Magnetic Materials: Units and Terminology

In the study of magnetism there are two systems of units currently in use:

- the mks (metres-kilograms-seconds) system, which has been adopted as the S.I. units
- the cgs (centimetres-grams-seconds) system, also known as the Gaussian system.

The cgs system is used by many magnets experts due to the numerical equivalence of the magnetic induction (B) and the applied field (H).

When a field is applied to a material it responds by producing a magnetic field, the magnetisation (M). This magnetisation is a measure of the magnetic moment per unit volume of material, but can also be expressed per unit mass, the specific magnetisation (σ). The field that is applied to the material is called the applied field (H) and is the total field that would be present if the field were applied to a vacuum. Another important parameter is the magnetic induction (B), which is the total flux of magnetic field lines through a unit cross sectional area of the material, considering both lines of force from the applied field and from the magnetisation of the material. B, H and M are related by equation 1a in S.I. units and by equation 1b in cgs units.

$$B = \mu o \, (H + M)$$ ***Equ.1a***

$$B = H + 4 \pi M$$ ***Equ.1b***

In equation 1a, the constant μo is the permeability of free space (4π x 10-7 Hm-1), which is the ratio of B/H measured in a vacuum. In cgs units the permeability of free space is unity and so does not appear in equation 1b. The units of B, H and M for both S.I. and cgs systems are given in table 2. Note that in the cgs system 4πM is usually quoted as it has units of Gauss and is numerically equivalent to B and H.

Another equation to consider at this stage is that concerning the magnetic susceptibility (x), equation 2, this is the same for S.I. and cgs units. The magnetic susceptibility is a parameter that demonstrates the type of magnetic material and the strength of that type of magnetic effect.

$$\chi = \frac{M}{H}$$ ***Equ.2***

Sometimes the mass susceptibility (χ_m) is quoted and this has the units of m^3kg^{-1} and can be calculated by dividing the susceptibility of the material by the density.

Another parameter that demonstrates the type of magnetic material and the strength of that type of magnetic effect is the permeability (μ) of a material, this is defined in equation 3 (the same for S.I. and cgs units).

$$\mu = \frac{B}{H}$$ ***Equ.3***

In the S.I. system of units, the permeability is related to the susceptibility, as shown in equation 4 and can also be broken down into μ_0 and the relative permeability (μ_r), as shown in equation 5.

$$\mu_r = \chi + 1 \quad \textbf{Equ.4}$$

$$\mu = \mu_o \mu_r \quad \textbf{Equ.5}$$

Finally, an important parameter (in S.I. units) to know is the magnetic polarisation (J), also referred to as the intensity of magnetisation (I). This value is effectively the magnetisation of a sample expressed in Tesla, and can be calculated as shown in equation 6.

$$J = \mu o\, M \quad \textbf{Equ.6}$$

Quantity	**Gaussian** (cgs units)	**S.I. Units**	**Conversion Factor** (cgs to S.I.)
Magnetic Induction (B)	G	T	10^{-4}
Applied Field (H)	Oe	$A\ m^{-1}$	$10^3 / 4\pi$
Magnetisation (M)	--	$A\ m^{-1}$	10^3
Magnetisation ($4\pi M$)	G	--	10^3
Magnetic Polarisation (J)	--	T	--
Specific Magnetisation (σ)	$emu\ g^{-1}$	$J\ T\ kg^{-1}$	1
Permeability (μ)	Dimensionless	$H\ m^{-1}$	$4\ \pi\ 10^{-7}$
Relative Permeability (μ_r)	--	Dimensionless	--
Susceptibility (χ)	$Emu\ cm^{-3}\ Oe^{-1}$	Dimensionless	4π
Maximum Energy Product (BH_{max})	M G Oe	$K\ J\ m^{-3}$	$10^2 / 4\pi$

Table 1: *The relationship between some magnetic parameters in cgs and S.I. units.*
(Where: G = Gauss, Oe = Oersted, T = Tesla)