QUESTION 1

(a) Why do domains form in ferromagnetic materials?

(b) Figure 1 shows the major hysteresis loop for a ferromagnetic material (solid line) and a minor hysteresis loop (dashed line). In class we gave a domain-based explanation for the form of the major hysteresis loop. Describe the corresponding variation in domain pattern around the minor hysteresis loop.

Figure 1: Major (solid line) and minor (dashed line) hysteresis loops for a ferromagnetic material

(c) Fig. 2 again shows the major hysteresis loop for our ferromagnetic material (solid line), and the dashed line shows a spiral path which returns the material back to the unmagnetized state. Give a domain-based explanation for the form of the path. How else might we convert a ferromagnetic material to an unmagnetized state?

Figure 2: Return of a ferromagnetic material to the unmagnetized state
(d) The boundary between domains is called a domain wall. The exchange energy cost per square meter, $\sigma_{ex}$, within a domain wall is given by

$$\sigma_{ex} = \frac{kT_c}{2} \left( \frac{\pi}{N} \right)^2 N \frac{1}{a^2} \text{Jm}^{-2},$$

where $N + 1$ is the number of atomic layers in the wall, and $a$ is the spacing between the atoms. The anisotropy energy cost per square meter, $\sigma_A$, is given by

$$\sigma_A = KNa \text{Jm}^{-2}$$

where $K$, the magnetocrystalline anisotropy constant, is a measure of the cost of not having all the atoms aligned along easy axes. Plot the form of the exchange energy cost, the anisotropy energy cost and the sum of these two energy costs, for iron, for which $K = 0.5 \times 10^5 \text{Jm}^{-3}$, $a = 0.3 \text{nm}$, and $T_c = 1014^\circ \text{C}$.

(e) Assuming that the exchange and anisotropy energies are the principal contributors to the domain wall energy, derive an expression for the number of atomic layers in a domain wall, as a function of the Curie temperature, the anisotropy constant, and the atomic spacing.

(f) Calculate the thickness of a domain wall in iron. How much energy is stored in $1 \text{ m}^2$ of an iron domain wall?
QUESTION 2

Doped perovskite structure rare earth manganites have been the subject of intense research activity since the observation of colossal magnetoresistance in $\text{La}_{1-x}\text{Ca}_x\text{MnO}_3$ in the mid-1990s. In this problem we will explore some of the properties of one member of the family, $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$.

(a) There are two types of manganese ions in $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$. What are the charges and electronic structures of each of them?

(b) Sketch the structure of a unit cell of $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ indicating particularly the chemical environment around the manganese ions. (You don’t need to distinguish between the different Mn ions, or between the La and Sr ions). Do you expect both orbital and spin components of the angular momentum to contribute to the magnetic moment of the manganese ions? Explain your answer.

(c) Calculate the magnetic moments of both types of manganese ion.

(d) At temperatures above a few hundred kelvin $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ is a paramagnetic insulator. Which theoretical model would you expect to describe its magnetic properties accurately? Derive an expression for the magnetization as a function of applied field within this model.

(e) Given that the heat capacity is defined to be the derivative of the energy with respect to temperature, estimate the magnetic contribution to the heat capacity in the paramagnetic state of $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$. Take the applied field to be 10 kOe, the lattice constant to be 4 Å and the temperature to be 400K. Explain why this number is so small.

(f) Figure 3 shows the measured heat capacity of $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$. What do you think is happening at 360K? Why?
Figure 3: Heat capacity of LSMO plotted versus temperature in external fields of 0 and 10 kOe.