CH.20 磁性質

搞懂基本的名詞 (單位要會)

$B = \mu H$ (在固體材料中) μ is called the **permeability,**

$B_0 = \mu_0 H$ (在真空中) μ_0 is the *permeability of a vacuum,*

$M = \chi_m H$ M, called the **magnetization**

χ_m is called the **magnetic susceptibility,**

$$\mathbf{H} \stackrel{def}{=} \frac{\mathbf{B}}{\mu_0} - \mathbf{M}$$

$$\mu_r = \frac{\mu}{\mu_0} \qquad \chi_m = \mu_r - 1$$

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

Quantity	*Symbol*	*SI Units* Derived	*SI Units* Primary	*cgs–emu Unit*
Magnetic induction (flux density)	B	tesla (Wb/m^2)[a]	kg/s-C	gauss
Magnetic field strength	H	amp-turn/m (A/m)	C/m-s	oersted
Magnetization	M (SI) I (cgs–emu)	amp-turn/m (A/m)	C/m-s	maxwell/cm^2

注意 M: 定義為單位體積的磁偶極矩，磁化強度的單位是安培／公尺。

$$\mathbf{M} \stackrel{def}{=} n\mathbf{m}\ ;$$

其中，$\mathbf{M}$ 是磁化強度，n 是磁偶極子密度，$\mathbf{m}$ 是每一個磁偶極子的磁偶極矩。

B 透過 permeability 與 H 成正比
M 透過 susceptibility 與 H 成正比
B 又透過 vacuum permeability 與(H+M)成正比

磁力矩的來源 (orbital&spin)→所有電子都有淨磁矩，原子不一定

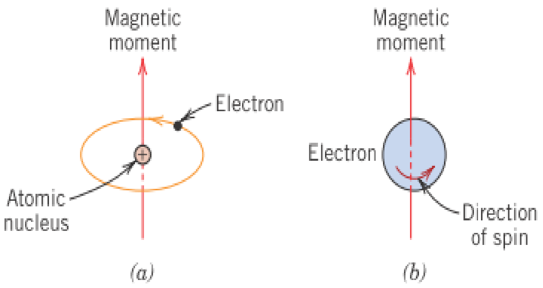


Figure 20.4 Demonstration of the magnetic moment associated with (*a*) an orbiting electron and (*b*) a spinning electron.

The most fundamental magnetic moment is the **Bohr magneton** μ_B, which is of magnitude 9.27×10^{-24} A-m^2. For each electron in an atom the spin magnetic moment is $\pm\mu_B$ (plus for spin up, minus for spin down). Furthermore, the orbital magnetic moment contribution is equal to $m_l\mu_B$, m_l being the magnetic quantum number of the electron, as mentioned in Section 2.3.

對於填滿的電子層和 subshell，軌道和旋轉力矩完全抵銷→無法永久磁化

Ex.惰性氣體 He.Ne.Ar 和某些離子材料

Diamagnetism	1.只有外加電場才出現，方向與外加電場相反 2.很弱，沒啥實際重要性 3.磁化率為負 -10^5 4.所有材料都有逆磁性!!!!!
Paramagnetism	1.Spin/orbital 不完全抵銷→permanent dipole moment 2.無外加磁場時，方向隨意，有外加磁場時產生順磁性 3.磁化率為正 10^-5~10-^-2 *逆磁和順磁視為”非磁性的”有外加磁場材有磁化特性
Ferromagnetism	1. 無外加電場就有永久磁力矩 →軌道磁力矩小於旋轉磁力矩 2.magnetic dipole coupling，造成鄰近原子的淨旋轉磁力矩(即使無外加磁場)，偶和力量來源未明，一般認為是電子結構，共同旋轉排列的大體積區域稱為 domain 3.BCC 阿法鐵.Co.Ni.Gd.. 4.磁化率 10^6，很高所以 $\bar{H} \ll M$ $B \cong \mu_0 M$ 5.飽和磁化量，所有磁偶極與外加電場共同排列時所產生的磁化量 = 淨磁力矩*單位體積原子個數(看例題) *淨磁力矩 Fe:2.22>Co:1.72>Ni:0.6 Bohr 磁子
Antiferromagnetism	1. 也有 coupling，起因於反平行的排列的旋轉力矩 2. MnO、Mg、Cr 3. 相反的磁力矩互相抵消，無淨磁力矩

Ferrimagnetism 亞鐵磁性，就意味著他是靠<u>八面體位置的亞鐵離子</u>貢獻的磁力矩	1. 某些 ceramic 也有永久的磁化，與 Ferromagnetism 差別在淨磁力矩的 source 2. cubic ferrites(<u>磁性</u>陶瓷)→MFe2O4→ inverse spinel crystal structure **prototype ferrites→Fe3O4→lodestone**(極鐵磁礦) 裡面含二價鐵離子:三價鐵離子= 1:2 二價：每個離子 4 Bohr magnetons 有淨貢獻，磁化量即計算 2 價離子，八面體位置 三價：每個離子 5 Bohr magnetons 但八面體位置和四面體位置相抵消，無淨貢獻 3. 飽和磁化量沒鐵磁性這麼高，但為比較好的電絕緣體，這性質在某些應用是好的 ex. high-frequency transformers

*magnetic dipole coupling 是永久磁化的原因!!鐵磁和以下的逆鐵磁亞鐵磁都有只是逆鐵磁剛好抵銷掉了，而順磁性沒有 couple，不能永久磁化。

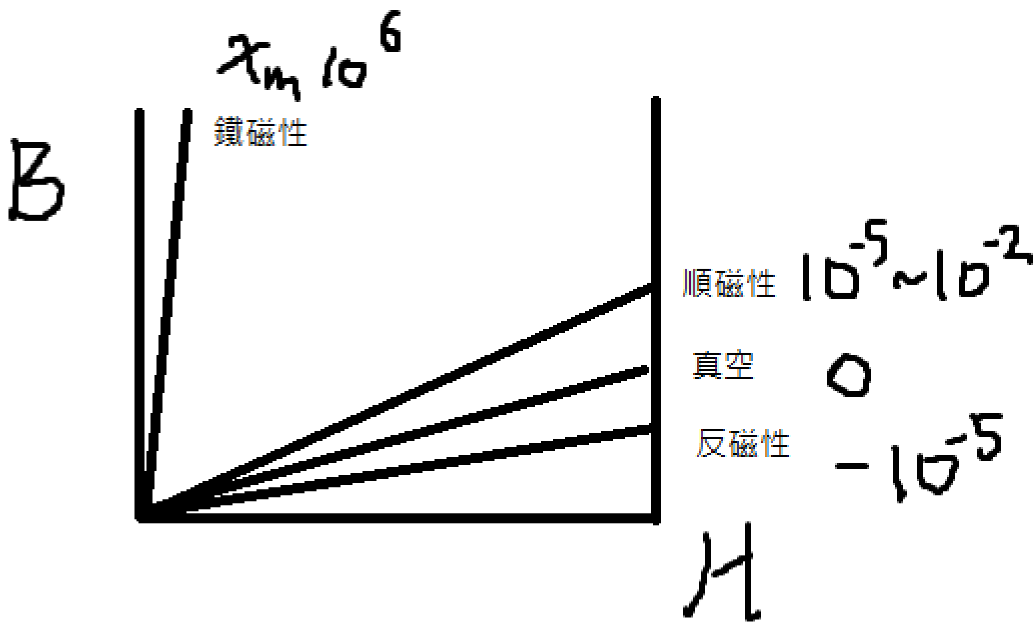
*後面補充—鐵磁和亞鐵磁比較

Cubic ferrite 具有 inverse spinel 結構

氧離子最密堆積面堆疊

Fe^{2+}全部都八面體位置，旋轉力矩有淨貢獻

Fe^{3+}一半在八面體位置，一半在四面體位置，旋轉力矩抵銷



Calculate **(a)** the saturation magnetization and **(b)** the saturation flux density for nickel, which has a density of 8.90 g/cm^3.

Solution

(a) The saturation magnetization is just the product of the number of Bohr magnetons per atom (0.60 as given above), the magnitude of the Bohr magneton μ_B, and the number N of atoms per cubic meter, or

$$M_s = 0.60\mu_B N \tag{20.9}$$

Now, the number of atoms per cubic meter is related to the density ρ, the atomic weight A_{Ni}, and Avogadro's number N_A, as follows:

$$N = \frac{\rho N_A}{A_{Ni}} \tag{20.10}$$

$$= \frac{(8.90 \times 10^6 \text{ g/m}^3)(6.023 \times 10^{23} \text{ atoms/mol})}{58.71 \text{ g/mol}}$$

$$= 9.13 \times 10^{28} \text{ atoms/m}^3$$

Finally,

$$M_s = \left(\frac{0.60 \text{ Bohr magneton}}{\text{atom}}\right)\left(\frac{9.27 \times 10^{-24} \text{ A-m}^2}{\text{Bohr magneton}}\right)\left(\frac{9.13 \times 10^{28} \text{ atoms}}{\text{m}^3}\right)$$

$$= 5.1 \times 10^5 \text{ A/m}$$

(b) From Equation 20.8, the saturation flux density is just

$$B_s = \mu_0 M_s$$

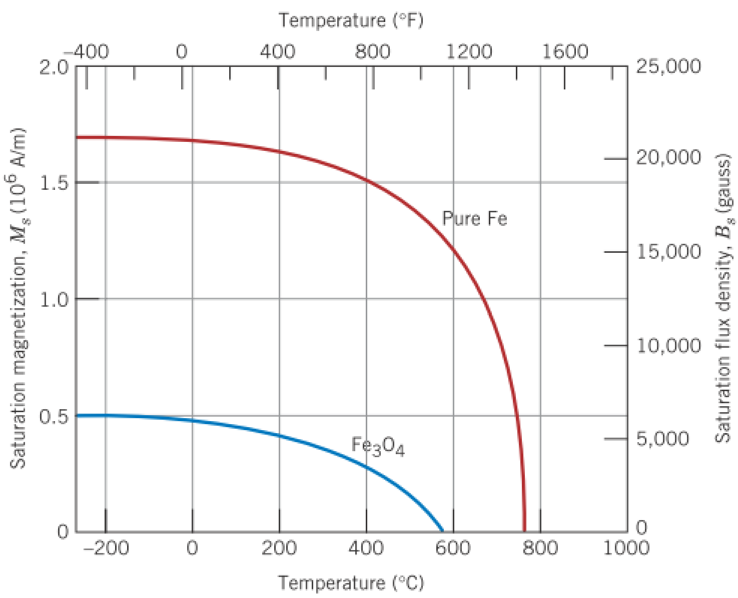
$$= \left(\frac{4\pi \times 10^{-7} \text{ H}}{\text{m}}\right)\left(\frac{5.1 \times 10^5 \text{ A}}{\text{m}}\right)$$

$$= 0.64 \text{ tesla}$$

*飽和磁化量是單位體積的總磁力矩!!所以 20.9 式那個 N 是單位體積的原子個數!!搞清楚單位!!

*算飽和 B，直接真空導磁率*飽和磁化量，不用算 H(也沒法兒算)

溫度對磁性行為的影響



鐵磁和亞鐵磁

T 提高→熱運動使力矩方位隨意化→鐵磁和亞鐵磁的磁化量減少

0 K 時，飽和磁化量 max

Tc 飽和磁化量降到 0→Curie Temperature→高於 Tc→變順磁性

Curie's Law

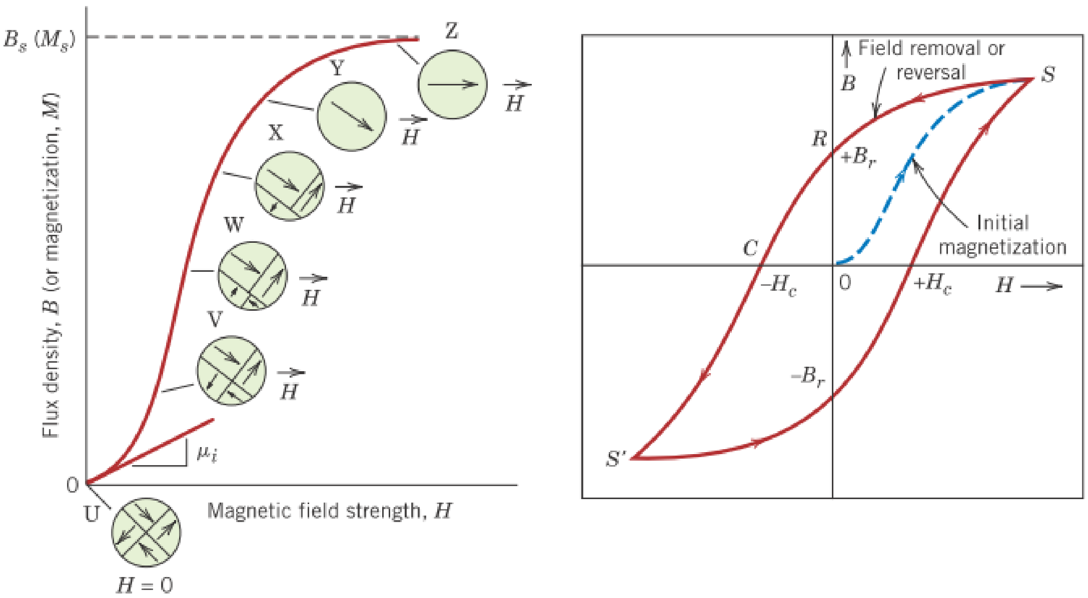
$$\mathbf{M} = C \cdot \frac{\mathbf{B}}{T},$$

反磁性

類似，但其溫度稱為 N'eel Temperature→高於 Tc→變順磁性

20.19 For ferromagnetic materials, the saturation magnetization decreases with increasing temperature because the atomic thermal vibrational motions counteract the coupling forces between the adjacent atomic dipole moments, causing some magnetic dipole misalignment. Ferromagnetic behavior ceases above the Curie temperature because the atomic thermal vibrations are sufficiently violent so as to completely destroy the mutual spin coupling forces.

磁域和磁滯



1. B 和 H 對鐵磁和亞鐵磁來說是不成比例的(如圖)最後達飽和時與 H 無關

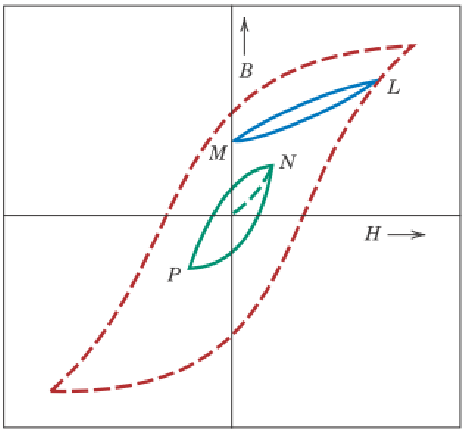
2.可知導磁率隨 H 而改變

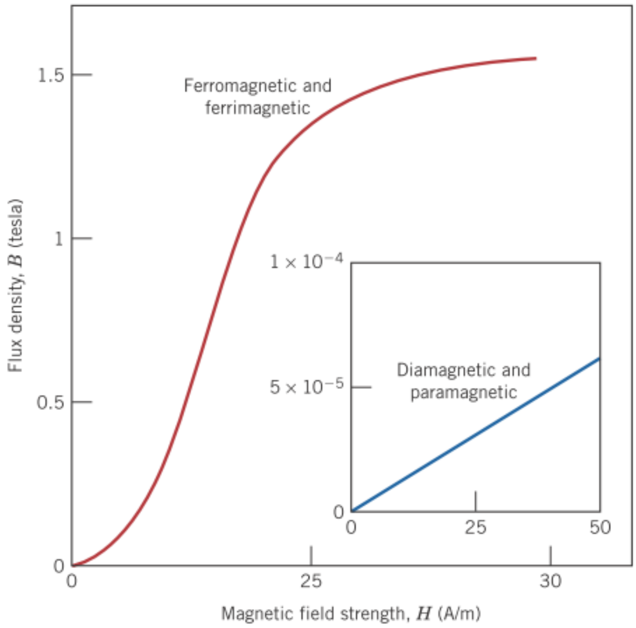
3. H=0 時的導磁率可視為材料性質(最初導磁率)

4.當施加 H 反方向，曲現不會延原路，B 會 lag(以磁域壁移動解釋)，H=0 時有 residual Br(remanence)

5.要將 B 減至 0，需作用 Hc(coercivity)

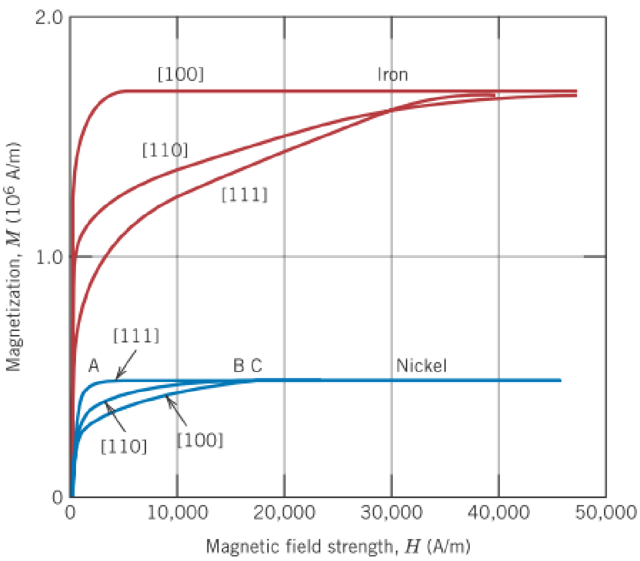
6.去磁:反覆改變 H 場方向和漸漸減小，反覆 cycle





*比較:反磁性的 B-H

Magnetic anisotropy

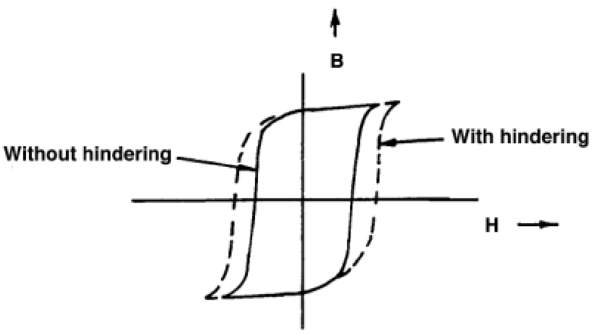


磁滯線形狀的影響因素

1. 單晶 or 多晶
2. 優選方位
3. 空孔.第 2 相顆粒
4. 溫度.外加應力
5. 上圖表不同方向有著不同的磁化容易度

軟磁材料

1. 磁滯曲現的環面積代表著每磁化-去磁循環單位體積的能量損失→熱能→增加溫度
2. 軟磁:磁場改變能量損失較少→環薄且窄→高最初導磁率.低 coercivity→容易磁化&消磁
3. 飽和磁場的磁化量 magnetization 僅由成分決定!!
   而磁滯曲現的 susceptibility and coercivity 對結構敏感
   Ex.保磁力低→容易移動的 domain
   結構缺陷(非磁性相的粒子或空孔)→限制 domain 移動→增加保磁力
4. 能量損失亦可由電流造成:磁場隨時間變化大小和方向產生電流→eddy current→要減少此能量消耗→增加電阻係數 EX.鐵磁性材料形成固溶合金

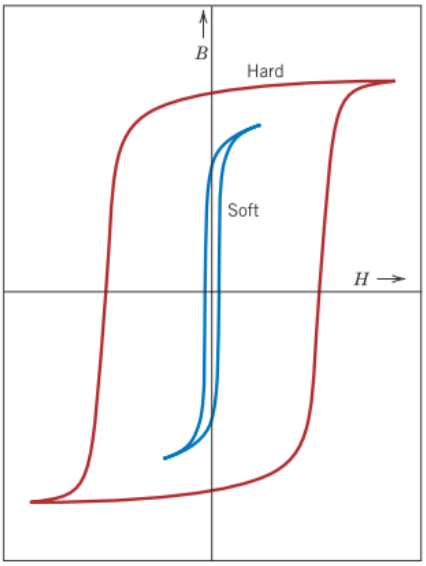


阻礙 domain 邊界
對 coercivity 的影響

硬磁材料

1. 永久磁鐵→高殘留磁力.保磁力.飽和磁通量密度.低最初導磁率.高能損
2. 材料應用最重要的 2 個特性
   *保磁力
   *能積 energy product ;(BH)max→第二像限內能構成的最大 B-H 矩形面積
   →是將一永久磁體去磁所需能量的代表 (KJ/m^3)(MGOe)
3.

傳統硬磁	1. BH $\boxed{2\sim80kJ/m^3}$ 2. alloyed with tungsten and/or chromium，藉由熱處理，form tungsten and chromium carbide precipitate particles→阻擋 domain 3. 熱處理產極小的 strongly magnetic iron-cobalt particles within a nonmagnetic matrix phase 4. EX. Magnet steel、cunife(Cu-Ni-Fe)、alnico(Al-Ni-Co)、hexagonal ferrites(BaO-$6Fe_2O_3$)
高能硬磁	BH $\boxed{>80\ kJ/m^3}$ EX. $SmCo_5$、$Nd_2Fe_{14}B$



看圖講出軟硬有啥特質

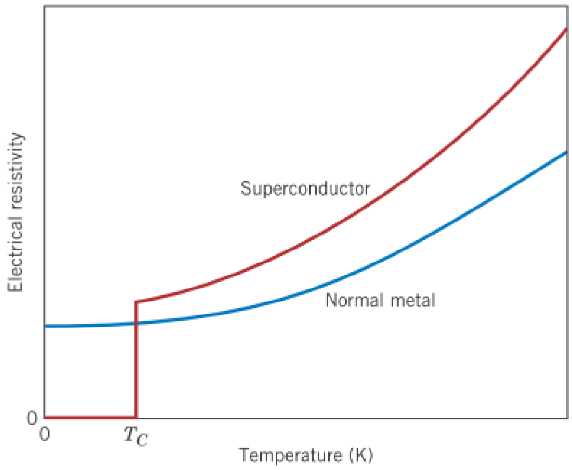
磁性的儲存

1. 兩種基本形式

particulate	γ-Fe_2O_3 ferrite or CrO_2 bonded to a polymeric film (for magnetic tapes) or to a metal or polymer disk.
thin film	CoPtCr or CoCrTa alloy

超導性

原理:成對電子相互吸引，因此同等運動避免了熱震動和不純物散射



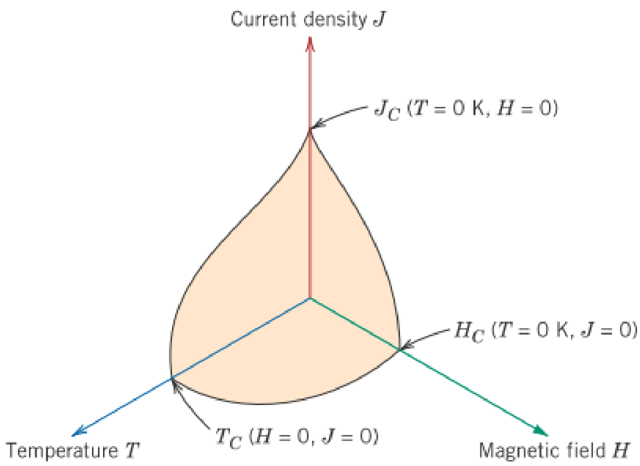
1.低於 Tc，電阻降至 0

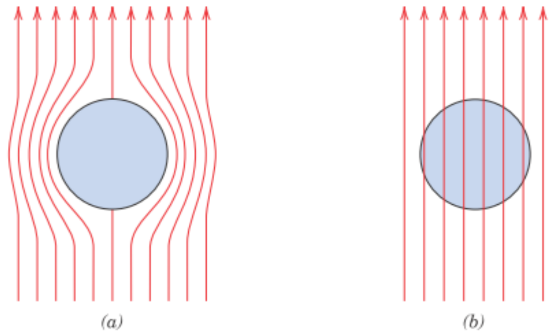
2.高溫超導體→某些 ceramic 的臨界溫度超過 100K

→主要 limit : ceramic too brittle!!

→實用上有點難

在這區域內是超導，界線之外是正常導體→



TYPE1	具 Meissner 效應(Al.Pb.Sn.Hg)→超導狀態具有完全的反磁性→超過臨界 Hc→變正常導體  **Figure 20.28** Representation of the Meissner effect. (*a*) While in the superconducting state, a body of material (circle) excludes a magnetic field (arrows) from its interior. (*b*) The magnetic field penetrates the same body of material once it becomes normally conductive.
TYPE2	1.低外加磁場有完全的反磁性，但要轉變成正常導體時，有上下兩個臨界 H，再 2 鄰介值之間，正常和超導的特性均出現 2.Nb-Zr. Nb-Ti. Nb3Sn 3.較實用，因為有較高的臨界溫度和臨界磁場

應用:磁共振影像 MRI 磁共振光譜儀 MRS

Elements[b]

Tungsten	0.02
Titanium	0.40
Aluminum	1.18
Tin	3.72
Mercury (α)	4.15
Lead	7.19

Al.Sn
Hg.Pb
Ti.W

type 1
超導狀態是完全反磁性

Compounds and Alloys[b]

Nb–Ti alloy	10.2
Nb–Zr alloy	10.8
$PbMo_6S_8$	14.0
V_3Ga	16.5
Nb_3Sn	18.3
Nb_3Al	18.9
Nb_3Ge	23.0

Nb!!

type 2
較type 1 高的臨界溫度
(比較好用)
低作用磁場時是完全反磁性
有上下臨界點

Ceramic Compounds

$YBa_2Cu_3O_7$	92
$Bi_2Sr_2Ca_2Cu_3O_{10}$	110
$Tl_2Ba_2Ca_2Cu_3O_{10}$	125
$HgBa_2Ca_2Cu_2O_8$	153

陶屬類
臨界溫度更高更有潛力
因為高過77K 可使用液態氮

補充鐵磁和亞鐵磁比較

20.12 The similarities between ferromagnetic and ferrimagnetic materials are as follows:

There is a coupling interaction between magnetic moments of adjacent atoms/cations for both material types.

Both ferromagnets and ferrimagnets form domains.

Hysteresis **B-H** behavior is displayed by both, and, thus, permanent magnetizations are possible.

The differences between ferromagnetic and ferrimagnetic materials are as follows:

Magnetic moment coupling is parallel for ferromagnetic materials, and antiparallel for ferrimagnetic.

Ferromagnetics, being metallic materials, are relatively good electrical conductors; inasmuch as ferrimagnetic materials are ceramics, they are electrically insulative.

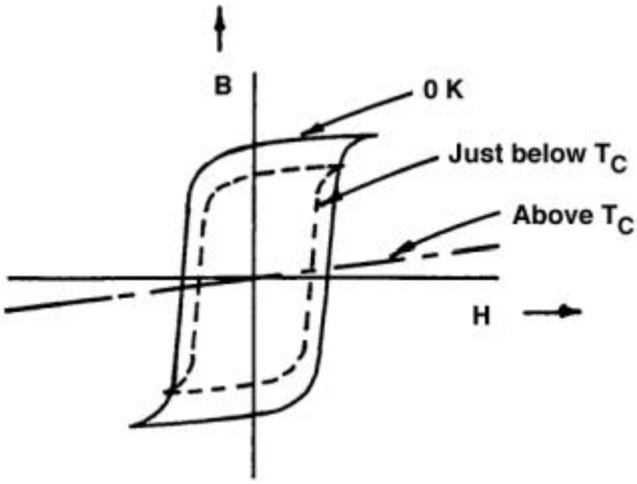
Saturation magnetizations are higher for ferromagnetic materials.

Spinel structure

20.13 Both spinel and inverse spinel crystal structures consist of FCC close-packed stackings of anions (O^{2-} ions). Two types of sites, tetrahedral and octahedral, exist among the anions which may be occupied by the cations. The divalent cations (e.g., Fe^{2+}) occupy tetrahedral positions for both structures. The difference lies in the occupancy for the trivalent cations (e.g., Fe^{3+}). For spinel, all trivalent ions reside on octahedral sites; whereas, for the inverse spinel, half are positioned on tetrahedral sites, the other half on octahedral.

*Hund's rule states that the spins of the electrons of a shell will add together in such a way as to yield the maximum magnetic moment. This means that as electrons fill a shell, the spins of the electrons that fill the first half of the shell are all oriented in the same direction

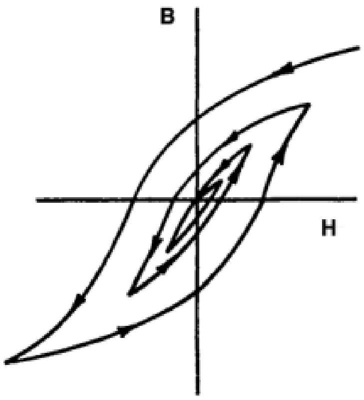
*為啥重複將永久磁石砸到地板可以去磁?
使 magnetic dipoles misaligned by dipole rotation



鐵磁性材料 B-H

0K 飽和磁化量最高→溫度越高→磁化量越少，超過 Tc 鐵磁行為停止→變順磁性
→低斜率

*去磁



***解釋 Meissner**

20.35 The Meissner effect is a phenomenon found in superconductors wherein, in the superconducting state, the material is diamagnetic and completely excludes any external magnetic field from its interior. In the normal conducting state complete magnetic flux penetration of the material occurs.