

Estructura de la Materia 2

Clase 14 - Teoría

Docentes

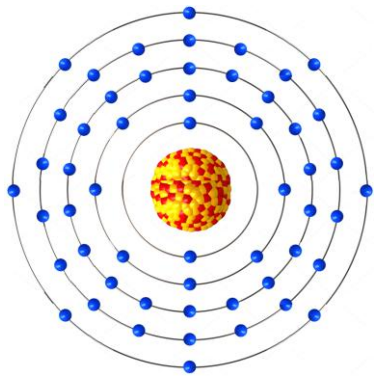
Gustavo Grinblat, Andrea Barral, Adán Garros

Departamento de Física, FCEN, UBA – Primer Cuatrimestre, 2025

Web: <https://asignaturas.df.uba.ar/edlm2-grinblat/>

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

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

Paramagnetismo de Curie

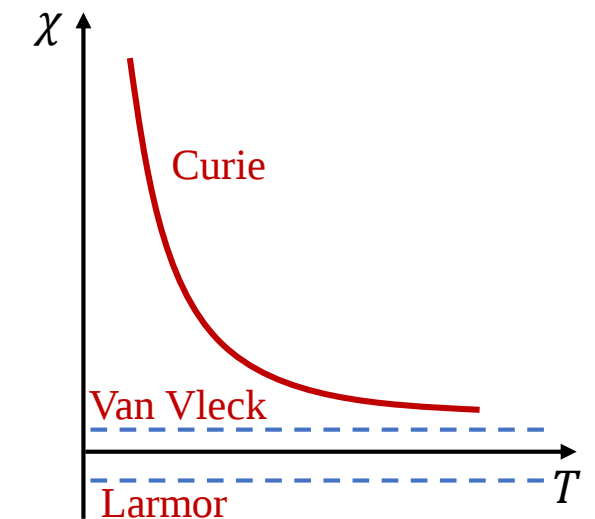
Paramagnetismo de Van Vleck

Diamagnetismo de Larmor

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

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

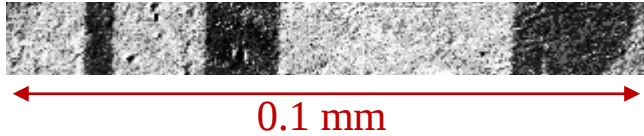
$$g_L \mu_B H \ll k_B T \longrightarrow \chi = \frac{\partial M}{\partial H} = \frac{N}{V} \frac{(g_L \mu_B)^2}{3k_B T} J(J + 1)$$



Magnetismo: Dominios e histéresis

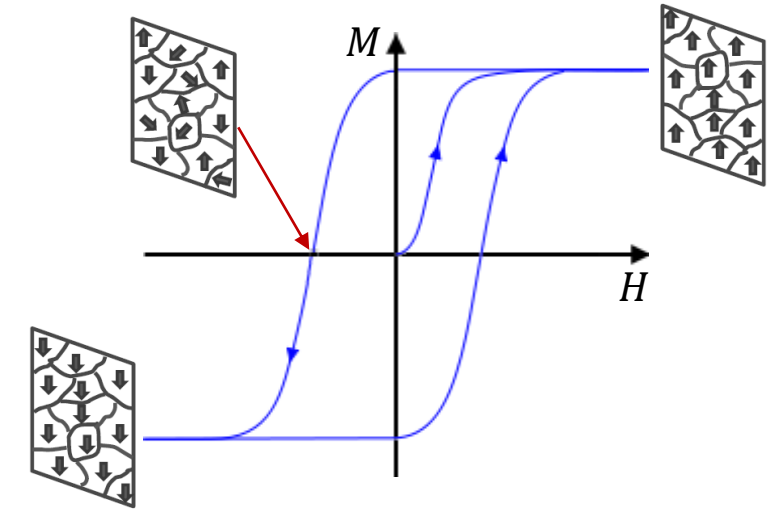
Dominios magnéticos (ferromagneto)

Aplicar un campo magnético externo desplaza paredes de dominio.

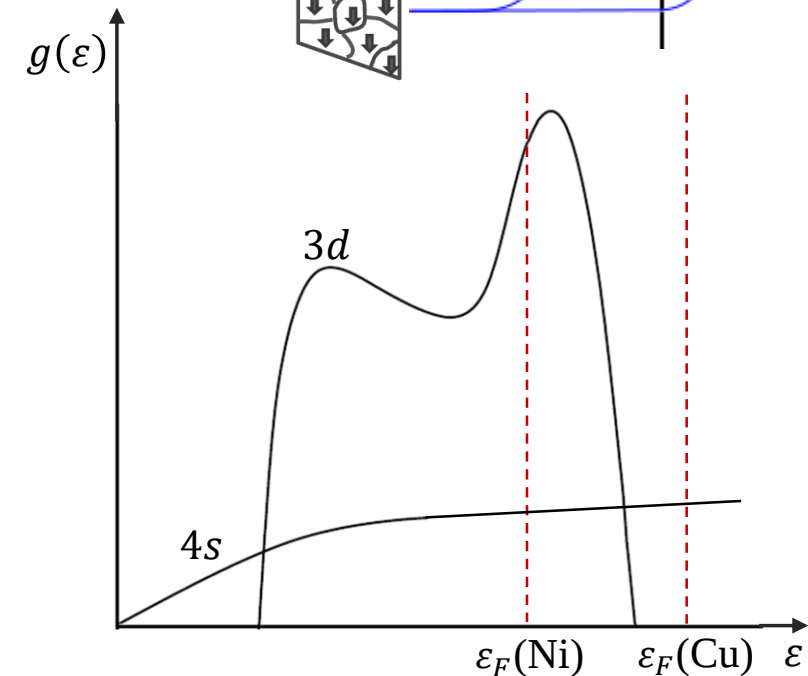
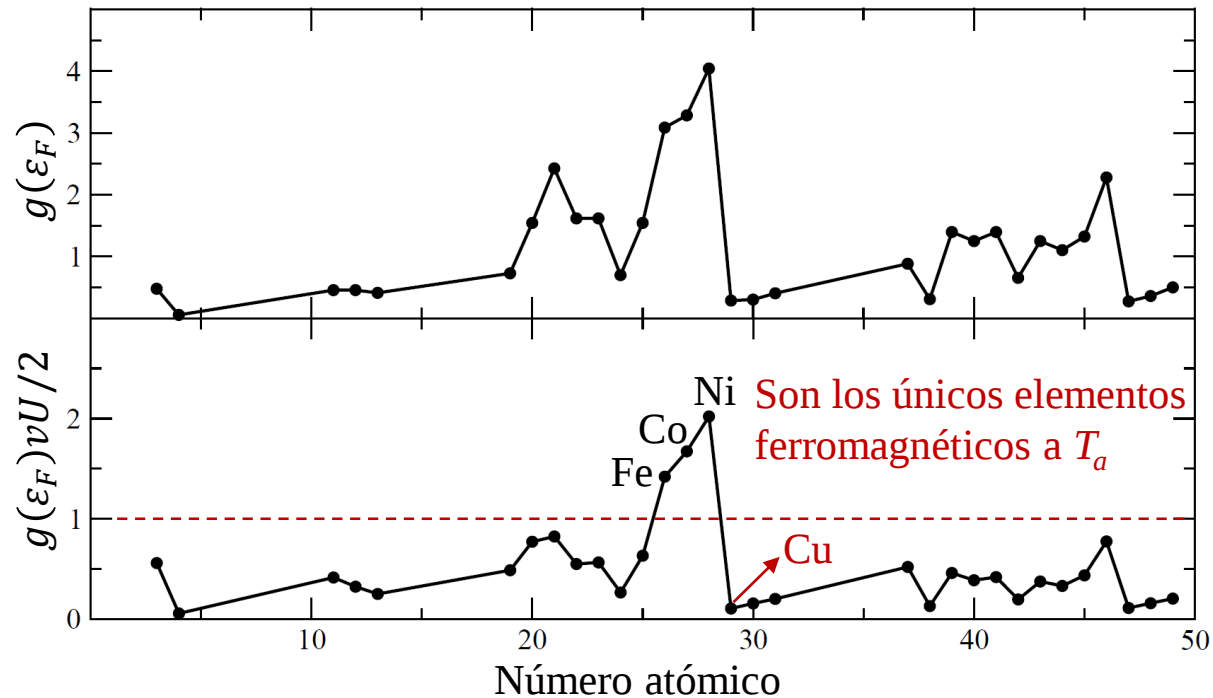


https://en.wikipedia.org/wiki/Magnetic_domain

Histéresis en ferromagnetos



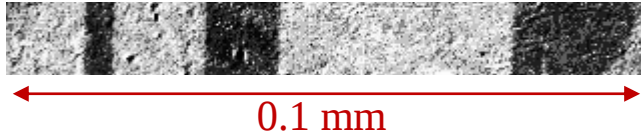
Magnetismo itinerante: Orden magnético a campo nulo



Magnetismo: Dominios e histéresis

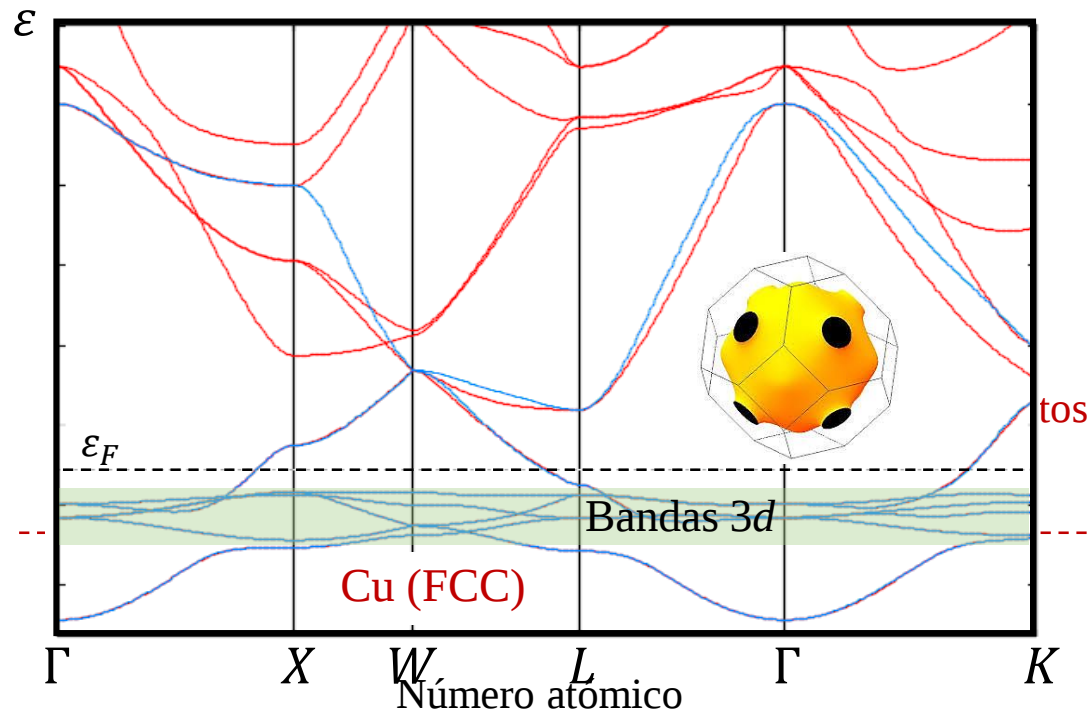
Dominios magnéticos (ferromagneto)

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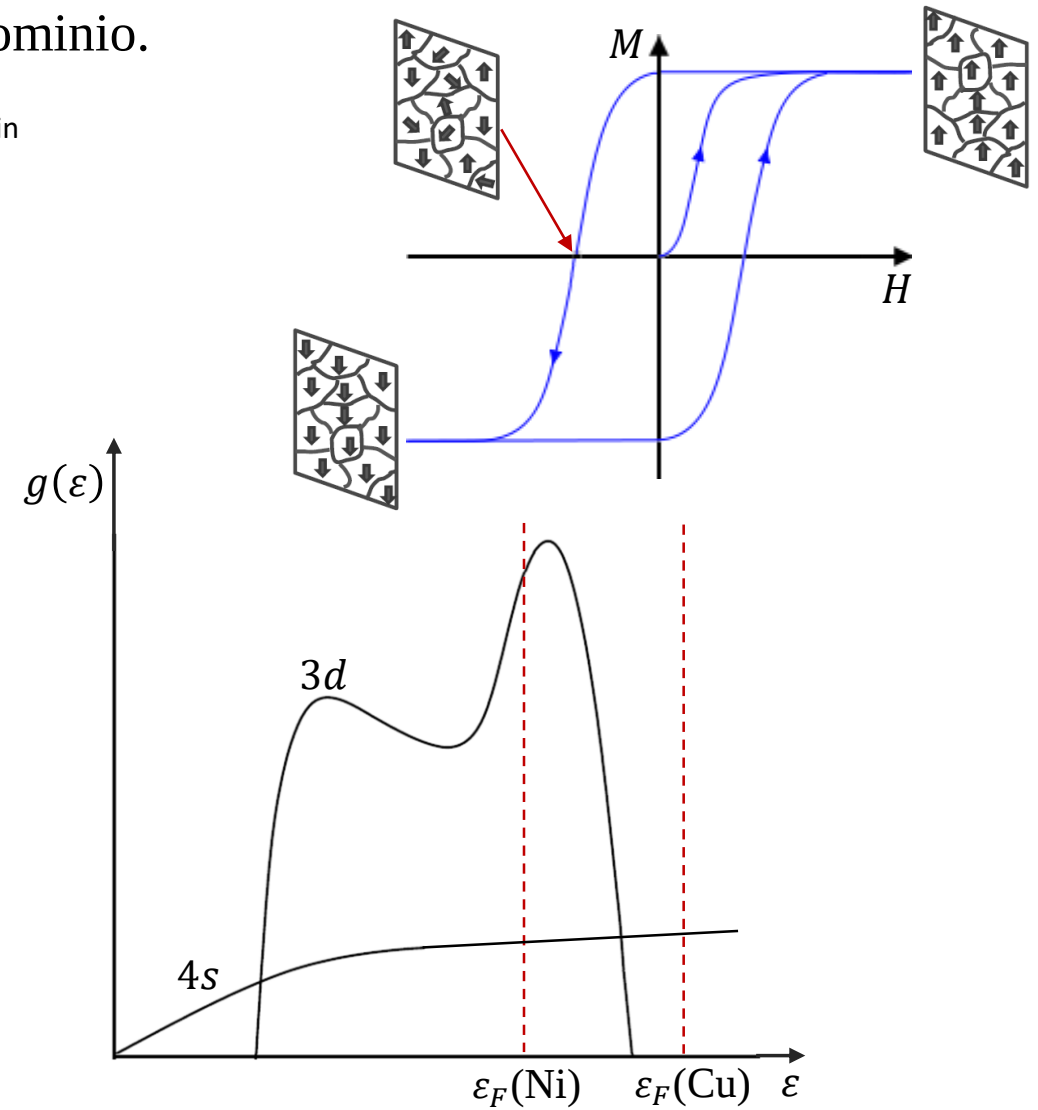


https://en.wikipedia.org/wiki/Magnetic_domain

Magnetismo itinerante: Orden magnético a campo nulo



Histéresis en ferromagnetos



Magnetismo: La tabla periódica

Magnetismo en la tabla periódica

Considerando todas las contribuciones, se obtiene un comportamiento dominante.

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

e⁻ libres

1

$-\frac{1}{3} \chi_{Pauli}$

1 1.0080 20.28 17.81 0.08988 1s ¹ H	2 6.97 7.016 4.002602 1s ² He	3 6.97 7.016 4.002602 1s ² Li	4 9.012182 9.012182 4.002602 1s ² Be	5 9.012182 9.012182 4.002602 1s ² B	6 12.011 12.011 4.002602 1s ² C	7 14.0069 14.0069 4.002602 1s ² N	8 15.9994 15.9994 4.002602 1s ² O	9 18.998403 18.998403 4.002602 1s ² F	10 20.1797 20.1797 4.002602 1s ² Ne	11 22.989769 22.989769 4.002602 1s ² Na	12 24.3050 24.3050 4.002602 1s ² Mg	13 26.981539 26.981539 4.002602 1s ² Al	14 28.085 28.085 4.002602 1s ² Si	15 30.973762 30.973762 4.002602 1s ² P	16 32.07 32.07 4.002602 1s ² S	17 35.45 35.45 4.002602 1s ² Cl	18 39.948 39.948 4.002602 1s ² Ar	19 39.0983 39.0983 4.002602 1s ² K	20 40.078 40.078 4.002602 1s ² Ca	21 44.955912 44.955912 4.002602 1s ² Sc	22 47.867 47.867 4.002602 1s ² Ti	23 50.9415 50.9415 4.002602 1s ² V	24 51.9961 51.9961 4.002602 1s ² Cr	25 54.938045 54.938045 4.002602 1s ² Mn	26 55.845 55.845 4.002602 1s ² Fe	27 58.933195 58.933195 4.002602 1s ² Co	28 58.6934 58.6934 4.002602 1s ² Ni	29 63.546 63.546 4.002602 1s ² Cu	30 65.38 65.38 4.002602 1s ² Zn	31 69.723 69.723 4.002602 1s ² Ga	32 72.63 72.63 4.002602 1s ² Ge	33 74.92160 74.92160 4.002602 1s ² As	34 78.96 78.96 4.002602 1s ² Se	35 79.904 79.904 4.002602 1s ² Br	36 83.798 83.798 4.002602 1s ² Kr	37 85.4678 85.4678 4.002602 1s ² Rb	38 87.62 87.62 4.002602 1s ² Sr	39 88.90585 88.90585 4.002602 1s ² Y	40 91.224 91.224 4.002602 1s ² Zr	41 92.906 92.906 4.002602 1s ² Nb	42 95.96 95.96 4.002602 1s ² Mo	43 97.9072 97.9072 4.002602 1s ² Tc	44 101.07 101.07 4.002602 1s ² Ru	45 102.90550 102.90550 4.002602 1s ² Rh	46 106.42 106.42 4.002602 1s ² Pd	47 107.8682 107.8682 4.002602 1s ² Ag	48 112.411 112.411 4.002602 1s ² Cd	49 114.818 114.818 4.002602 1s ² In	50 118.710 118.710 4.002602 1s ² Sn	51 121.760 121.760 4.002602 1s ² Sb	52 127.60 127.60 4.002602 1s ² Te	53 126.90447 126.90447 4.002602 1s ² I	54 131.293 131.293 4.002602 1s ² Xe	55 132.905452 132.905452 4.002602 1s ² Cs	56 137.327 137.327 4.002602 1s ² Ba	57 174.9668 174.9668 4.002602 1s ² Lu	58 178.49 178.49 4.002602 1s ² Hf	59 180.94788 180.94788 4.002602 1s ² Ta	60 183.84 183.84 4.002602 1s ² W	61 186.207 186.207 4.002602 1s ² Re	62 190.23 190.23 4.002602 1s ² Os	63 192.217 192.217 4.002602 1s ² Ir	64 195.084 195.084 4.002602 1s ² Pt	65 196.966569 196.966569 4.002602 1s ² Au	66 200.59 200.59 4.002602 1s ² Hg	67 204.384 204.384 4.002602 1s ² Tl	68 207.2 207.2 4.002602 1s ² Pb	69 208.98040 208.98040 4.002602 1s ² Bi	70 208.98040 208.98040 4.002602 1s ² Po	71 209.9871 209.9871 4.002602 1s ² At	72 211.223 211.223 4.002602 1s ² Rn	73 223.0197 223.0197 4.002602 1s ² Fr	74 223.0197 223.0197 4.002602 1s ² Ra	75 223.0197 223.0197 4.002602 1s ² Ac	76 223.0197 223.0197 4.002602 1s ² Th	77 223.0197 223.0197 4.002602 1s ² Pa	78 223.0197 223.0197 4.002602 1s ² U	79 223.0197 223.0197 4.002602 1s ² Np	80 223.0197 223.0197 4.002602 1s ² Pu	81 223.0197 223.0197 4.002602 1s ² Am	82 223.0197 223.0197 4.002602 1s ² Cm	83 223.0197 223.0197 4.002602 1s ² Bk	84 223.0197 223.0197 4.002602 1s ² Cf	85 223.0197 223.0197 4.002602 1s ² Es	86 223.0197 223.0197 4.002602 1s ² Fm	87 223.0197 223.0197 4.002602 1s ² Md	88 223.0197 223.0197 4.002602 1s ² No	89 223.0197 223.0197 4.002602 1s ² La	90 223.0197 223.0197 4.002602 1s ² Ce	91 223.0197 223.0197 4.002602 1s ² Pr	92 223.0197 223.0197 4.002602 1s ² Nd	93 223.0197 223.0197 4.002602 1s ² Pm	94 223.0197 223.0197 4.002602 1s ² Sm	95 223.0197 223.0197 4.002602 1s ² Eu	96 223.0197 223.0197 4.002602 1s ² Gd	97 223.0197 223.0197 4.002602 1s ² Tb	98 223.0197 223.0197 4.002602 1s ² Dy	99 223.0197 223.0197 4.002602 1s ² Ho	100 223.0197 223.0197 4.002602 1s ² Er	101 223.0197 223.0197 4.002602 1s ² Tm	102 223.0197 223.0197 4.002602 1s ² Yb	103 223.0197 223.0197 4.002602 1s ² Lu	104 223.0197 223.0197 4.002602 1s ² Hf	105 223.0197 223.0197 4.002602 1s ² Ta	106 223.0197 223.0197 4.002602 1s ² W	107 223.0197 223.0197 4.002602 1s ² Re	108 223.0197 223.0197 4.002602 1s ² Os	109 223.0197 223.0197 4.002602 1s ² Ir	110 223.0197 223.0197 4.002602 1s ² Pt	111 223.0197 223.0197 4.002602 1s ² Au	112 223.0197 223.0197 4.002602 1s ² Hg	113 223.0197 223.0197 4.002602 1s ² Tl	114 223.0197 223.0197 4.002602 1s ² Pb	115 223.0197 223.0197 4.002602 1s ² Bi	116 223.0197 223.0197 4.002602 1s ² Po	117 223.0197 223.0197 4.002602 1s ² At	118 223.0197 223.0197 4.002602 1s ² Rn	119 223.0197 223.0197 4.002602 1s ² Fr	120 223.0197 223.0197 4.002602 1s ² Ra	121 223.0197 223.0197 4.002602 1s ² Ac	122 223.0197 223.0197 4.002602 1s ² Th	123 223.0197 223.0197 4.002602 1s ² Pa	124 223.0197 223.0197 4.002602 1s ² U	125 223.0197 223.0197 4.002602 1s ² Np	126 223.0197 223.0197 4.002602 1s ² Pu	127 223.0197 223.0197 4.002602 1s ² Am	128 223.0197 223.0197 4.002602 1s ² Cm	129 223.0197 223.0197 4.002602 1s ² Bk	130 223.0197 223.0197 4.002602 1s ² Cf	131 223.0197 223.0197 4.002602 1s ² Es	132 223.0197 223.0197 4.002602 1s ² Fm	133 223.0197 223.0197 4.002602 1s ² Md	134 223.0197 223.0197 4.002602 1s ² No	135 223.0197 223.0197 4.002602 1s ² La	136 223.0197 223.0197 4.002602 1s ² Ce	137 223.0197 223.0197 4.002602 1s ² Pr	138 223.0197 223.0197 4.002602 1s ² Nd	139 223.0197 223.0197 4.002602 1s ² Pm	140 223.0197 223.0197 4.002602 1s ² Sm	141 223.0197 223.0197 4.002602 1s ² Eu	142 223.0197 223.0197 4.002602 1s ² Gd	143 223.0197 223.0197 4.002602 1s ² Tb	144 223.0197 223.0197 4.002602 1s ² Dy	145 223.0197 223.0197 4.002602 1s ² Ho	146 223.0197 223.0197 4.002602 1s ² Er	147 223.0197 223.0197 4.002602 1s ² Tm	148 223.0197 223.0197 4.002602 1s ² Yb	149 223.0197 223.0197 4.002602 1s ² Lu	150 223.0197 223.0197 4.002602 1s ² Hf	151 223.0197 223.0197 4.002602 1s ² Ta	152 223.0197 223.0197 4.002602 1s ² W	153 223.0197 223.0197 4.002602 1s ² Re	154 223.0197 223.0197 4.002602 1s ² Os	155 223.0197 223.0197 4.002602 1s ² Ir	156 223.0197 223.0197 4.002602 1s ² Pt	157 223.0197 223.0197 4.002602 1s ² Au	158 223.0197 223.0197 4.002602 1s ² Hg	159 223.0197 223.0197 4.002602 1s ² Tl	160 223.0197 223.0197 4.002602 1s ² Pb	161 223.0197 223.0197 4.002602 1s ² Bi	162 223.0197 223.0197 4.002602 1s ² Po	163 223.0197 223.0197 4.002602 1s ² At	164 223.0197 223.0197 4.002602 1s ² Rn	165 223.0197 223.0197 4.002602 1s ² Fr	166 223.0197 223.0197 4.002602 1s ² Ra	167 223.0197 223.0197 4.002602 1s ² Ac	168 223.0197 223.0197 4.002602 1s ² Th	169 223.0197 223.0197 4.002602 1s ² Pa	170 223.0197 223.0197 4.002602 1s ² U	171 223.0197 223.0197 4.002602 1s ² Np	172 223.0197 223.0197 4.002602 1s ² Pu	173 223.0197 223.0197 4.002602 1s ² Am	174 223.0197 223.0197 4.002602 1s ² Cm	175 223.0197 223.0197 4.002602 1s ² Bk	176 223.0197 223.0197 4.002602 1s ² Cf	177 223.0197 223.0197 4.002602 1s ² Es	178 223.0197 223.0197 4.002602 1s ² Fm	179 223.0197 223.0197 4.002602 1s ² Md	180 223.0197 223.0197 4.002602 1s ² No	181 223.0197 223.0197 4.002602 1s ² La	182 223.0197 223.0197 4.002602 1s ² Ce	183 223.0197 223.0197 4.002602 1s ² Pr	184 223.0197 223.0197 4.002602 1s ² Nd	185 223.0197 223.0197 4.002602 1s ² Pm	186 223.0197 223.0197 4.002602 1s ² Sm	187 223.0197 223.0197 4.002602 1s ² Eu	188 223.0197 223.0197 4.002602 1s ² Gd	189 223.0197 223.0197 4.002602 1s ² Tb	190 223.0197 223.0197 4.002602 1s ² Dy	191 223.0197 223.0197 4.002602 1s ² Ho	192 223.0197 223.0197 4.002602 1s ² Er	193 223.0197 223.0197 4.002602 1s ² Tm	194 223.0197 223.0197 4.002602 1s ² Yb	195 223.0197 223.0197 4.002602 1s ² Lu	196 223.0197 223.0197 4.002602 1s ² Hf	197 223.0197 223.0197 4.002602 1s ² Ta	198 223.0197 223.0197 4.002602 1s ² W	199 223.0197 223.0197 4.002602 1s ² Re	200 223.0197 223.0197 4.002602 1s ² Os	201 223.0197 223.0197 4.002602 1s ² Ir	202 223.0197 223.0197 4.002602 1s ² Pt	203 223.0197 223.0197 4.002602 1s ² Au	204 223.0197 223.0197 4.002602 1s ² Hg	205 223.0197 223.0197 4.002602 1s ² Tl	206 223.0197 223.0197 4.002602 1s ² Pb	207 223.0197 223.0197 4.002602 1s ² Bi	208 223.0197 223.0197 4.002602 1s ² Po	209 223.0197 223.0197 4.002602 1s ² At	210 223.0197 223.0197 4.002602 1s ² Rn	211 223.0197 223.0197 4.002602 1s ² Fr	212 223.0197 223.0197 4.002602 1s ² Ra	213 223.0197 223.0197 4.002602 1s ² Ac	214 223.0197 223.0197 4.002602 1s ² Th	215 223.0197 223.0197 4.002602 1s ² Pa	216 223.0197 223.0197 4.002602 1s ² U	217 223.0197 223.0197 4.002602 1s ² Np	218 223.0197 223.0197 4.002602 1s ² Pu</
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Resumen

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

