

Estructura de la Materia 2

Clase 14 - Teoría

Docentes

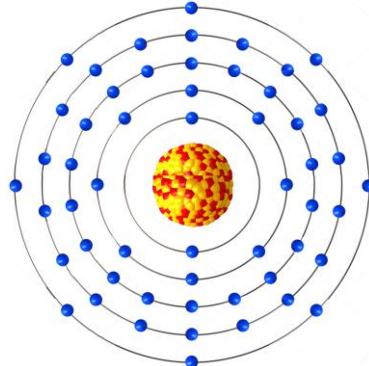
Gustavo Grinblat, Andrea Barral, Franco Mayo, Alejandra Fernández

Departamento de Física, FCEN, UBA – Segundo Cuatrimestre, 2022

Web: <http://materias.df.uba.ar/edlm2a2022c2>

Repaso

Magnetismo en átomos aislados



$$\Delta\mathcal{H}_T = \mu_B \bar{H} \cdot (\bar{L} + g\bar{S}) + \frac{e^2}{8m_e c^2} \sum_i |\bar{H} \times \bar{r}_i|^2$$

Reglas de Hund

$$\Delta E_n = \mu_B \bar{H} \cdot \langle n | \bar{L} + g\bar{S} | n \rangle + \underbrace{\sum_{n' \neq n} \frac{|\langle n | \mu_B \bar{H} \cdot (\bar{L} + g\bar{S}) | n' \rangle|^2}{E_n - E_{n'}}}_{\text{Paramagnetismo de Curie}} + \underbrace{\frac{e^2}{8m_e c^2} \langle n | \sum_i |\bar{H} \times \bar{r}_i|^2 | n \rangle}_{\text{Diamagnetismo de Larmor}}$$

Paramagnetismo de Curie

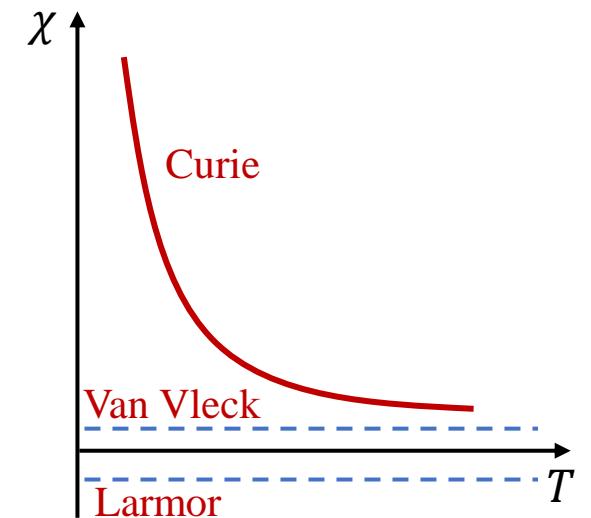
Paramagnetismo de Van Vleck

Diamagnetismo de Larmor

$$J \neq 0 \text{ (Paramagnetismo de Curie)} \longrightarrow \Delta E_n = g_L \mu_B \bar{H} \cdot \langle n | \bar{J} | n \rangle$$

$$\longrightarrow M = \frac{N}{V} \frac{g_L \mu_B}{2} \left[(2J+1) \coth \left(\frac{\beta g_L \mu_B H (2J+1)}{2} \right) - \coth \left(\frac{\beta g_L \mu_B H}{2} \right) \right]$$

$$g_L \mu_B H \ll k_B T \longrightarrow \chi = \frac{\partial M}{\partial H} = \frac{N}{V} \frac{(g_L \mu_B)^2}{3k_B T} J(J+1)$$



Repasso

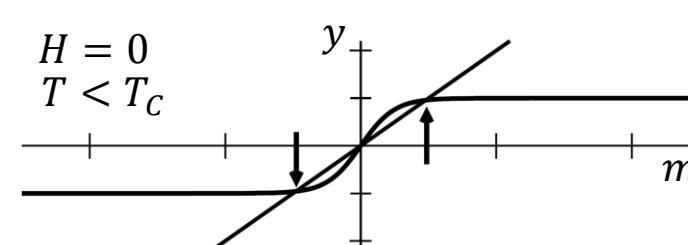
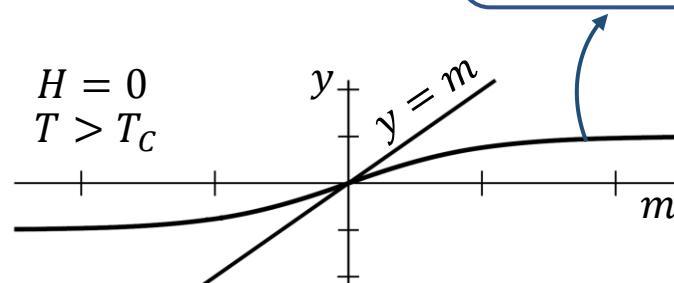
Interacción entre espines: Orden ferromagnético

$$\mathcal{H} = -\frac{J_{int}}{2} \sum_{\langle i,j \rangle} \bar{S}_i \cdot \bar{S}_j + g_L \mu_B \bar{H} \cdot \sum_i \bar{S}_i, \quad J_{int} > 0$$

Campo medio → Para el sitio i : $\mathcal{H}_i = \bar{S}_i \cdot \left[-J_{int} \sum_j \langle \bar{S}_j \rangle + g_L \mu_B \bar{H} \right] = \bar{S}_i \cdot g_L \mu_B \bar{H}_{ef}$

$g_L \mu_B H_{ef} \ll k_B T$ → $\chi = \frac{N}{V} \frac{(g_L \mu_B)^2}{3k_B(T - T_C)} S(S+1)$, con $T_C = \frac{zJ_{int}S(S+1)}{3k_B}$ (Ley de Curie-Weiss)

A campo nulo: $m = \frac{g_L \mu_B}{2} \left[(2S+1) \coth \left(\frac{\beta(2S+1)zJ_{int}}{2g_L \mu_B} m \right) - \coth \left(\frac{\beta zJ_{int}}{2g_L \mu_B} m \right) \right]$

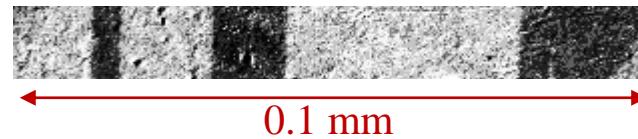


!Magnetización espontánea cuando $T < T_c$!

Magnetismo: Dominios e histéresis

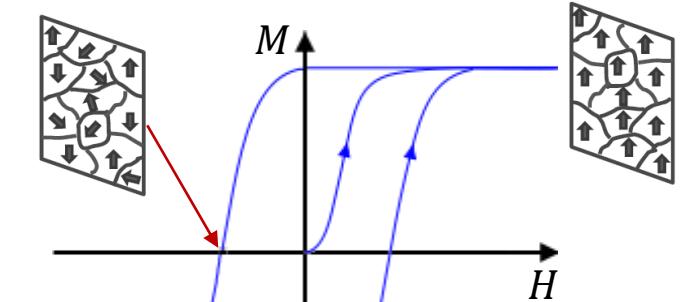
Dominios magnéticos (ferromagneto)

Aplicar un campo magnético externo desplaza paredes de dominio.

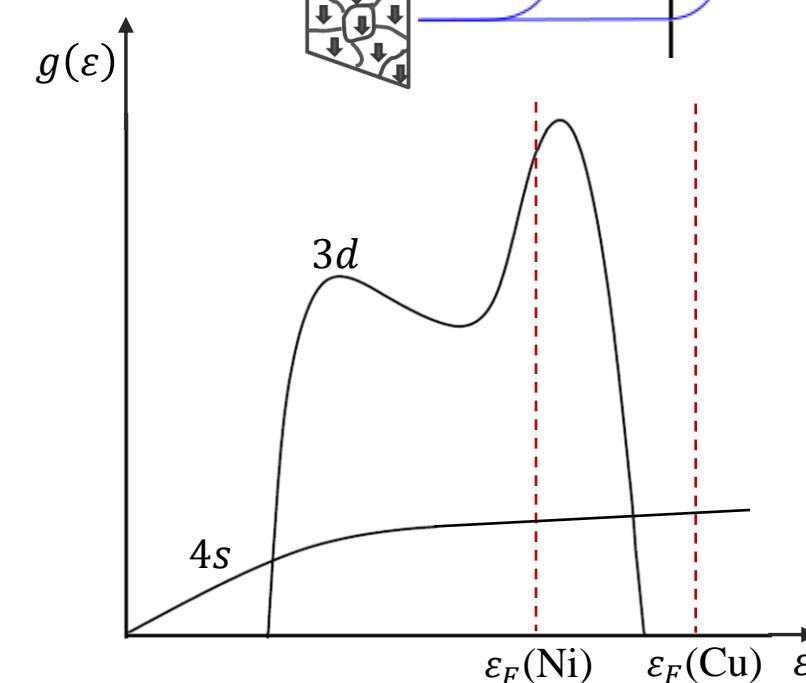
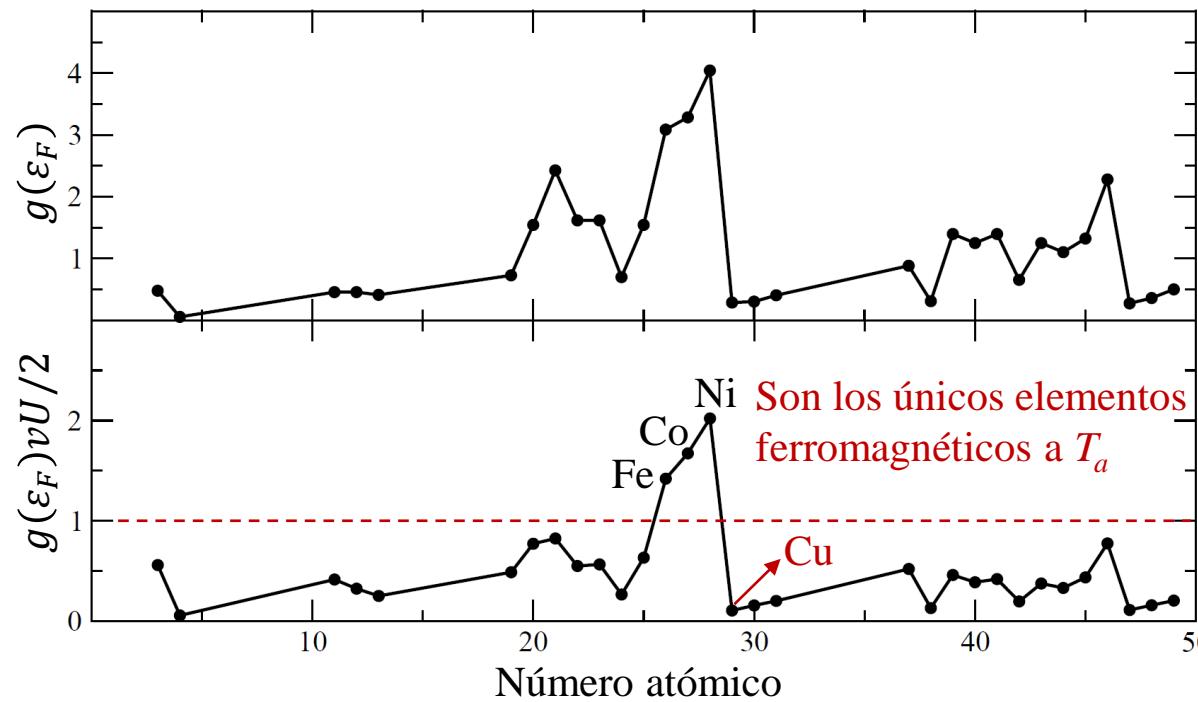


https://en.wikipedia.org/wiki/Magnetic_domain

Histéresis en ferromagnetos



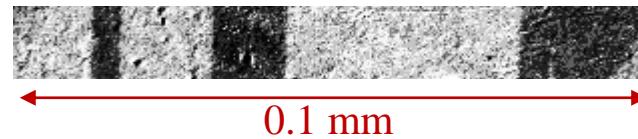
Magnetismo itinerante: Orden magnético a campo nulo



Magnetismo: Dominios e histéresis

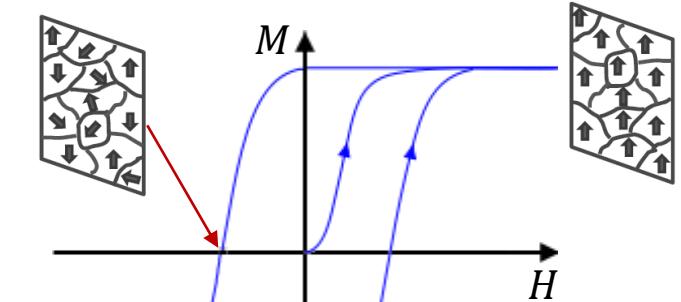
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Aplicar un campo magnético externo desplaza paredes de dominio.

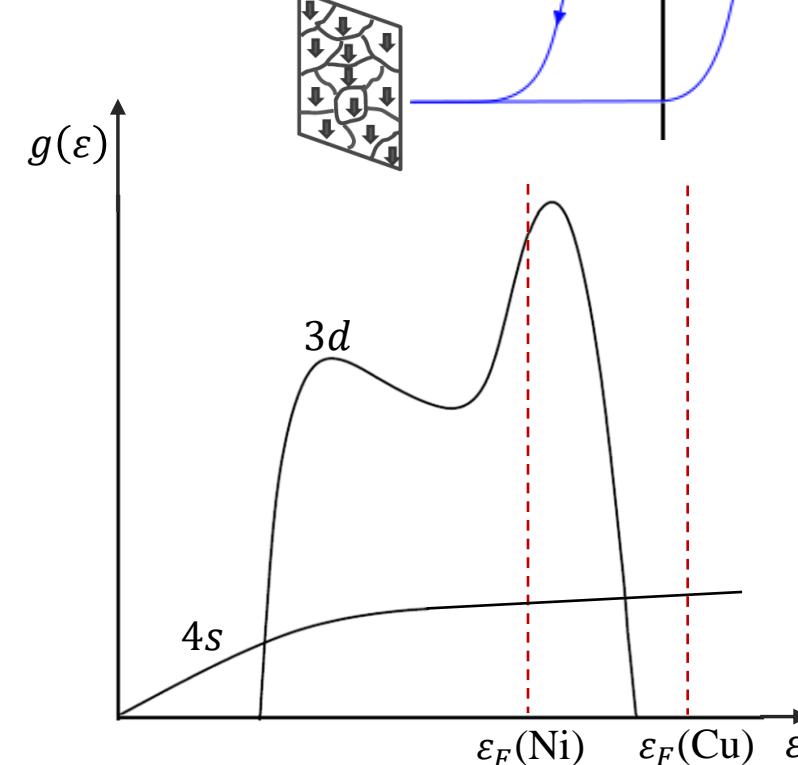
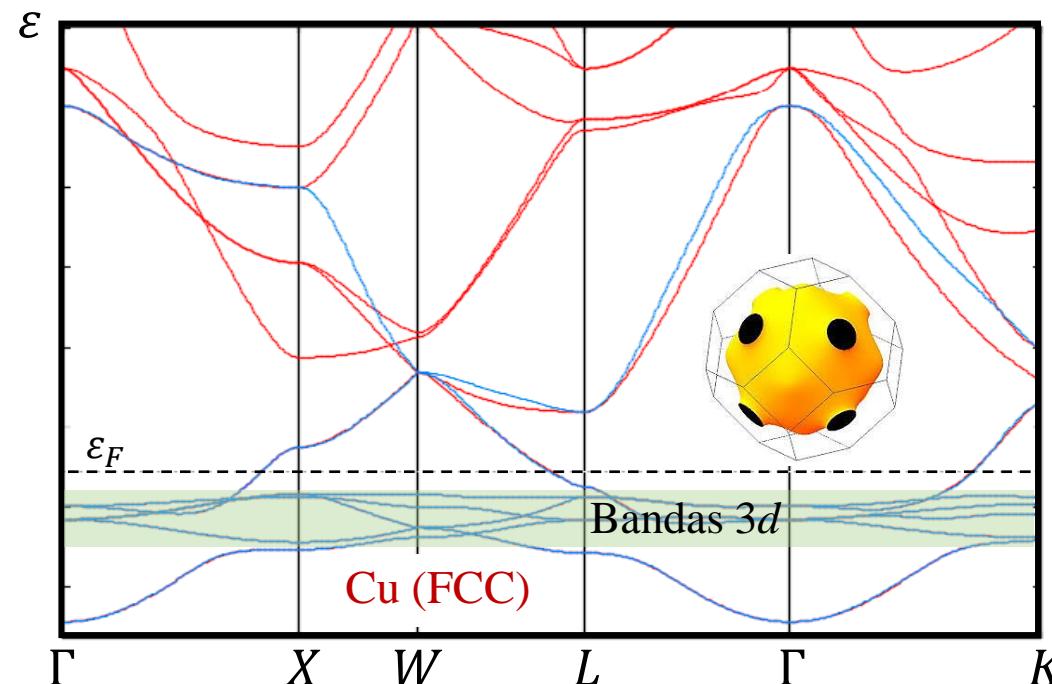


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Histéresis en ferromagnetos



Magnetismo itinerante: Orden magnético a campo nulo



Magnetismo: La tabla periódica

Magnetismo en la tabla periódica

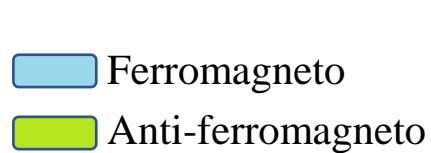
Considerando todas las contribuciones, se obtiene un comportamiento dominante.

(e⁻ de conducción: paramagnetismo de Pauli: $\chi_{Pauli} = \mu_B^2 g(\varepsilon_F)$; diamagnetismo de Landau: $\chi_{Landau} = -\frac{1}{3} \chi_{Pauli}$)

$$e^- \text{ libres} \quad | \quad 1$$

$$(e^- \text{ de conducción: paramagnetismo de Pauli: } \chi_{Pauli} = \mu_B^2 g(\varepsilon_F); \text{ diamagnetismo de Landau: } \chi_{Landau} = -\frac{1}{3} \chi_{Pauli})$$

1	1.0080	±1
20.28		
17.81		
0.08988		
H	1s ¹	



2	4.002602	0
4.216		
0.8 (0 bar)		
0.1787		
He	1s ²	

70	173.054	2(3)
1469		
1092		
6.98		
Yb	[Xe]6s ² 4f ¹⁴	

57	138.90547	3
1191		
3737		
1071±3		
La	3706 [Xe]6s ² 4f ¹ 5d ¹	
6.7		
6.7		
13 K		
58	140.116	(3),4
3793		
1204		
3793 [Xe]6s ² 4f ¹ 5d ¹		
Ce		
6.77		
13 K		
59	140.90765	(3),(4)
3793		
1204		
3793 [Xe]6s ² 4f ¹ 5d ¹		
Pr		
7.00		
3347		
1294		
1294 [Xe]6s ² 4f ¹		
Nd		
3. (3)		
60	144.242	3
3300 (est.)		
1315		
1315 [Xe]6s ² 4f ¹		
Pm		
6.47		
5.29		
5.29 [Xe]6s ² 4f ¹		
61	[144.9127]	3
347		
1347		
1347 [Xe]6s ² 4f ¹		
Sm		
2. (3)		
62	150.36	3
3546		
1800		
1800 [Xe]6s ² 4f ¹		
Eu		
3. (3)		
63	151.964	3
1586		
1586 [Xe]6s ² 4f ¹		
Gd		
3. (3)		
64	157.25	3
3803		
1865		
1865 [Xe]6s ² 4f ¹		
Tb		
3. (3)		
65	158.925	3
7.895		
7.895 [Xe]6s ² 4f ¹		
Dy		
3. (3)		
66	162.500	3
2840		
1865		
1865 [Xe]6s ² 4f ¹		
Tb		
3. (3)		
67	164.93032	3
2973		
1747		
1747 [Xe]6s ² 4f ¹		
Ho		
3. (3)		
68	167.259	3
3141		
1862		
1862 [Xe]6s ² 4f ¹		
Er		
3. (3)		
69	168.93421	2(3)
2223		
1818		
1818 [Xe]6s ² 4f ¹		
Tm		
2. (3)		
70	173.054	2(3)
1469		
1092		
6.98		
Yb	[Xe]6s ² 4f ¹⁴	

89	[227.0278]	3
1323		
3500±300		
10.07		
Ac	4273 [Rn]7s ² 6d ¹	
11.70		
—		
Th	[Rn]7s ² 6d ²	
—		
91	[231.0359]	4
4091		
1873		
1873 [Rn]7s ² 5f ⁶ d ¹		
Pa		
18.90		
18.90 [Rn]7s ² 5f ⁶ d ¹		
U		
13.6		
13.6 [Rn]7s ² 5f ⁶ d ¹		
Np		
3. (4),6		
4175		
913		
913 [Rn]7s ² 5f ⁶ d ¹		
Pu		
3. (4),6		
3505		
2888		
2888 [Rn]7s ² 5f ⁶ d ¹		
Am		
3. (4),6		
1613		
1613 [Rn]7s ² 5f ⁶ d ¹		
Cm		
3. (4),6		
13.5		
13.5 [Rn]7s ² 5f ⁶ d ¹		
Bk		
3. (4)		
97		
97 [247.0704]		
—		
98		
98 [251.0796]		
—		
99		
99 [252.0830]		
—		
100		3
—		
101		2,3
—		
102		2,3
—		

Resumen

- Modelo de campo medio en un antiferromagneto
- Anisotropía magnetocristalina y formación de dominios
- Ciclo de histéresis de un ferromagneto
- Magnetismo itinerante
- Hamiltoniano de Hubbard y Criterio de Stoner

