Problem Set 3 - Magnetism & Spintronics ELEG/PHYS 667

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Due Wednesday, April 5 2006, in class

1. The Weiss model of ferromagnetism predicts a temperature below which ferromagnetic ordering causes nonzero magnetization at zero applied field.

   (a) we can predict the behavior of the magnetization, M, at various temperatures by solving the two nonlinear coupled equations graphically without approximation. Use a numerical method (MATLAB or similar) to plot M(T) for 0<T<1000K at H=0 for a spin-1/2 ferromagnet. Explicitly state the values of variables you use in an example calculation.

   (b) From your graph, what is the critical temperature T_C? How does it compare to the calculated value using a linear approximation to the $B_{1/2}$ Brillouin function?

2. Consider three identical uniaxial magnets, each of total magnetic moment μ, which are antiferromagnetically coupled to each other (see R. Cowburn, Phys. Rev. B, 65 092409 (2002)). There are two magnetic fields interacting with the system: a constant magnetic field parallel to the easy axis and another perpendicular to the axis, in-plane.

   (a) Write down the total energy of the *middle* magnet as a function of magnetization direction, including anisotropy and "Zeeman" terms from the stray and external fields, properly parameterized. Assume that the magnetization of the left and right magnets are fixed by anisotropy.

   (b) For what magnetic field conditions will the magnetization of the middle magnet be bistable, i.e. two distinct energy minima?

   (c) If information is encoded in the ("up" or "down") magnetization of the magnets, describe how this system of three antiferromagnetically coupled magnets can realize a universal NAND gate. (Hint: the perpendicular field acts as a parameter to lower the energy barrier between "up" and "down".) Give some acceptable values for the parameters of the working system.

3. According to the Stoner-Wohlfarth theory, the energy of a uniaxial magnet in a magnetic field is
   $E = 2K\sin^2\theta + MH\cos(\theta - \phi)$
   where θ is the angle between M and the easy axis and ϕ is the angle between H and the easy axis.

   (a) Use energy minimization to derive the easy axis and hard axis M-H loops.

   (b) If the applied fields along the easy axis and hard axis are H_x and H_y, respectively, show that the applied fields at which irreversible coherent rotation will occur satisfy the following equation: $H_x^{2/3} + H_y^{2/3} = H_k^{2/3}$

   (c) Plot this condition on the [Hx, Hy] plane. The obtained curve is often called the Stoner-Wohlfarth asteroid.