## B. The Demagnetisation Curve and its Parameters

In hard magnetic materials the second quadrant of hysteresis is most important and is called **demagnetization curve.** Demagnetization curves as well as the other quadrants of hysteresis can be drawn both in the J(H) picture as well as in the B(H) description which follows from eq. (A.8). This is also the case in Fig. B1, which supplies those basic parameters of the demagnetization curve, which are mainly used in technical literature about permanent magnets.

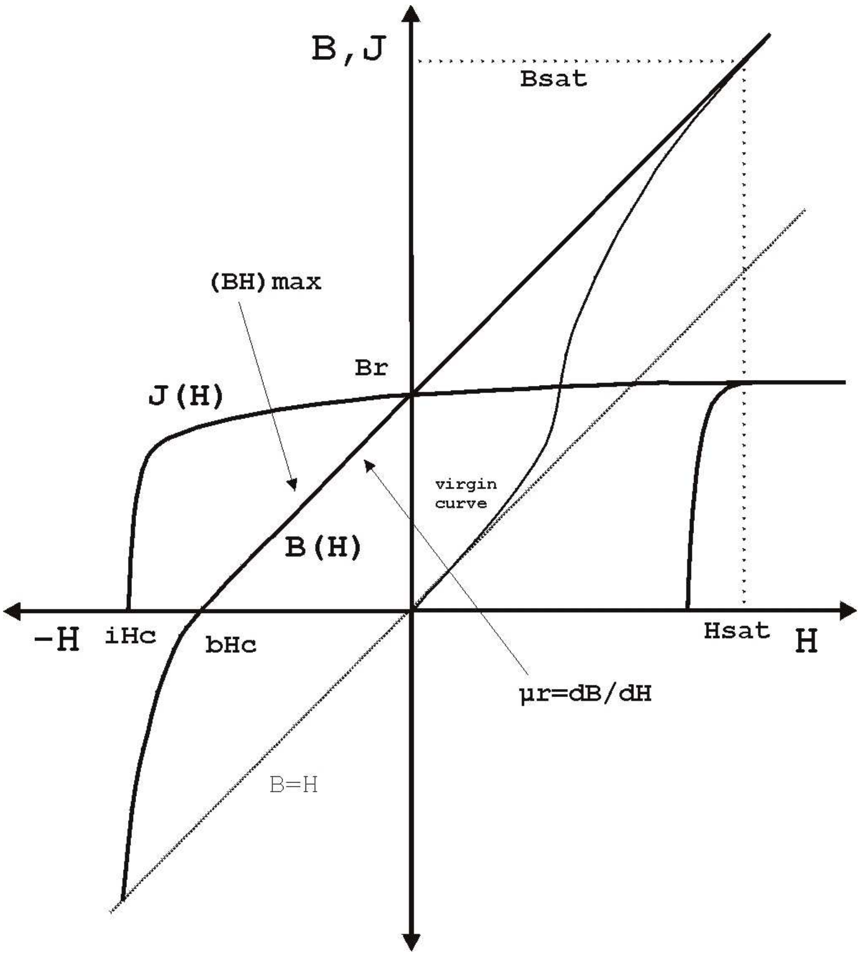


**Fig.B1:** Demagnetization curve ( second quadrant) as well as the first and parts of the third quadrant of magnetic hysteresis. The first quadrant is located at the top rightside of the coordinate cross, the second quadrant is the top left side. The third quadrant is placed at the bottom left side. The demagnetization curve, i.e. the second quadrant, defines the parameters Br, bHc, jHc, $\mu_r$ and $(BH)_{max}$.

The most important parameters of a demagnetization curve are named as:

$B_r$ = **Remanence induction** [T]
${}_jH_c$ = **Coercitivity of J** [A/m], ${}_bH_c$ = **Coercitivity of B** [A/m]
$\mu_r$ = **Recoil permeability** [no units]
$(BH)_{max}$ = **Maximum energy product** [kJ/m$^3$]

Now lets describe the behavior of demagnetization curves in more detail. As we examine here only one spatial direction, a scalar description is used.

In modern magnetic materials we have a nearly linear behavior of J(H) and B(H) on the demagnetization curve up to a point where the curve bents down more or less sharply. If the magnets working points are located in this linear area, these points can be moved up and down by external H changes without leaving the demagnetization curve. The behavior of the magnet is then called to be reversible

In the M(H) picture the linearity of the demagnetization curve is described by introducing a constant recoil susceptiblity $\chi_r$ by:

$$M(H) = M_r + \chi_r \cdot H \tag{B.1}$$

Here $M_r$ is the remanent magnetization. Using eq. (A.2) we get for J(H)

$$J(H) = B_r + \mu_0 \cdot \chi_r \cdot H \tag{B.2}$$

From this we get that the remanence induction in fig. B1 is related to the remanence magnetization simply by the factor $\mu_0$:

$$B_r = \mu_0 \cdot M_r \tag{B.3}$$

In the B(H) description it follows from eq. (A.7) that:

$$B(H) = B_r + \mu_0 \cdot \mu_r \cdot H \tag{B.4}$$

Here we have introduced the recoil permeability (or often called permanent permeability) by

$$\mu_r = 1 + \chi_r \tag{B.5}$$

The recoil permeability describes the steepness of the demagnetization curve in the B(H) description. The above formulas are not only true for linear demagnetization curves but can also be used, when there is a deviation from linearity. In this case $\mu_r$ and $\chi_r$ are H dependent.

From the above equations it can be seen, that the remanence induction is equivalent to the magnetization nearly over the whole linear or quasilinear range of the demagnetization curve. This can be taken especially from eq. (B.1), as $\chi r$ is close to zero ($\mu r$ close to one)for most modern magnetic materials. As the spatial distribution of magnetization determines the field of permanent magnets, see in chapter E, the importance of remanence induction can easily be understood.

The coercivity of B i.e. ${}_bH_c$ describes that magnetic field which makes the B distribution in the magnet to change its direction. It is smaller than iHc which is the field being necessary to demagnetize the polarization or magnetization to zero. Generally it can be stated that as higher the iHc value as more energy has to be used to magnetize a magnet to its saturation. This means that a higher $h_{sat}$ is needed which can be found in the first quadrant of hysteresis.

The Maximum Energy Product, i.e. the point on the demagnetization curve were the product B*H has its maximum, is introduced mainly for purposes of comparison, since the energy of a magnetic field is given by:

$$E = \frac{1}{2}\int \vec{B} \cdot \vec{H} dV \tag{B.6}$$

This means that the maximum field energy in an ideal magnetic circuit is at its maximum, when B*H on the demagnetization curve is at its maximum. When the permanent magnet behaves linearly with a constant recoil permeability μr the maximum energy product can be expressed simply by:

$$(BH)_{max} = \frac{1}{4 \cdot \mu_r \cdot \mu_0} \cdot B_r^2 \tag{B.7}$$

Up to now we have learned about different parameters of the demagnetization curve as well as some mathematical descriptions of its behavior. The origin for the importance of the demagnetization curve can be found in the fact, that all single magnets as well as most magnets in magnetic systems have their (B,H)-working points in the second quadrant of hysteresis. For the case of the single magnet this can be easily understood by the general difference between the B- and the H-fields. Fig. B2 shows the B as well as the H distribution of a single homogeneously magnetized sphere. Whereas the B field forms closed loops and is externally to the magnet equal to $\mu_0 H$ ($\mu_r$=1 in air, comp to eq. (A.11)), in the inner of the sphere the H field is reversed in comparison to B. So the internal field H tends to demagnetize its own source and is located on the negative branch of the coordinate system.

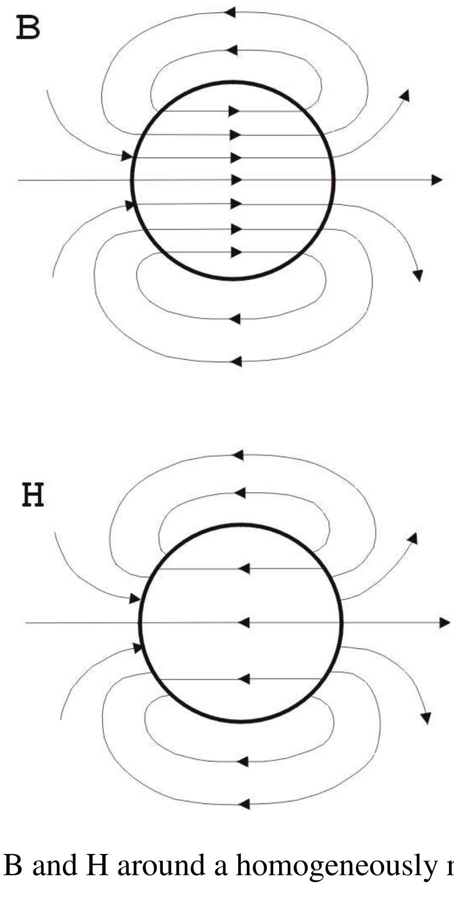


Fig.B2: Field distributions B and H around a homogeneously magnetized sphere.

For isolated magnets in case of ellipsoids the internal H field can be computed with the help of the **demagnetization factor** N:

$$H = -N M \tag{B.8}$$

0 <= N <= 1, N ~>1: oblate ellipsoid, N~>0: prolate ellipsoid. Sphere: N=1/3.

For other magnets either an estimate of demagnetization factors can be given, if their geometry is close to an ellipsoid, or there is a distribution of different working points, i.e. different H fields in the body. Generally it can be stated that the length to diameter ratio (L/D) determines the strength of H (L||M):

$$L/D \gg 1: H \sim 0, \quad L/D \ll 1: \text{ H is high} \tag{B.9}$$

In magnetic systems consisting of more units than only one permanent magnetic field source, in most cases the remaining demagnetizing fields in the magnet are still higher than any other external fields, despite those external fields probably act in the opposite direction. So also here the H fields are still negative, leading to working points still remaining on the demagnetization curve.