The Vocabulary of Magnetism

Symbols for key magnetic parameters continue to represent a challenge: they are changing and vary by author, country and company. Here are a few equivalent symbols for selected parameters. Subscripts in symbols are often ignored so as to simplify writing and typing. The subscripted letters are sometimes capital letters to be more legible. In ASTM documents, symbols are italicized. According to NIST's guide for the use of SI, symbols are not italicized. IEC uses italics for the main part of the symbol, but not for the subscripts. I have not used italics in the following definitions. For additional information the reader is directed to ASTM A340[11] and the NIST Guide to the use of SI[12]. Be sure to read the latest edition of ASTM A340 as it is undergoing continual updating to be made consistent with industry, NIST and IEC usage. Abbreviations are presented below from the oldest to the more recent and most common; the last abbreviation for each is most consistent with SI and what industry is moving toward and is bold faced and blue. Symbols are shown in Figures 1 and 2.

- Br = **B_R** = **Residual induction** and is equal to J_R (residual polarization) and $4\pi M_R$ (residual magnetization). Although J_R is often seen, B_R remains the more common symbol. Units of Br are tesla, T (SI units), and gauss, G (cgs units), where 10,000 gauss = one tesla.
- Hc = Hcb = **H_{cB}** = **coercivity** or normal coercivity or normal coercive field strength. "b" or "B" are probably used as the H_{cB} point is the intersection of the normal ("B versus H") curve and the H axis, that is, where B = 0. Units of coercivity are A/m (or kA/m, SI) and oersted, Oe (or kOe, cgs), where 1 Oe = 4•π•kA/m = 12.566•kA/m.
- Hci = iHc = mHc = Hcj = **H_{cJ}** = **intrinsic coercivity**, a measure of a magnet's resistance to demagnetization. The "I" or "J" are probably used as this point is on the Intrinsic curve, also called the polarization (J) curve, where J = 0. Units of coercivity are A/m (or kA/m, SI) and oersteds (Oe, cgs).
- (BdHd)m = (BdHd)max = BHmax = (BH)max = **$(BH)_{MAX}$** = **maximum energy product**. Every point on the normal curve has a value of B and a corresponding value of H. There is a product of B•H for every point on the curve. This product is called the energy product. The point where the product of B•H is maximum is called the maximum energy point and the value of B•H at this point is the maximum energy product. (You may have noticed that typing the parentheses for $(BH)_{MAX}$ conveniently avoids autocorrecting the two sequential capital letters). Units of maximum energy product are kilojoules per cubic meter, kJ/m^3 (SI) and megagauss•oersted, MGOe (cgs).
- μ_r = μ_{rec} = **$\mu_{(rec)}$** = **recoil permeability** is measured on the normal curve. It has also been called relative recoil permeability. When referring to the corresponding slope on the intrinsic curve it is called the intrinsic recoil permeability. In the cgs-Gaussian system where 1 gauss equals 1 oersted, the intrinsic recoil equals the normal recoil minus 1. For example, a typical rare earth magnet might have a $\mu_{(rec)}$ = 1.05 and the corresponding Intrinsic $\mu_{(rec)}$ = 0.05. The symbol μ_r is more appropriately used to represent relative or reversible permeability. There are other permeabilities, for example, initial permeability (μ_o) and maximum permeability, $\mu_{(max)}$. Strictly speaking recoil permeability is unitless (i.e., without units) although it is sometimes shown as G/Oe representing the slope of the recoil line.
- Pc = **P_C** = **permeance coefficient**. This is a calculated value dependent primarily on the dimensions of the magnet when the magnet is in open circuit. Calculation of P_C is also dependent upon the magnetic material for which the effects are large in alnico, FeCrCo, Vicalloy and similar materials. The effects are usually ignored for "straight line" materials such as ferrite, SmCo and NdFeB. The two most often used calculations are based either on the Evershed polar model (N_B, ballistic demagnetizing factor) or on Joseph's uniform material (magnetometric, N_M factor) or the similar fluxmetric (N_F, demagnetizing factor) the latter of which incorporates the materials' susceptibility. Pc is related to the demagnetizing factor by the relationship: P_C = 1-(1/N) where N is any of the above demagnetization factors. In the cgs-Gaussian system, the intrinsic permeance coefficient, $P_{CI} = P_C+1$.
- H_X and **H_K**. In these cases the symbol is the name of the parameter. Both parameters are meant to indicate the value of H corresponding to the location of the knee of the intrinsic curve,

that value of H where the intrinsic curve falls quickly toward the H axis. For a more complete explanation of the origin and use of these terms see Figure 2 and References 1, 16, 17.

- **H_K/H_{cJ} = squareness** (ratio). Since H_k is an indicator for the onset of demagnetization and H_{cJ} is a measure of a magnet's resistance to demagnetization, a value of H_k approaching H_{cJ} is considered beneficial. The ratio of H_k is to H_{cJ} is the squareness ratio with 1 as an upper limit and values greater than 0.85 considered typical – for square loop materials such as permanent magnet ferrites, NdFeB and SmCo.
- **H_a = anisotropy field**, a "quantitative measure of the strength of the magneto-crystalline... anisotropy". That field needed to saturate the magnet in the hard direction (orientation), usually perpendicular to the easy direction such as in tetragonal, hexagonal and rhombohedral crystalline magnetic materials. $H_a = 2K_a / \mu_o M_S$ where K_a is the effective anisotropy constant.
- $4\pi M_S$ = **J_S = Saturation magnetization** (referring to M) or saturation polarization (referring to polarization). This is the maximum value of intrinsic magnetic field strength achievable by a ferro- or ferri-magnetic material. It is observed in the 1st quadrant and is one of the key figures of merit for soft magnetic materials. Refer to Figure 1.
- $M_S/M_R = M_S/B_R$ = **J_S/J_R** = 1st quadrant **squareness ratio**. Less frequently used in industry but often used in magnetics research. It is a measure of a permanent magnet's resistance to spontaneous demagnetization and is often an indicator of a potentially strong permanent magnet material.

Additional thoughts…
Though the B versus H curve will become straight at material saturation, it should never level-off. It is the sum of the applied field and the magnetization. When saturation takes place, additional H results in a corresponding increase in B. The intrinsic curve, however, will become flat (level) at saturation as it represents only the material's magnetization.

The scales of the H and B axes can be extremely different so care should be applied in interpreting slope of the normal and intrinsic curves. When making measurements in closed loop hysteresigraphs, the combination of applied and induced fields can exceed the pole cap flux-carrying capacity resulting in distorted curves.

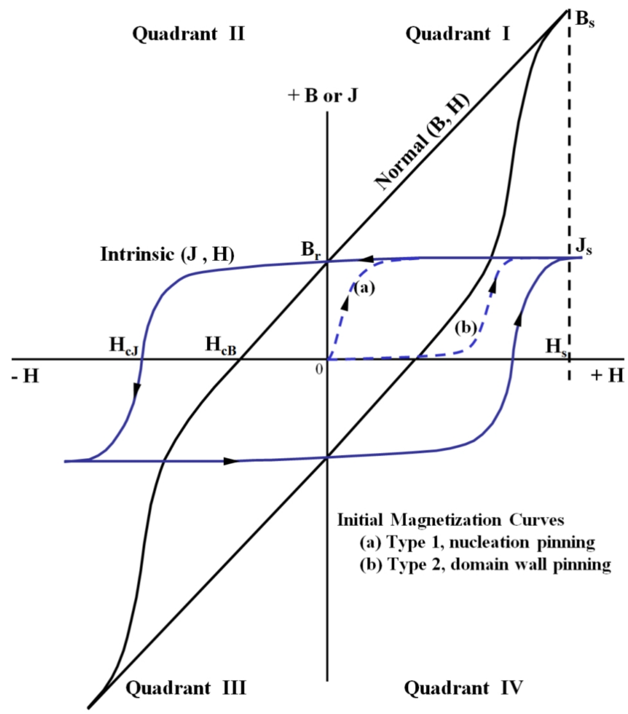

Figure 1. Normal and intrinsic magnetic hysteresis loops showing all four quadrants and indicating many key figures of merit. This chart is based on Figure 1 of *ASTM A977M Standard Test Method for Magnetic Properties of High-Coercivity Permanent Magnet Materials Using Hysteresigraphs*.

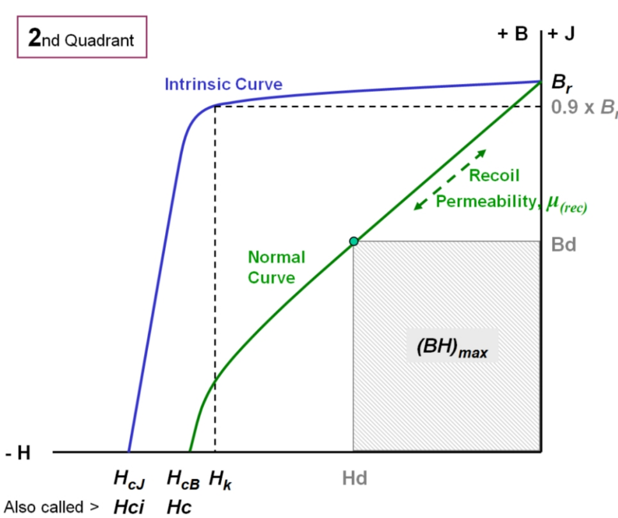

Figure 2. Second quadrant showing both normal and intrinsic hysteresis curves and key figures of merit. Maximum energy product, $(BH)_{max}$, is represented by the shaded area.

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