

Magnetic Materials: Properties

The intrinsic properties of a magnetic material are those properties that are characteristic of the material and are unaffected by the microstructure (e.g. grain size, crystal orientation of grains). These properties include the Curie temperature, the saturation magnetisation and the magnetocrystalline anisotropy.

Saturation Magnetisation

The saturation magnetisation (M_S) is a measure of the maximum amount of field that can be generated by a material. It will depend on the strength of the dipole moments on the atoms that make up the material and how densely they are packed together. The atomic dipole moment will be affected by the nature of the atom and the overall electronic structure within the compound. The packing density of the atomic moments will be determined by the crystal structure (i.e. the spacing of the moments) and the presence of any non-magnetic elements within the structure.

For ferromagnetic materials, at finite temperatures, M_S will also depend on how well these moments are aligned, as thermal vibration of the atoms causes misalignment of the moments and a reduction in M_S . For ferrimagnetic materials not all of the moments align parallel, even at zero Kelvin and hence M_S will depend on the relative alignment of the moments as well as the temperature.

The saturation magnetisation is also referred to as the spontaneous magnetisation, although this term is usually used to describe the magnetisation within a single magnetic domain. Table 3 gives some examples of the saturation polarisation (J_S) and Curie temperature (T_C) of materials commonly used in magnetic applications.

Material	Magnetic Structure	J_S at 298K	T_C (°C)
Fe	Ferro	2.15	770
Co	Ferro	1.76	1131
Ni	Ferro	0.60	358
Nd ₂ Fe ₁₄ B	Ferro	1.59	312
SmCo ₅	Ferro	1.14	720
Sm ₂ Co ₁₇	Ferro	1.25	820
BaO.6Fe ₂ O ₃	Ferri	0.48	450
SrO.6Fe ₂ O ₃	Ferri	0.48	450
Fe 3wt% Si	Ferro	2.00	740
Fe 4wt% Si	Ferro	1.97	690
Fe 35wt% Co	Ferro	2.45	970
Fe 78wt% Ni	Ferro	0.70	580
Fe 50wt% Ni	Ferro	1.55	500
MnO.Fe ₂ O ₃	Ferri	0.51	300

Table 3: The saturation polarisation (J_S) and Curie temperature (T_C) of a range of magnetic materials.

Magnetic Anisotropy

In a crystalline magnetic material the magnetic properties will vary depending on the crystallographic direction in which the magnetic dipoles are aligned. Figure 4 demonstrates this effect for a single crystal of cobalt. The hexagonal crystal structure of Co can be magnetised easily in the $[0001]$ direction (i.e. along the c-axis), but has hard directions of magnetisation in the $\langle 1010 \rangle$ type directions, which lie in the basal plane (90° from the easy direction).

A measure of the magnetocrystalline anisotropy in the easy direction of magnetisation is the anisotropy field, H_a (illustrated in figure 4), which is the field required to rotate all the moments by 90° as one unit in a saturated single crystal. The anisotropy is caused by a coupling of the electron orbitals to the lattice, and in the easy direction of magnetisation this coupling is such that these orbitals are in the lowest energy state.

The easy direction of magnetisation for a permanent magnet, based on ferrite or the rare earth alloys, must be uniaxial, however, it is also possible to have materials with multiple easy axes or where the easy direction can lie anywhere on a certain plane or on the surface of a cone. The fact that a permanent magnet has uniaxial anisotropy means that it is difficult to demagnetise as it is resistant to rotation of the direction of magnetisation.

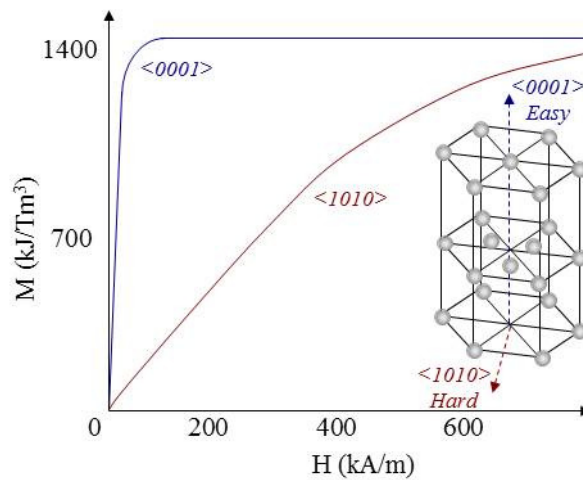


Figure 4: The magnetocrystalline anisotropy of cobalt.