

Magnetic Materials: Domains

In order to explain the fact that ferromagnetic materials with spontaneous magnetisation could exist in the demagnetised state Weiss proposed the concept of magnetic domains. Weiss built on earlier work carried out by Ampère, Weber and Ewing suggesting their existence. The findings of this work revealed that within a domain large numbers of atomic moments are aligned typically 10^{12} - 10^{18} , over a much larger volume than was previously suspected. The magnetisation within the domain is saturated and will always lie in the easy direction of magnetisation when there is no externally applied field. The direction of the domain alignment across a large volume of material is more or less random and hence the magnetisation of a specimen can be zero.

Magnetic domains exist in order to reduce the energy of the system. A uniformly magnetised specimen as shown in figure 5(a) has a large magnetostatic energy associated with it. This is the result of the presence of magnetic free poles at the surface of the specimen generating a demagnetising field, H_d . From the convention adopted for the definition of the magnetic moment for a magnetic dipole the magnetisation within the specimen points from the south pole to the north pole, while the direction of the magnetic field points from north to south. Therefore, the demagnetising field is in opposition to the magnetisation of the specimen. The magnitude of H_d is dependent on the geometry and magnetisation of the specimen. In general if the sample has a high length to diameter ratio (and is magnetised in the long axis) then the demagnetising field and the magnetostatic energy will be low.

The break-up of the magnetisation into two domains as illustrated in figure 5(b) reduces the magnetostatic energy by half. In fact if the magnet breaks down into N domains then the magnetostatic energy is reduced by a factor of $1/N$, hence figure 5(c) has a quarter of the magnetostatic energy of figure 5(a). Figure 5(d) shows a closure domain structure where the magnetostatic energy is zero, however, this is only possible for materials that do not have a strong uniaxial anisotropy, and the neighbouring domains do not have to be at 180° to each other.

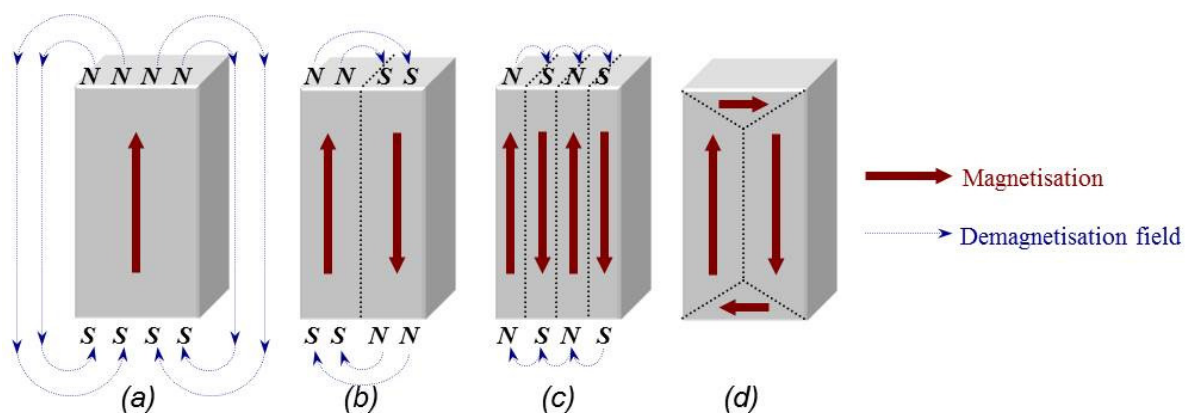


Figure 5: Schematic illustration of the break-up of magnetisation into domains:
(a) single domain; (b) two domains; (c) four domains; (d) closure domains.

The introduction of a domain raises the overall energy of the system, therefore the division into domains only continues while the reduction in magnetostatic energy is greater than the energy required to form the domain wall. The energy associated with a domain wall is proportional to its area. The schematic representation of the domain wall, shown in figure 6, illustrates that the dipole moments of the atoms within the wall are not pointing in the easy direction of magnetisation and hence are in a higher energy state. In addition, the atomic dipoles within the wall are not at 180° to each other and so the exchange energy is also raised within the wall. Therefore, the domain wall energy is an intrinsic property of a material depending on the degree of magnetocrystalline anisotropy and the strength of the exchange interaction between neighbouring atoms. The thickness of the wall will also vary in relation to these parameters, as a strong magnetocrystalline anisotropy will favour a narrow wall, whereas a strong exchange interaction will favour a wider wall.

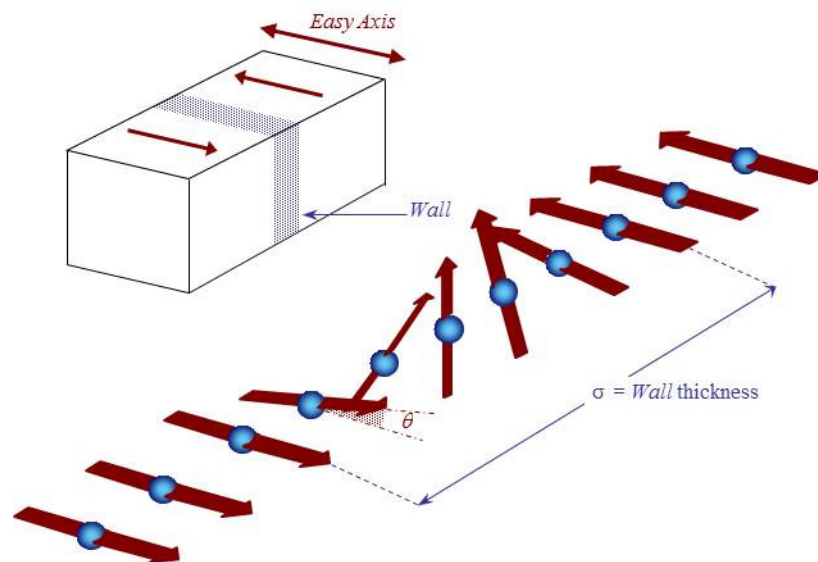


Figure 6: Schematic representation of a 180° domain wall

A minimum energy can therefore be achieved with a specific number of domains within a specimen. This number of domains will depend on the size and shape of the sample (which will affect the magnetostatic energy) and the intrinsic magnetic properties of the material (which will affect the magnetostatic energy and the domain wall energy).