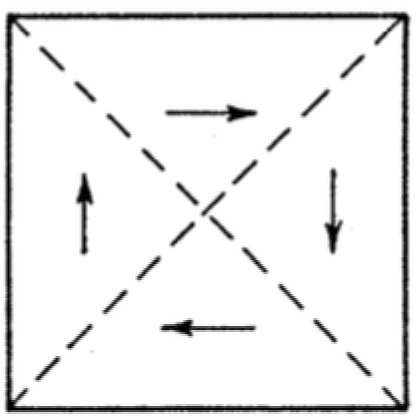
Charles Kittel Magnetic Domain Walls

The paper that I chose to review was – “Physical Theory of Ferroelectric Domains”. It is a reasonably old paper, but it still bears significant relevance in modern technology, particularly in the storage of data in magnetic devices(Hard Disk Drives, MRAM, etc.)

<u>Research goal and high level explanation:</u>

The physical phenomena that this paper explores is the idea of magnetization within materials. The traditional concept that has been taught in high school and introductory physics II Classes is that the reason that ferromagnetic materials(materials that are inclined towards magnetism) like iron are not naturally occurring magnets is that the individual molecules are arranged in a random manner, and this leads to the net magnetic field canceling out.

This paper proves that the above theory on natural magnetism is only partially correct. In the actual material, the molecules or individual magnetic moments align themselves in groups or domains. These domains are arranged in a random manner which leads to a net zero magnetization.



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Important aspects of magnetic domains:

The important aspects that are of physical concern are:

1) Size of domains
2) Position of domain walls
3) Domain Wall transition nature
4) Orientation of Domain Walls

While the factors that affect the domains themselves are:

1) Coercive force – External magnetic field that was applied to the system.
2) Relative Permeability – The permittivity of the magnetic force through the material.
3) Hysteresis – The responsivity of the material to the magnetic field.
4) Magnetic Forces – This is the breakdown of the fields within the material
    a) Exchange Energy – The magnetic field that adjacent moments exert on each other.
    b) Anisotropy – The magnetic tendencies of the system due to the natural asymmetries of the system.
    c) Magnetoelastic – The repulsive magnetic field's physical effects.
    d) Magnetic – Self energy – The natural magnetic field of the ferroelectric tendencies.

Analyzing the magnetic effects using classical electromagnetic theory, we derive the following equations describing the formation and equilibrium of domain walls:

$$\text{Exchange:} \quad f_{ex} = JS^2 \sum_{i>j} \varphi_{ij}^2$$

$$\text{Anisotropy:} \quad f_K = K_1(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2)$$

$$\text{Magnetoelastic:} \quad f_{me} = \tfrac{3}{2}\lambda T \sin^2\theta$$

$$\text{Magnetic:} \quad f_{mag} = -\tfrac{1}{2}\mathbf{H} \cdot \mathbf{I} \text{ (for self-energy)}$$

Applications of this analysis:

The applications of this analysis on magnetic domain walls are vast. The most important one being the storage of data in the form of magnetic fields. In modern MRAM(Magnetic Random Access Memory) which is famously the most dense memory, the formation of magnetic domains leads to the microstructure analysis of the system which is used to work out the relevant read and write electromagnetic systems.

In addition to this, the concept of magnetic domain wall motion due to the Dzyaloshinskii-Mariia Effect(The effect due to which the domain walls move on external field applications) has been applied in the Data Storage Systems center at CMU in order to make a novel all metal switching transistor.