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Understanding Permanent Magnets
An Attempt at Universal Magnetic Literacy

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The Three Vectors, CGS version

$$B = H + 4\pi M$$

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The Three Vectors, SI version

$$B = \mu_0 H + \mu_0 M$$

$$J = \mu_0 M$$

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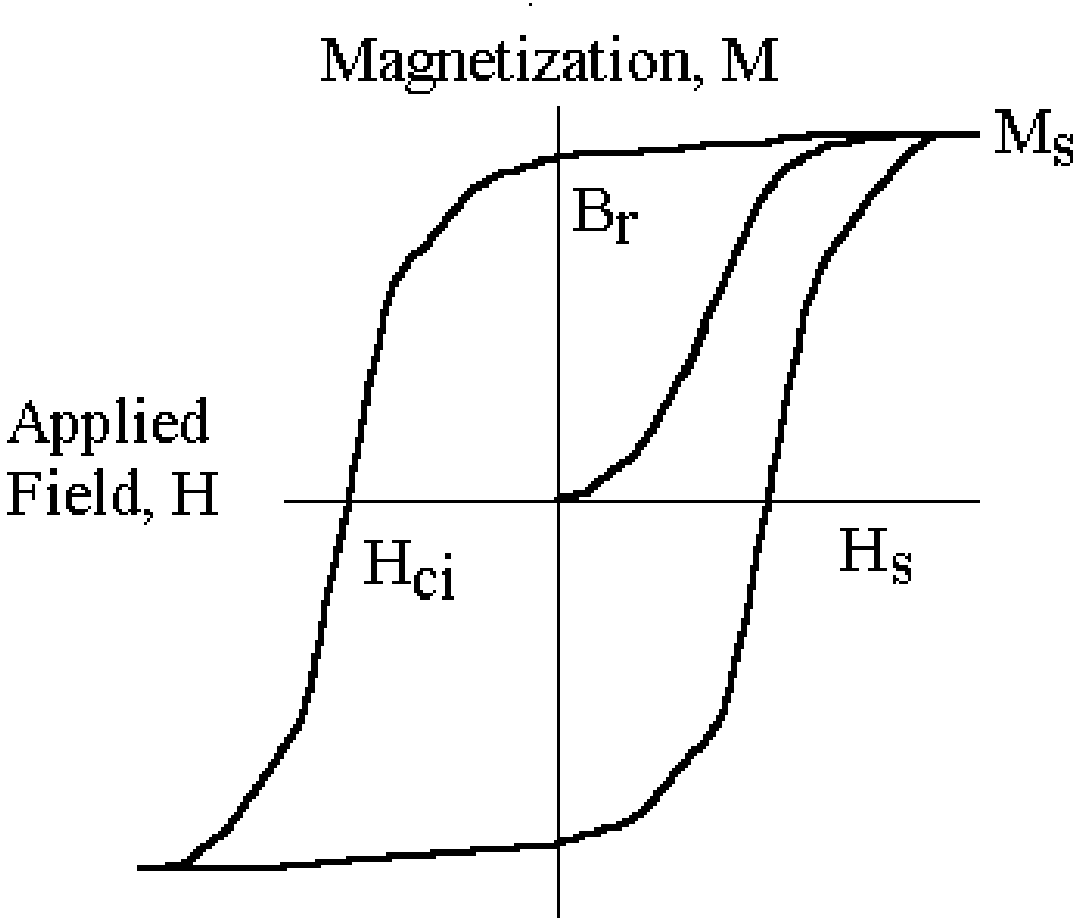
Magnetic Hysteresis, M vs. H



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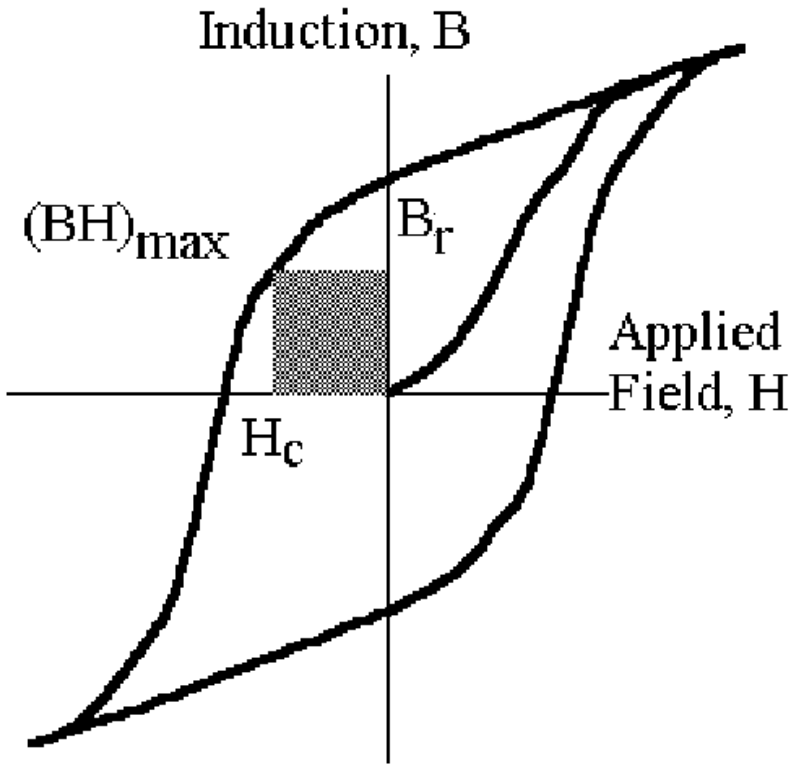
Magnetic Hysteresis, B vs. H



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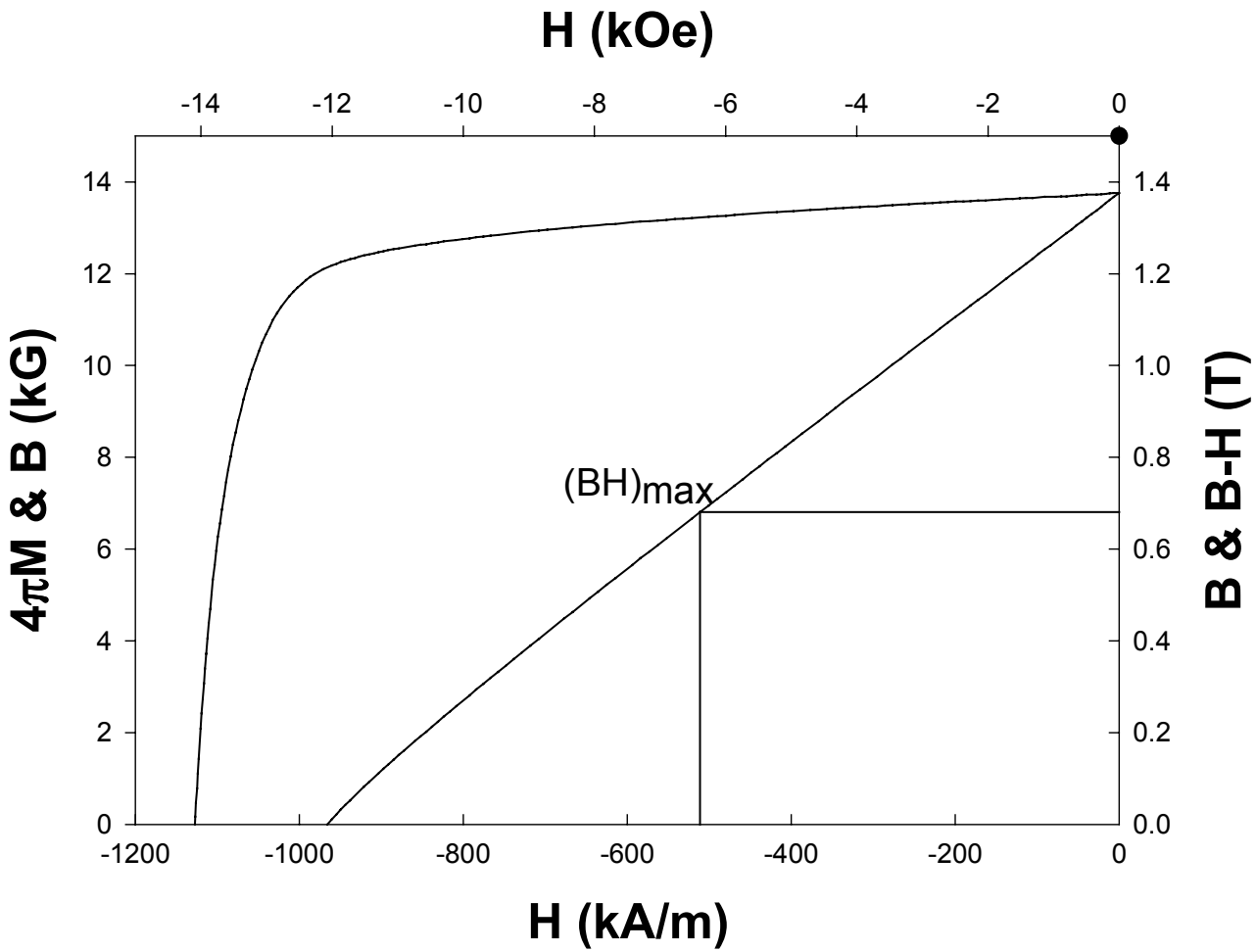
Demagnetization curves



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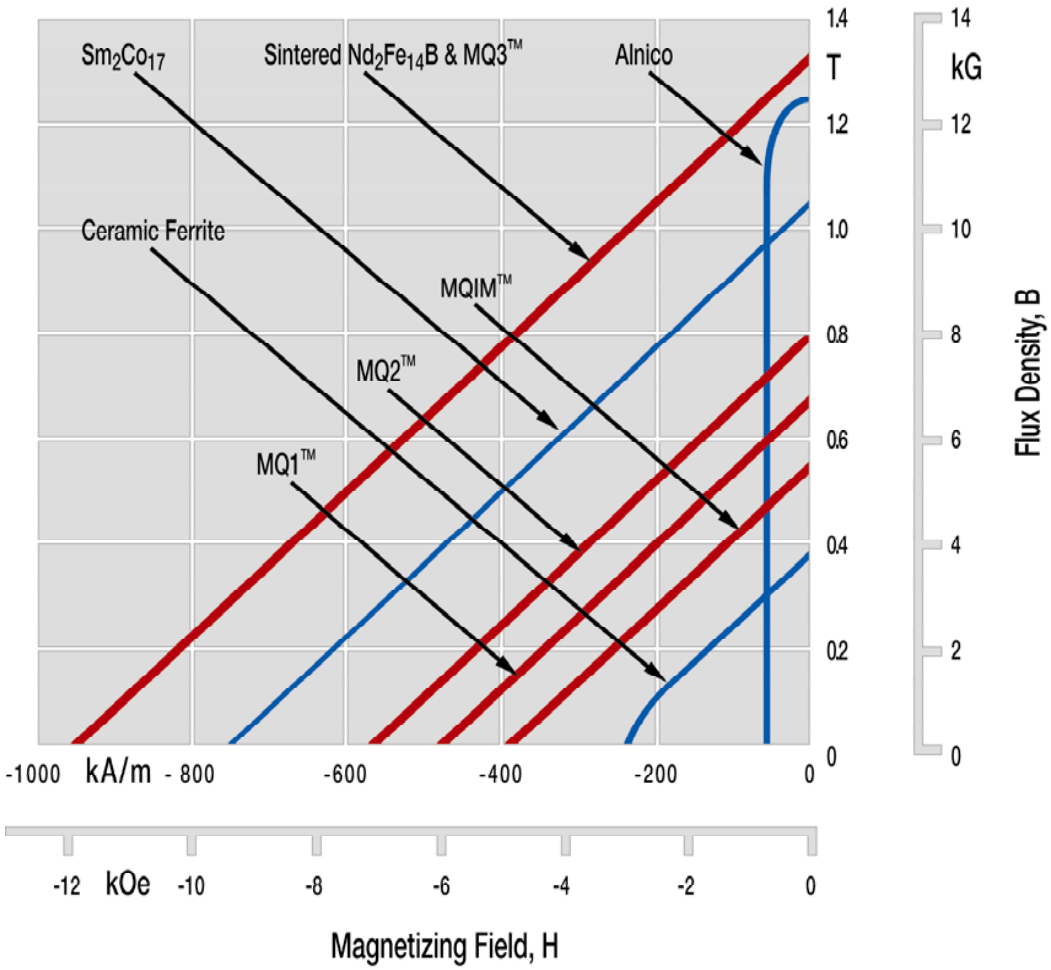
Demagnetization curves



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Four Families of Permanent Magnets

Property	Ferrite	Alnico	SmCo		NdFeB			
	Ceramic 8	Alnico 5	Recoma-20	Recoma-26	Ugimax 43A2	MQ1-B	MQ2-E	MQ3-F
B_r (kG)	4.0	12.5	9.0	10.4	13.4	6.9	8.25	13.1
$(BH)_{max}$ MGOe	3.8	5.5	20	26	43	10	15	42
H_{ci} (kOe)	3.3	0.64	30	25	15	9	17.5	16
T_c (°C)	460	890	727	825	310	360	335	370

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The Rare Earths

		Sc														
		Y														
		La														

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

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Bonded NdFeB benefits

- Smaller size
- Lower weight
- Higher efficiency
- More torque
- Improved low temperature performance

Checklist: ferrite to bonded NdFeB conversions

Material selection

- Select primary consideration: high B_r, high H_{ci}, high T_c, low irreversible loss, low cost
- Verify manufacturability with supplier

Magnetic circuit analysis

- Don't copy ferrite dimensions or shapes, especially in motors, rings are the preferred shape for bonded NdFeB with 4 or more poles
- Check that other flux carrying parts, return path, laminations etc. are not saturated

Corrosion protection

- Coat or overmold? Determine if necessary

Checklist: ferrite to bonded NdFeB conversions

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EMW Electrical Manufacturing Coil Winding Association

Magnetizing

- Apply adequate magnetizing field, verify magnets are really saturated. New fixture and magnetizer likely
- Verify that the flux is correctly oriented in the fixture; unlike anisotropic magnets, isotropic bonded magnets assume the same flux pattern supplied by the fixture

Temperature

- Determine maximum operating temperature
- Verify material is compatible with this limit
- Determine irreversible loss, if necessary
- Check effect of armature reaction at the maximum operating temperature

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Redesign comparison

	Constant Stack Length		Constant Diameter	
Magnet Material	Diameter (mm)	% Reduction	Stack length (mm)	% Reduction
Ceramic 8	48	0	48	0
MQIM™-O w/ PPS	39.2	18.3	44	8.3
MQIM™-B+ w/nylon 11	36.9	23.1	43	10.4
MQ1™-O	33.8	29.6	41.5	13.5

- Appliance motor, 2 pole
- Redesigned to maintain similar performance
- Two approaches: constant stack length and constant diameter
- Thicker wire, fewer turns, wider rotor teeth
- Higher efficiency

Education on Magnetic Materials

- Need
- Resources
- Methods

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Summary

- Review of hysteresis
- Salient features of permanent magnet materials
- Rare Earths
- Ferrite to bonded magnet checklist and comparison
- Magnetic education