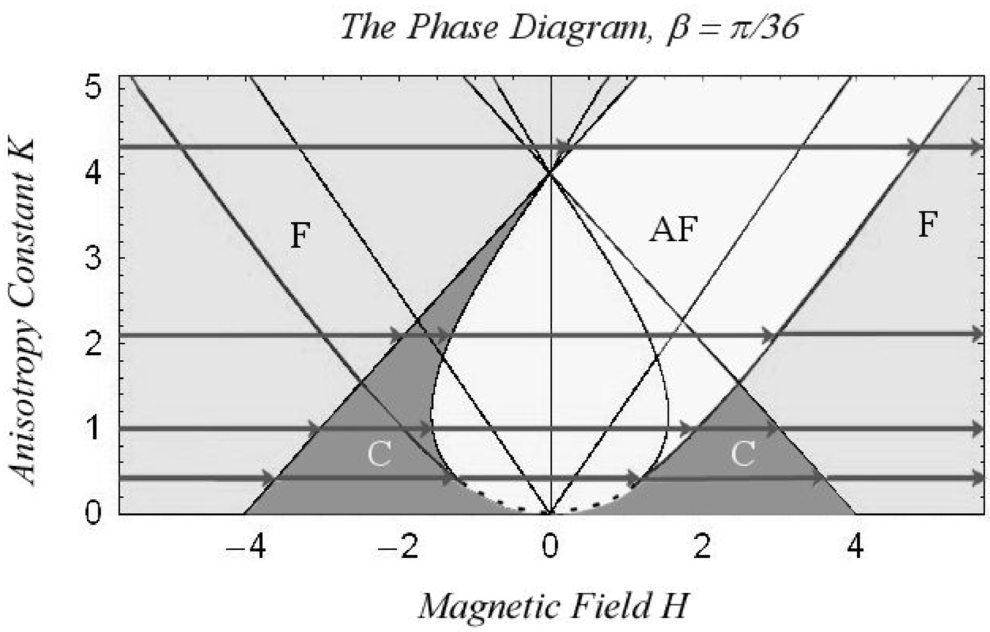

Figure 1: The anisotropy constant K as a function of the applied magnetic field H that is applied at an angle β.

We analysed all the possible angles of applied magnetic field and how the system will react for different geometries of magnetic dot. A complete knowledge of the energies, magnetisations, and anisotropies is given in response to the applied field. The stack of magnetic particles is proposed for use as an element for magnetic random access memory. This form of memory is important because it retains information even when the computer is switched off completely, i.e. there is no need for a boot up process when using this form of memory. It falls into a class of memory that is called non-volatile. Another application for these types of magnetic particle comes in forms that could perform logic. The particles contain single domains and are of nanoscale proportions. This means that large densities of particles can be fitted onto a processor.

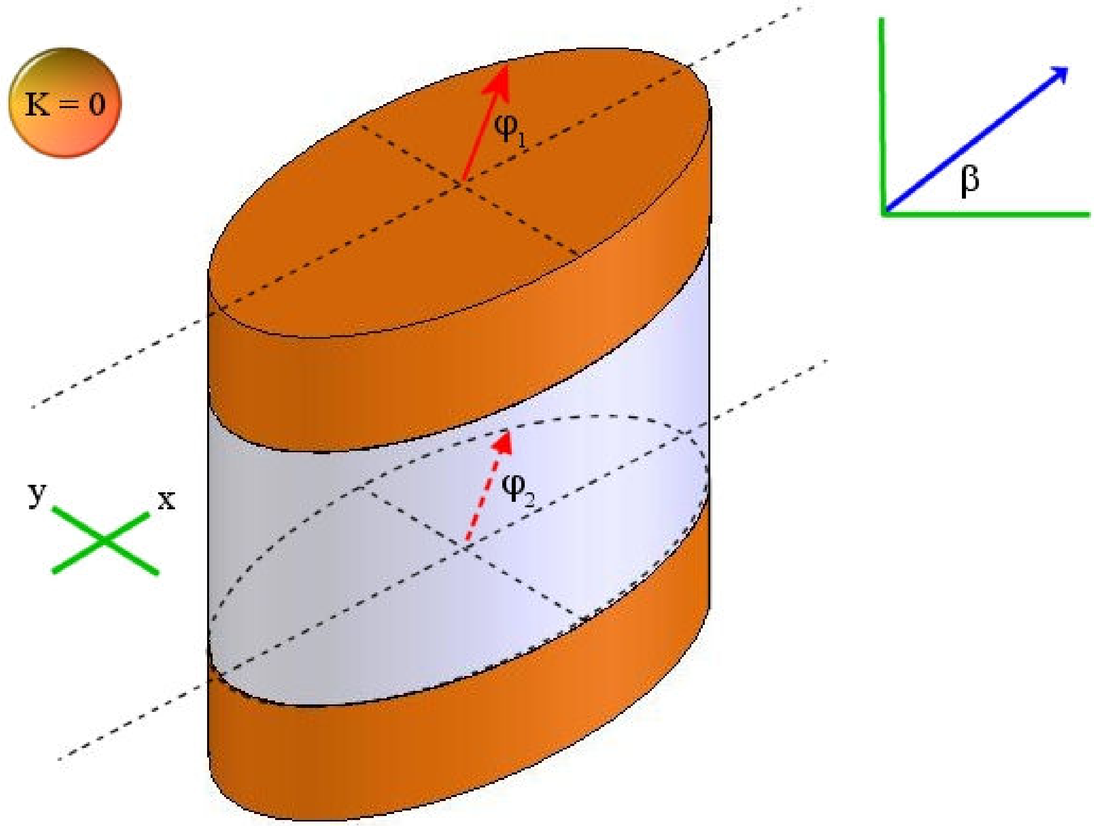

Figure 2: Two nanoscale magnetic particles sharing the same elliptical geometry. The angles of the magnetic moments in particle 1 and particle 2 are φ_1 and φ_2 respectively. Also, the magnetic field is applied at an angle β. When the particle is completely circular the anisotropy, K, is zero.

An example of the magnetic hysteresis is given in fig. 3 and it charts the progress through the phase diagram of fig. 1 at a level of anisotropy $K = 2.1$ when the field is ramped upwards from a negative value. All the stable minima (MIN), unstable maxima (MAX), and metastable saddle point (SP) states in the system are also shown.

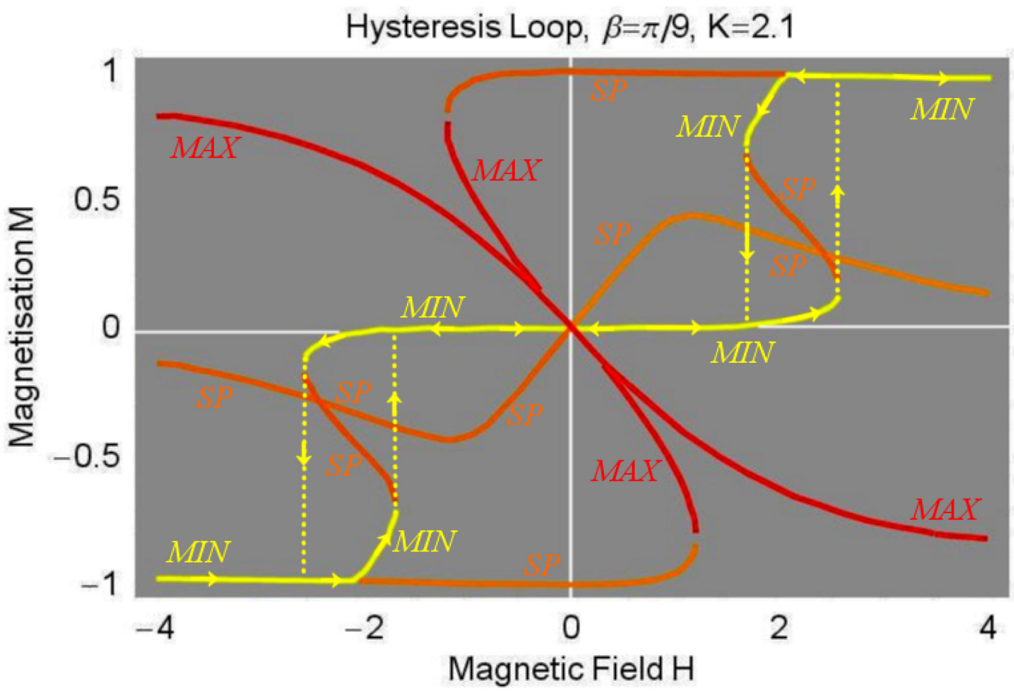

Figure 3: Magnetisation as a function of the applied magnetic field. The magnetic field is applied at 20 degrees and the anisotropy is $K = 2.1$. *The hysteresis of the system is charted through the stable minima in the system (yellow lines and MIN depiction).*

So, to summarise: we have found new ways to analyse the two particle interaction and build up a clear picture of how the system behaves. Future research will build upon this for more complicated systems and it is hoped that new technologies will emerge. The results of this research can be found in Physical Review B [1]

[1] D M Forrester, F V Kusmartsev, K E Kuerten, "Two particle element for magnetic memory" , 76, 134404, Physical Review B, 8-pages, October (2007)