

# Estructura de la Materia 2

Clase 15 - Teoría

## Docentes

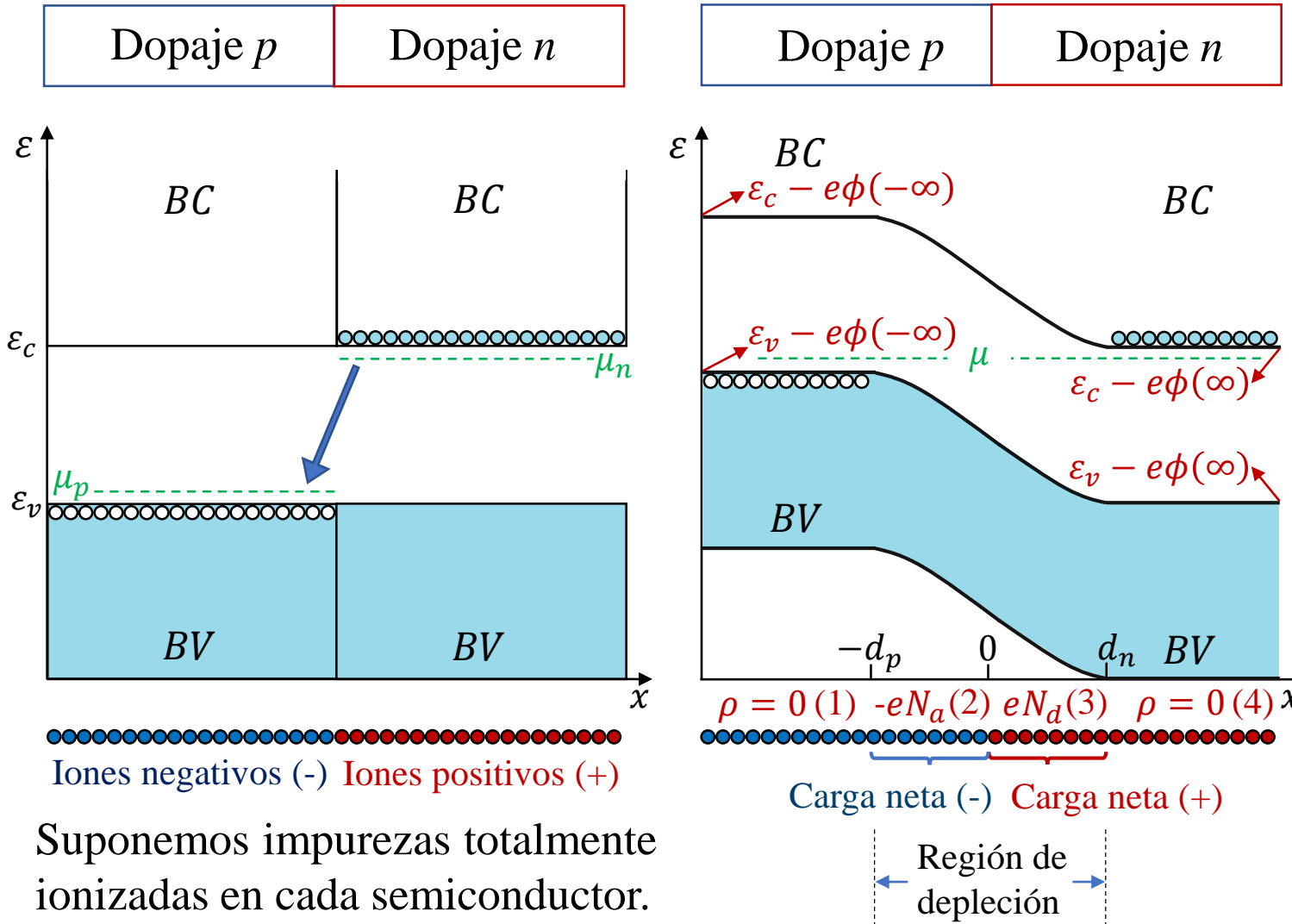
Gustavo Grinblat, Mariano Marziali Bermúdez, Tomás Bortolin

Departamento de Física, FCEN, UBA - 1er Cuatrimestre, 2020

Web: <http://materias.df.uba.ar/edlm2a2020c1>

# Repaso

## Juntura semiconductor p-n: Equilibrio térmico



$$e\Delta\phi = \overset{\mu_p = \mu_n = \mu}{\downarrow} E_g + k_B T \ln \left[ \frac{N_d N_a}{N_c P_v} \right] \sim E_g$$

$$\nabla^2 \phi = \frac{d^2 \phi}{dx^2} = -\frac{4\pi\rho(x)}{\epsilon} \quad (\text{Poisson})$$

$$\phi = \begin{cases} \phi(\infty) & (1) \\ \phi(\infty) - \frac{2\pi e N_d}{\epsilon} (x - d_n)^2 & (2) \\ \phi(-\infty) + \frac{2\pi e N_a}{\epsilon} (x + d_p)^2 & (3) \\ \phi(-\infty) & (4) \end{cases}$$

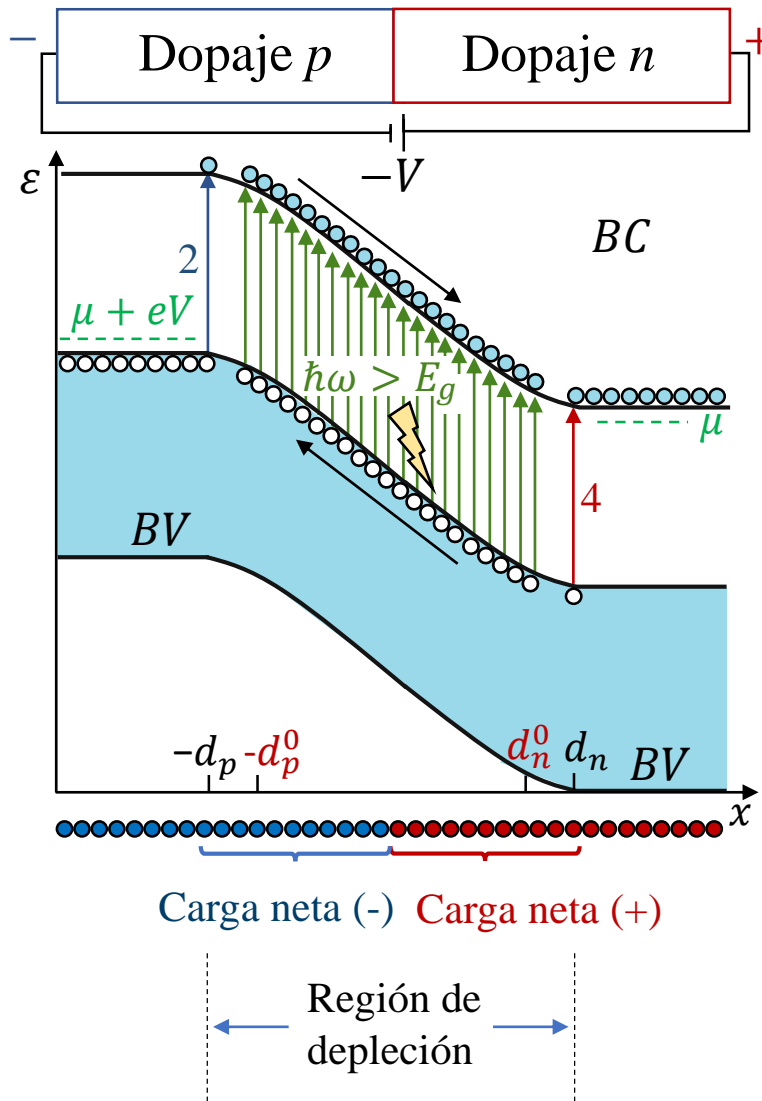
Continuidad de  $\phi$ ,  $\phi'$  en  $x = 0$ :

$$\rightarrow N_d d_n = N_a d_p$$

$$\rightarrow d_{n,p} = \left[ \frac{(N_a/N_d)^{\pm 1} \epsilon \Delta\phi}{N_d + N_a} \frac{1}{2\pi e} \right]^{1/2}$$

# Repaso

## Juntura semiconductor p-n: Potencial externo



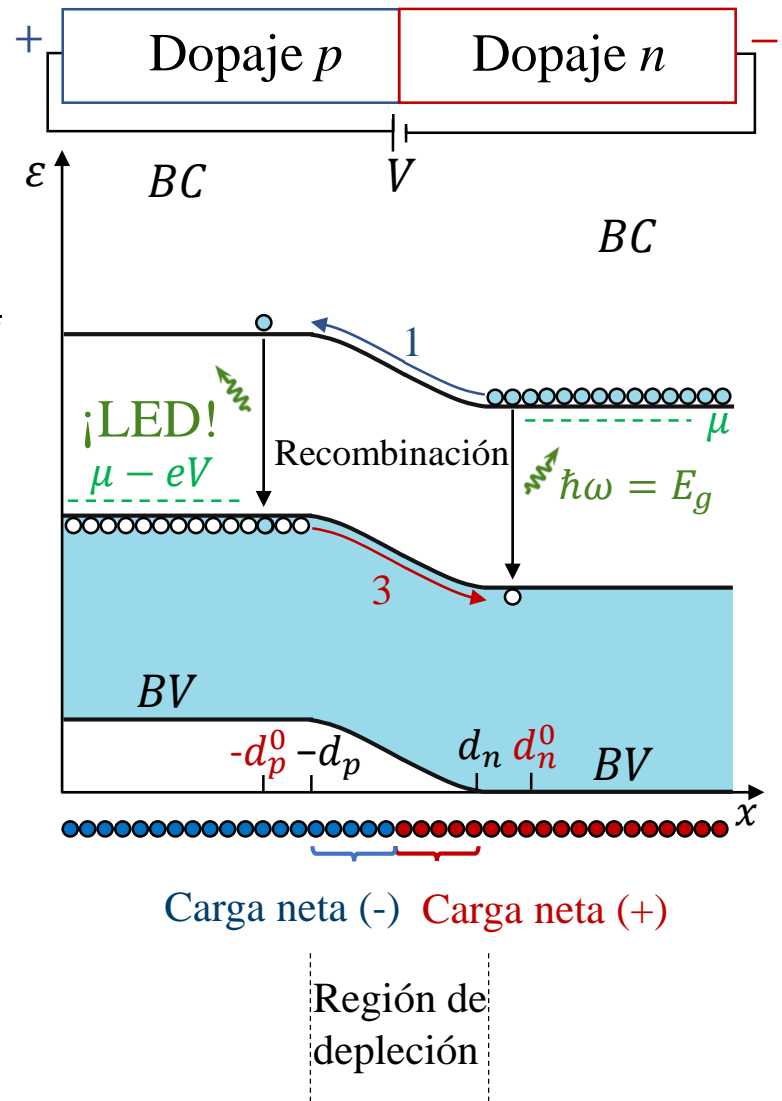
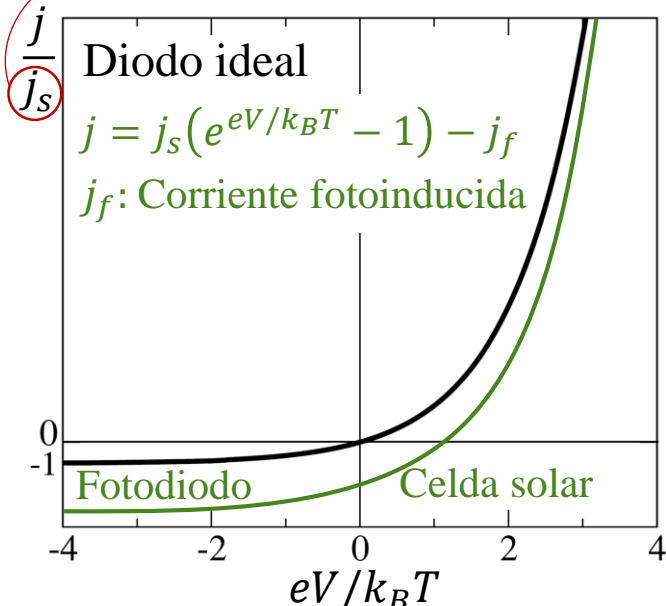
$V \neq 0 \rightarrow \Delta\phi = (\Delta\phi)_0 - V$

$d_{n,p}(V) = d_{n,p}(0) \sqrt{1 - V/(\Delta\phi)_0}$

(1)  $J_e^{rec} \propto e^{-\frac{e\Delta\phi}{k_B T}}$  (2)  $J_e^{gen} \propto e^{-\frac{E_g}{k_B T}}$

(3)  $J_h^{rec} \propto e^{-\frac{e\Delta\phi}{k_B T}}$  (4)  $J_h^{gen} \propto e^{-\frac{E_g}{k_B T}}$

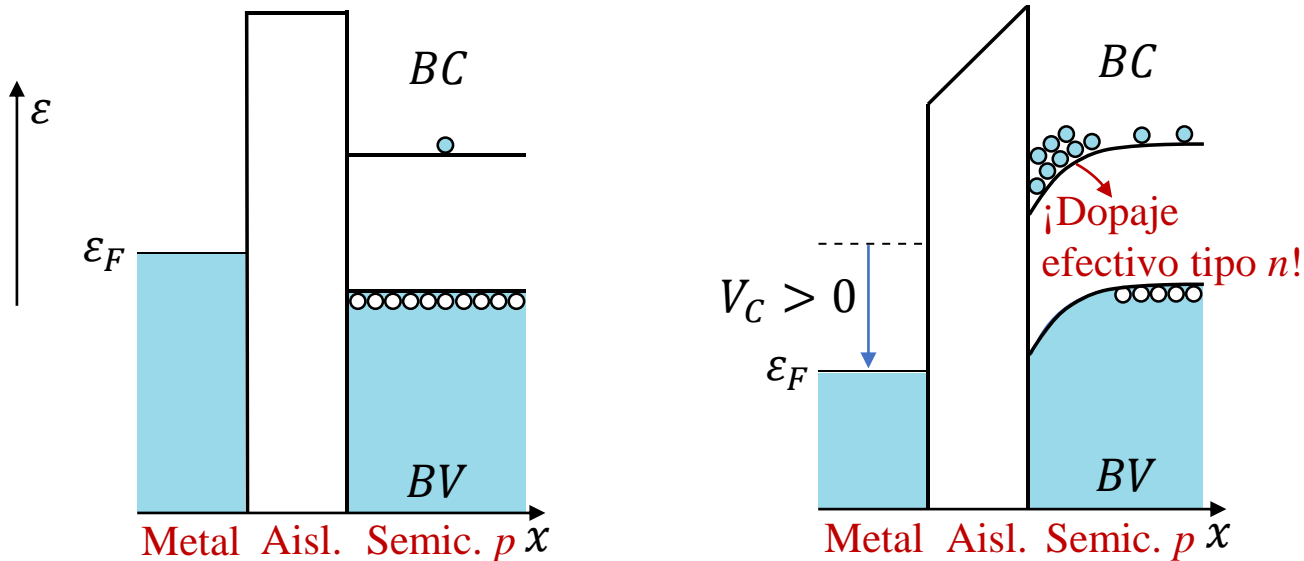
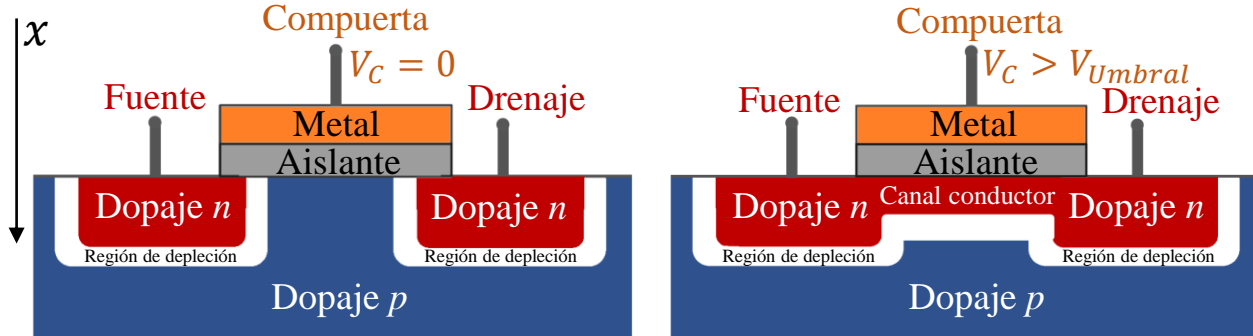
$j = [e(J_e^{gen} + J_h^{gen})] (e^{eV/k_B T} - 1)$



# Transistor y pozos cuánticos

## Transistor de efecto de campo (MOSFET)

Se utiliza principalmente como interruptor o amplificador.

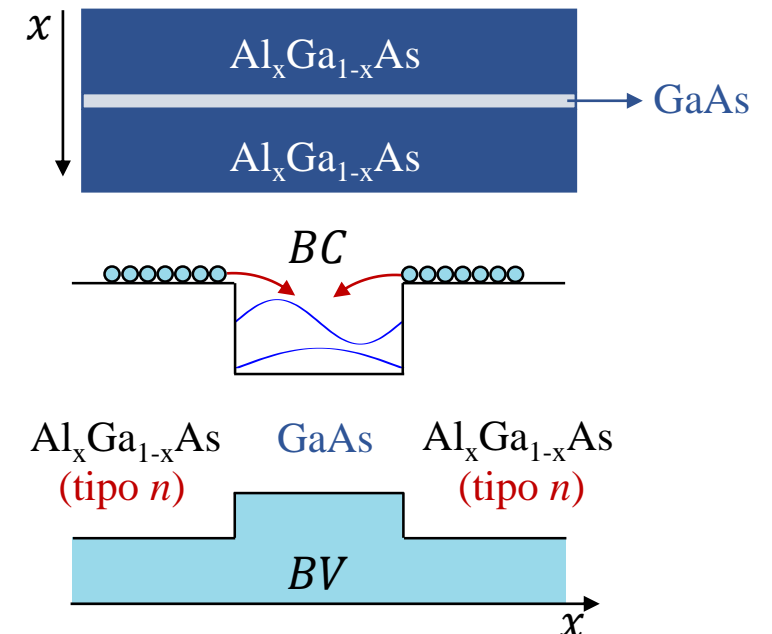


Al aumentar  $V_C$  por encima de  $V_{umbral}$ , se crea un canal de conducción, cuyo tamaño (y resistencia) depende de  $V_C$ .

## Pozos cuánticos

GaAs y AlAs son semiconductores de *gap* directo con  $E_g^{GaAs} = 1.4$  eV y  $E_g^{AlAs} = 2.7$  eV. Aleaciones  $Al_xGa_{1-x}As$  tienen  $E_g$  intermedios.

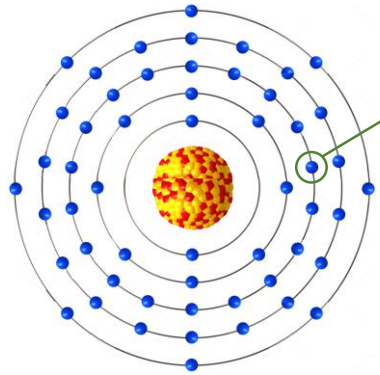
→ Heteroestructuras de  $Al_xGa_{1-x}As/GaAs/Al_xGa_{1-x}As$  pueden formar pozos cuánticos.



Utilizando  $Al_xGa_{1-x}As$  tipo  $n(p)$ ,  $e^- (h^+)$  “caen” al pozo creando un gas bidimensional de  $e^- (h^+)$ .

# Magnetismo

## Magnetismo localizado



$$\mathcal{H}_{at} = \frac{\bar{p}^2}{2m_e} + V(\bar{r}) \xrightarrow{\text{Agregamos } \bar{H}} \mathcal{H} = \frac{\left(\bar{p} + \frac{e}{c} \bar{A}\right)^2}{2m_e} + g\mu_B \bar{H} \cdot \bar{\sigma} + V(\bar{r})$$

Vector potencial  
 Factor giromagnético  
 Espín

$$\bar{l} = \bar{r} \times \bar{p} / \hbar \quad \bar{A} = \bar{H} \times \bar{r} / 2$$

$$\mathcal{H} = \mathcal{H}_{at} + \mu_B \bar{H} \cdot (g\bar{\sigma} + \bar{l}) + \frac{e^2}{8m_e c^2} |\bar{H} \times \bar{r}|^2$$

Es siempre positivo y aumenta la energía

Sumando sobre todos los e<sup>-</sup>

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

Factor de Landé



> 0: Ferromagneto  
< 0: Antiferromagneto

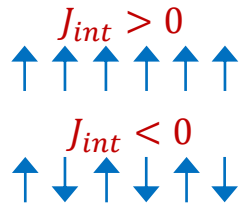
Paramagnetismo  
Diamagnetismo

Agregamos  $J_{int}$   
(Despreciamos diamagnetismo)

$$\Delta \mathcal{H}_{cristal} = \mu_B g_L \bar{H} \cdot \sum_m \bar{J}_m - \frac{J_{int}}{2} \sum_{m,n} \bar{J}_m \bar{J}_n$$

Corre sobre sitios de la red

Se usa para iones de tierras raras por orbitales localizados 4f.



57 3737 1191 6.7 [Xe]6s <sup>2</sup> 5d <sup>1</sup>	58 3706 1071±3 6.78 [Xe]6s <sup>2</sup> 4f <sup>1</sup> 5d <sup>1</sup>	59 3793 1204 6.77 [Xe]6s <sup>2</sup> 4f <sup>3</sup>	60 3347 1294 7.00 [Xe]6s <sup>2</sup> 4f <sup>4</sup>	61 3300 (est.) 1315 6.475 [Xe]6s <sup>2</sup> 4f <sup>5</sup>	62 2067 1347 7.54 [Xe]6s <sup>2</sup> 4f <sup>6</sup>	63 1800 1095 5.259 [Xe]6s <sup>2</sup> 4f <sup>7</sup>	64 3546 1586 7.895 [Xe]6s <sup>2</sup> 4f <sup>7</sup> 5d <sup>1</sup>	65 3503 1629 8.27 [Xe]6s <sup>2</sup> 4f <sup>9</sup>	66 2840 1685 8.536 [Xe]6s <sup>2</sup> 4f <sup>10</sup>	67 2973 1747 8.80 [Xe]6s <sup>2</sup> 4f <sup>11</sup>	68 3141 1802 9.05 [Xe]6s <sup>2</sup> 4f <sup>12</sup>	69 2223 1818 9.33 [Xe]6s <sup>2</sup> 4f <sup>13</sup>	70 1469 1092 6.98 [Xe]6s <sup>2</sup> 4f <sup>14</sup>
138.90547 3 <b>La</b>	140.116 (3),4 <b>Ce</b>	140.90765 (3),(4) <b>Pr</b>	144.242 3 <b>Nd</b>	[144.9127] 3 <b>Pm</b>	150.36 2,(3) <b>Sm</b>	151.964 2,(3) <b>Eu</b>	157.25 3 <b>Gd</b>	158.925 (3),4 <b>Tb</b>	162.500 3 <b>Dy</b>	164.93032 3 <b>Ho</b>	167.259 3 <b>Er</b>	168.93421 2,(3) <b>Tm</b>	173.054 2,(3) <b>Yb</b>

# Magnetismo

## Magnetismo itinerante: Orden magnético a campo nulo

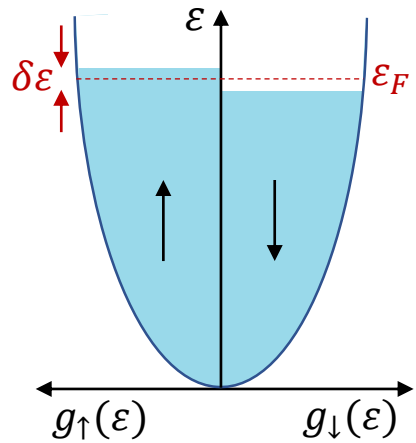
$$\mathcal{H} = \mathcal{H}_{\text{Tight-Binding}} + \mathcal{H}_{\text{Hubbard}} \quad \mathcal{H}_{\text{Hubbard}} = U \sum_i n_{i\uparrow} n_{i\downarrow}$$

$i$ : Corre sobre sitios de la red

$U$ : Costo energético por tener  $2e^-$  en el mismo sitio

$n_{i\uparrow}(n_{i\downarrow})$ : N° de  $e^-$  con espín  $\uparrow$  ( $\downarrow$ ) en el sitio  $i$

¿Conviene tener  $\rho_{\uparrow} \neq \rho_{\downarrow}$ ?



$$\begin{cases} \varepsilon_{F,\uparrow} = \varepsilon_F + \delta\varepsilon/2 \\ \varepsilon_{F,\downarrow} = \varepsilon_F - \delta\varepsilon/2 \end{cases}$$

$$\rho_{\uparrow} - \rho_{\downarrow} = \int_0^{\varepsilon_F + \frac{\delta\varepsilon}{2}} \frac{g(\varepsilon)}{2} d\varepsilon - \int_0^{\varepsilon_F - \frac{\delta\varepsilon}{2}} \frac{g(\varepsilon)}{2} d\varepsilon \approx \delta\varepsilon \frac{g(\varepsilon_F)}{2}$$

N° medio de  $e^-$  por sitio:  $x = (\rho_{\uparrow} - \rho_{\downarrow})v$

Aproximo:  $U n_{i\uparrow} n_{i\downarrow} = \frac{U}{4} (n_{i\uparrow} + n_{i\downarrow})^2 - \frac{U}{4} (n_{i\uparrow} - n_{i\downarrow})^2 \approx \frac{U}{4} \langle n_{i\uparrow} + n_{i\downarrow} \rangle^2 - \frac{U}{4} \langle n_{i\uparrow} - n_{i\downarrow} \rangle^2$

Magnetización:  $M = -\frac{g}{2} \mu_B (\rho_{\uparrow} - \rho_{\downarrow}) = -\frac{g \mu_B \delta\varepsilon}{4} g(\varepsilon_F) \rightarrow \frac{E_{\text{Hubbard}}}{V} = \boxed{\frac{U x^2}{4 v} - \frac{U}{v} \left( \frac{M v}{g \mu_B} \right)^2}$

$E$  cinética:  $\frac{K}{V} = \int_0^{\varepsilon_F + \frac{\delta\varepsilon}{2}} \varepsilon \frac{g(\varepsilon)}{2} d\varepsilon + \int_0^{\varepsilon_F - \frac{\delta\varepsilon}{2}} \varepsilon \frac{g(\varepsilon)}{2} d\varepsilon = 2 \int_0^{\varepsilon_F} \varepsilon \frac{g(\varepsilon)}{2} d\varepsilon + \int_{\varepsilon_F}^{\varepsilon_F + \frac{\delta\varepsilon}{2}} \varepsilon \frac{g(\varepsilon)}{2} d\varepsilon - \int_{\varepsilon_F - \frac{\delta\varepsilon}{2}}^{\varepsilon_F} \varepsilon \frac{g(\varepsilon)}{2} d\varepsilon$

$= K(M=0)$

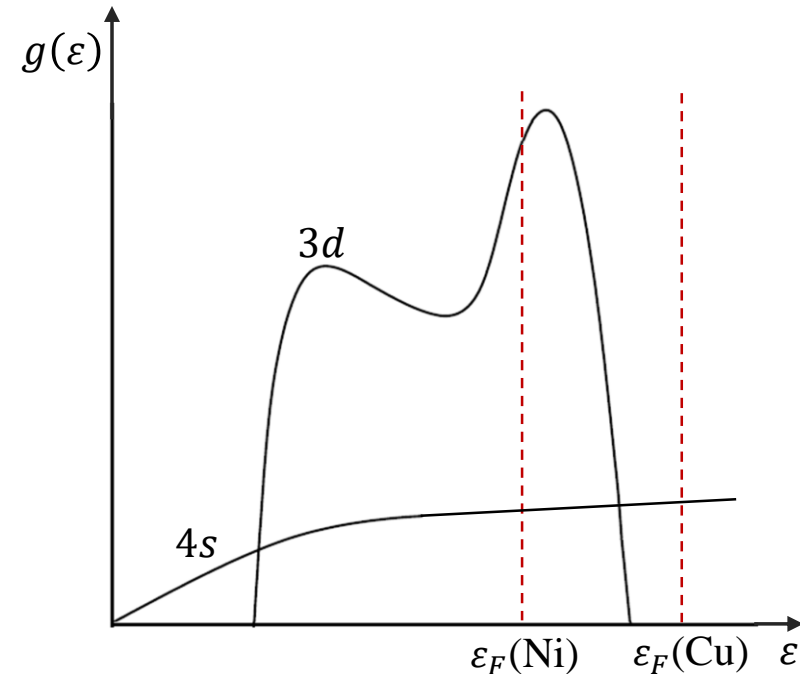
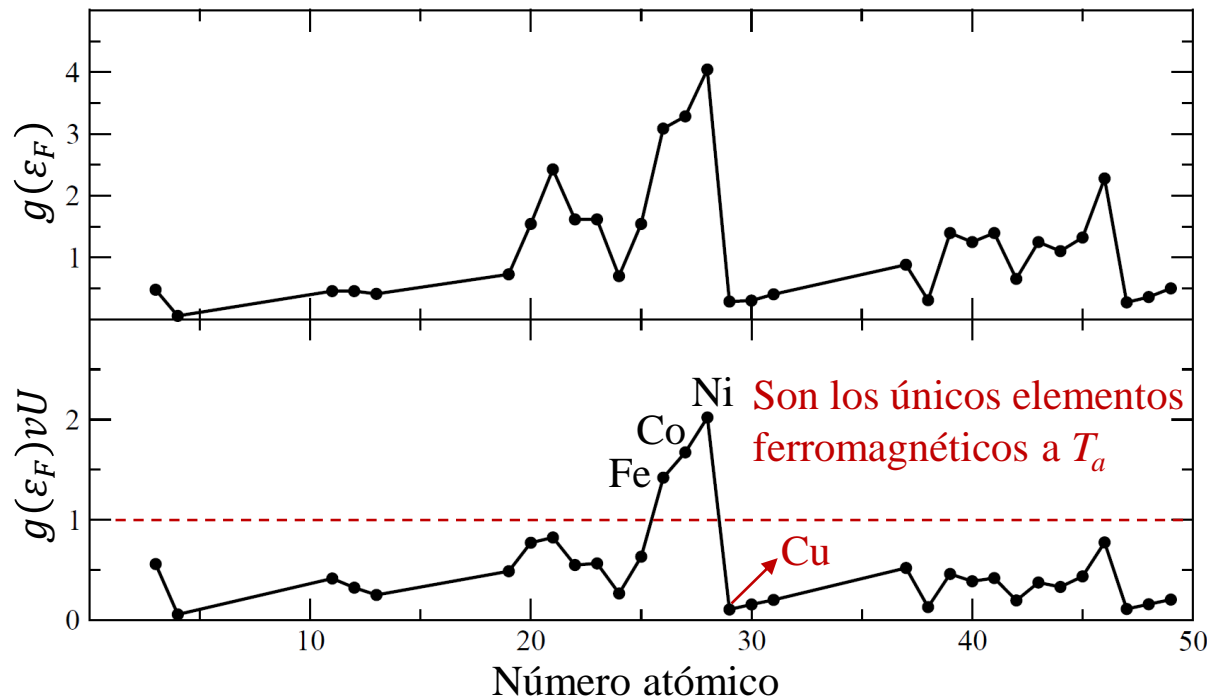
$$\approx \frac{K_0}{V} + \frac{g(\varepsilon_F)}{2} \left\{ \left[ \frac{(\varepsilon_F + \delta\varepsilon/2)^2}{2} - \frac{\varepsilon_F^2}{2} \right] - \left[ \frac{\varepsilon_F^2}{2} - \frac{(\varepsilon_F - \delta\varepsilon/2)^2}{2} \right] \right\} = \frac{K_0}{V} + \frac{g(\varepsilon_F)}{2} \left( \frac{\delta\varepsilon}{2} \right)^2 = \boxed{\frac{K_0}{V} + \frac{g(\varepsilon_F)}{2} \left( \frac{2M}{g \mu_B g(\varepsilon_F)} \right)^2}$$

# Magnetismo

## Magnetismo itinerante: Orden magnético a campo nulo

$$\frac{E}{V} = \frac{K + E_{Hubbard}}{V} = \frac{K_0 + \overbrace{U_0}^{= E_{Hubbard}(M=0)}}{V} + \frac{1}{2g(\varepsilon_F)} \left( \frac{2M}{g\mu_B} \right)^2 - \frac{U}{v} \left( \frac{Mv}{g\mu_B} \right)^2 = \frac{\overbrace{E_0}^{= E(M=0)}}{V} + \left( \frac{M}{g\mu_B} \right)^2 \left[ \frac{2}{g(\varepsilon_F)} - vU \right]$$

¿Cuándo conviene tener  $M \neq 0$ ?  $\rightarrow \frac{2}{g(\varepsilon_F)} - vU < 0 \rightarrow g(\varepsilon_F) > \frac{2}{vU} \rightarrow g(\varepsilon_F)vU > 1$  **Criterio de Stoner**



# Magnetismo

## Magnetismo en la tabla periódica

Considerando todas las contribuciones, se obtiene un comportamiento dominante.

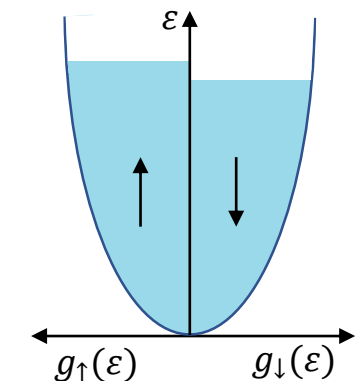
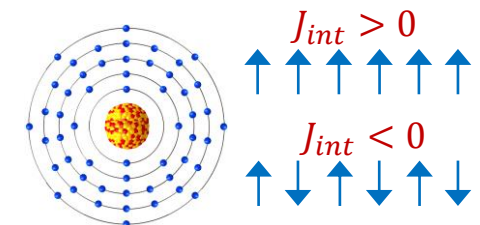
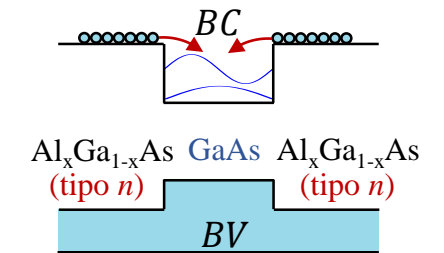
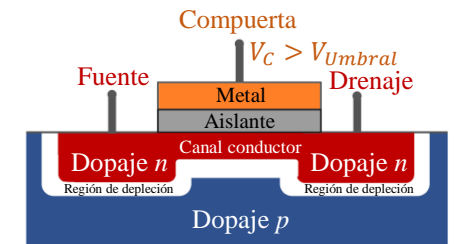
1																		18																	
1 1.0080 ±1 <b>H</b> 20.28 17.81 0.08988 1s <sup>1</sup>																	2 4.002602 0 <b>He</b> 4.216 0.8 (26 bar) 0.1787 1s <sup>2</sup>																		
3 6.97 1 <b>Li</b> 1615 453.69 0.53 [He]2s <sup>1</sup>	4 9.012182 2 <b>Be</b> 2745 1560 1.848 [He]2s <sup>2</sup>																	5 10.81 3 <b>B</b> 4273 2352 2.34 [He]2s <sup>2</sup> 2p <sup>1</sup>	6 12.011 2,(4) <b>C</b> 5100 4098 (sub.) 2.62 [He]2s <sup>2</sup> 2p <sup>2</sup>	7 14.0069 ±1,±2,(±3),4,5 <b>N</b> 77.4 63.29 1.2506 [He]2s <sup>2</sup> 2p <sup>3</sup>	8 15.9994 -2 <b>O</b> 90.188 54.8 1.429 [He]2s <sup>2</sup> 2p <sup>4</sup> 35 K	9 18.998403 -1 <b>F</b> 85.01 27.102 24.48 0.8999 [He]2s <sup>2</sup> 2p <sup>5</sup>	10 20.1797 0 <b>Ne</b> 27.102 24.48 0.8999 [He]2s <sup>2</sup> 2p <sup>6</sup>												
11 22.989769 1 <b>Na</b> 1156.1 370.96 0.971 [Ne]3s <sup>1</sup>	12 24.3050 2 <b>Mg</b> 1363 922 1.738 [Ne]3s <sup>2</sup>																	13 26.981539 3 <b>Al</b> 2792 933.52 2.702 [Ne]3s <sup>2</sup> 3p <sup>1</sup>	14 28.085 2,(4),-4 <b>Si</b> 3538 1683 2.33 [Ne]3s <sup>2</sup> 3p <sup>2</sup>	15 30.973762 ±3,(5) <b>P</b> 550 317.3 1.82 [Ne]3s <sup>2</sup> 3p <sup>3</sup>	16 32.07 -2,(4),(6) <b>S</b> 717.8 388.36 2.07 [Ne]3s <sup>2</sup> 3p <sup>4</sup>	17 35.45 +1,3,5,7 <b>Cl</b> 238.6 172.17 3.214 [Ne]3s <sup>2</sup> 3p <sup>5</sup>	18 39.948 0 <b>Ar</b> 87.5 84 1.7824 [Ne]3s <sup>2</sup> 3p <sup>6</sup>												
19 39.0983 1 <b>K</b> 1033.1 336.4 0.862 [Ar]4s <sup>1</sup>	20 40.078 2 <b>Ca</b> 1757 1814 1.85 [Ar]4s <sup>2</sup>	21 44.955912 3 <b>Sc</b> 3103 1941±10 3.00 [Ar]4s <sup>2</sup> 3d <sup>1</sup>	22 47.867 2,3,(4) <b>Ti</b> 3560 2163±10 4.50 [Ar]4s <sup>2</sup> 3d <sup>2</sup>	23 50.9415 2,3,4,(5) <b>V</b> 3680 2130 6.80 [Ar]4s <sup>2</sup> 3d <sup>3</sup>	24 51.9961 2,(3),6 <b>Cr</b> 2945 1941±10 7.33 [Ar]4s <sup>1</sup> 3d <sup>5</sup> 312 K	25 54.938045 (2),3,4,6,7 <b>Mn</b> 2334 1768 7.43 [Ar]4s <sup>2</sup> 3d <sup>5</sup> 96 K	26 55.845 2,(3) <b>Fe</b> 3134 1808 7.86 [Ar]4s <sup>2</sup> 3d <sup>6</sup> 1043 K	27 58.933195 (2),3 <b>Co</b> 3200 1768 8.90 [Ar]4s <sup>2</sup> 3d <sup>7</sup> 629 K	28 58.6934 2,(3) <b>Ni</b> 3186 1726 8.90 [Ar]4s <sup>2</sup> 3d <sup>8</sup>	29 63.546 1,(2) <b>Cu</b> 2840 1356 8.96 [Ar]4s <sup>1</sup> 3d <sup>10</sup>	30 65.38 2 <b>Zn</b> 1180 692.73 7.14 [Ar]4s <sup>2</sup> 3d <sup>10</sup>	31 69.723 3 <b>Ga</b> 2477 302.93 5.907 [Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>1</sup>	32 72.63 2,(4) <b>Ge</b> 3103 1210.6 5.323 [Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>2</sup>	33 74.92160 ±3,(5) <b>As</b> 886 (sub.) 490 5.72 [Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>3</sup>	34 78.96 -2,(4),(6) <b>Se</b> 958.1 490 4.79 [Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>4</sup>	35 79.904 +1,(5) <b>Br</b> 331.93 266 3.119 [Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>5</sup>	36 83.798 0 <b>Kr</b> 120.9 116.6 3.708 [Ar]4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>6</sup>																		
37 85.4678 1 <b>Rb</b> 959 312.04 1.53 [Kr]5s <sup>1</sup>	38 87.62 2 <b>Sr</b> 1657 1042 2.60 [Kr]5s <sup>2</sup>	39 88.90585 3 <b>Y</b> 3611 1795±8 4.47 [Kr]5s <sup>2</sup> 4d <sup>1</sup>	40 91.224 4 <b>Zr</b> 4650 2125±2 6.40 [Kr]5s <sup>2</sup> 4d <sup>2</sup>	41 92.906 3,(5) <b>Nb</b> 5015 2471±10 8.57 [Kr]5s <sup>1</sup> 4d <sup>4</sup>	42 95.96 2,3,4,5,(6) <b>Mo</b> 4885 2890 10.20 [Kr]5s <sup>1</sup> 4d <sup>5</sup>	43 97.9072 4,6,(7) <b>Tc</b> 5150 2607 11.5 [Kr]5s <sup>2</sup> 4d <sup>5</sup>	44 101.07 2,(3),(4) <b>Ru</b> 4423 2607 12.20 [Kr]5s <sup>1</sup> 4d <sup>6</sup>	45 102.90550 2,(3),(4) <b>Rh</b> 3968 2239±3 12.40 [Kr]5s <sup>1</sup> 4d <sup>6</sup>	46 106.42 2,(4) <b>Pd</b> 3213 1825 12.02 [Kr]4d <sup>10</sup>	47 107.8682 1 <b>Ag</b> 2435 1235.08 10.50 [Kr]5s <sup>1</sup> 4d <sup>10</sup>	48 112.411 2 <b>Cd</b> 1038 594.1 8.65 [Kr]5s <sup>2</sup> 4d <sup>10</sup>	49 114.818 3 <b>In</b> 2353 429.76 7.31 [Kr]5s <sup>2</sup> 4d <sup>10</sup> 5p <sup>1</sup>	50 118.710 2,(4) <b>Sn</b> 2875 505.12 7.30 [Kr]5s <sup>2</sup> 4d <sup>10</sup> 5p <sup>2</sup>	51 121.760 ±3,(5) <b>Sb</b> 1860 903.89 6.884 [Kr]5s <sup>2</sup> 4d <sup>10</sup> 5p <sup>3</sup>	52 127.60 -2,(4),(6) <b>Te</b> 1263.1 722.7 6.24 [Kr]5s <sup>2</sup> 4d <sup>10</sup> 5p <sup>4</sup>	53 126.90447 +1,(5),(7) <b>I</b> 497.26 (sub.) 387 4.93 [Kr]5s <sup>2</sup> 4d <sup>10</sup> 5p <sup>5</sup>	54 131.293 0 <b>Xe</b> 166.1 161.3 5.88 [Kr]5s <sup>2</sup> 4d <sup>10</sup> 5p <sup>6</sup>																		
55 132.905452 1 <b>Cs</b> 942.5 301.55 1.873 [Xe]6s <sup>1</sup>	56 137.327 2 <b>Ba</b> 2170 998 3.51 [Xe]6s <sup>2</sup>	71 174.9668 3 <b>Lu</b> 3675 1936 9.85 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>1</sup>	72 178.49 4 <b>Hf</b> 4875 2500 13.2 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>2</sup>	73 180.94785 5 <b>Ta</b> 5700±100 3269 19.3 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>3</sup>	74 183.84 2,3,4,5,(6) <b>W</b> 5933 3683±20 18.6 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>4</sup>	75 186.207 -1,2,4,6,(7) <b>Re</b> 5900 (est.) 3453 21.0 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>5</sup>	76 190.23 2,3,(4),(6),(8) <b>Os</b> 5300 3327 22.4 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>6</sup>	77 192.217 2,3,(4),(6) <b>Ir</b> 4403 2683 22.4 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>7</sup>	78 195.084 2,(4) <b>Pt</b> 4100 2045 21.45 [Xe]6s <sup>1</sup> 4f <sup>14</sup> 5d <sup>9</sup>	79 196.966569 1,(3) <b>Au</b> 3081 1337.58 19.32 [Xe]6s <sup>1</sup> 4f <sup>14</sup> 5d <sup>10</sup>	80 200.59 1,(2) <b>Hg</b> 629.73 234.28 13.546 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup>	81 204.384 1,(1),(3) <b>Tl</b> 1730±10 576.7 11.85 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup> 6p <sup>1</sup>	82 207.2 2,(4) <b>Pb</b> 2013 600.652 11.34 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup> 6p <sup>2</sup>	83 208.98040 3,(5) <b>Bi</b> 1833±5 544.5 9.80 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup> 6p <sup>3</sup>	84 [208.9824] 2,(4) <b>Po</b> 1235 527 9.80 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup> 6p <sup>4</sup>	85 [209.9871] ±1,3,5,7 <b>At</b> 610 575 9.73 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup> 6p <sup>5</sup>	86 [222.0176] 0 <b>Rn</b> 211 202 9.73 [Xe]6s <sup>2</sup> 4f <sup>14</sup> 5d <sup>10</sup> 6p <sup>6</sup>																		
87 [223.0197] 1 <b>Fr</b> 950 300 — [Rn]7s <sup>1</sup>	88 [226.0254] 2 <b>Ra</b> 1413 973 6.0 [Rn]7s <sup>2</sup>																																		
* 3737 1191 6.7 [Xe]6s <sup>2</sup> 5d <sup>1</sup>	57 138.90547 3 <b>La</b> 3706 1071±3 6.78 [Xe]6s <sup>2</sup> 4f <sup>1</sup>	58 140.116 (3),4 <b>Ce</b> 3793 1204 6.77 [Xe]6s <sup>2</sup> 4f <sup>2</sup>	59 140.90765 (3),(4) <b>Pr</b> 3347 1294 7.00 [Xe]6s <sup>2</sup> 4f <sup>3</sup>	60 144.242 3 <b>Nd</b> 3300 (est.) 1315 6.475 [Xe]6s <sup>2</sup> 4f <sup>4</sup>	61 [144.9127] 3 <b>Pm</b> 2067 1347 7.54 [Xe]6s <sup>2</sup> 4f <sup>5</sup>	62 150.36 2,(3) <b>Sm</b> 1800 1095 8.259 [Xe]6s <sup>2</sup> 4f <sup>6</sup>	63 151.964 2,(3) <b>Eu</b> 3546 1686 7.895 [Xe]6s <sup>2</sup> 4f <sup>7</sup>	64 157.25 3 <b>Gd</b> 3503 1629 8.27 [Xe]6s <sup>2</sup> 4f <sup>7</sup> 5d <sup>1</sup>	65 158.925 (3),4 <b>Tb</b> 2840 1685 8.536 [Xe]6s <sup>2</sup> 4f <sup>9</sup>	66 162.500 3 <b>Dy</b> 2973 1747 8.80 [Xe]6s <sup>2</sup> 4f <sup>10</sup>	67 164.93032 3 <b>Ho</b> 3141 1802 9.05 [Xe]6s <sup>2</sup> 4f <sup>11</sup>	68 167.259 3 <b>Er</b> 2223 1818 9.33 [Xe]6s <sup>2</sup> 4f <sup>12</sup>	69 168.93421 2,(3) <b>Tm</b> 1469 1092 6.98 [Xe]6s <sup>2</sup> 4f <sup>13</sup>	70 173.054 2,(3) <b>Yb</b> 1469 1092 6.98 [Xe]6s <sup>2</sup> 4f <sup>14</sup>																					
** 3500±300 1323 10.07 [Rn]7s <sup>6</sup> 6d <sup>1</sup>	89 [227.0278] 3 <b>Ac</b> 4273 2023 11.70 [Rn]7s <sup>6</sup> 6d <sup>2</sup>	90 232.0381 4 <b>Th</b> 4091 1873 15.40 [Rn]7s <sup>6</sup> 5f <sup>2</sup> 6d <sup>1</sup>	91 [231.0359] 4,(5) <b>Pa</b> 492 1405 18.90 [Rn]7s <sup>6</sup> 5f <sup>3</sup> 6d <sup>1</sup>	92 238.02891 3,4,5,(6) <b>U</b> 4175 913 20.45 [Rn]7s <sup>6</sup> 5f <sup>4</sup> 6d <sup>1</sup>	93 [237.0482] 3,4,(5),(6) <b>Np</b> 3505 914 18.90 [Rn]7s <sup>6</sup> 5f <sup>6</sup>	94 [244.0642] 3,(4),5,6 <b>Pu</b> 1267 13.5 — [Rn]7s <sup>6</sup> 5f <sup>6</sup>	95 [243.0614] 3,(4),5,6 <b>Am</b> 1613 — — [Rn]7s <sup>6</sup> 5f <sup>7</sup>	96 [247.0703] 3,(4) <b>Cm</b> — — — [Rn]7s <sup>6</sup> 5f <sup>8</sup>	97 [247.0703] 3,(4),(7) <b>Bk</b> — — — [Rn]7s <sup>6</sup> 5f <sup>9</sup>	98 [251.0796] 3,(4) <b>Cf</b> — — — [Rn]7s <sup>6</sup> 5f <sup>10</sup>	99 [252.0830] 2,(3) <b>Es</b> — — — [Rn]7s <sup>6</sup> 5f <sup>11</sup>	100 [257.0951] 3 <b>Fm</b> — — — [Rn]7s <sup>6</sup> 5f <sup>12</sup>	101 [258.0984] 2,3 <b>Md</b> — — — [Rn]7s <sup>6</sup> 5f <sup>13</sup>	102 [259.1010] 2,3 <b>No</b> — — — [Rn]7s <sup>6</sup> 5f <sup>14</sup>																					

Ferromagneto  
 Anti-ferromagneto  
 Diamagneto  
 Paramagneto



# Resumen

- Transistor y pozos cuánticos
- Magnetismo localizado
- Ferromagneto/Anti-ferromagneto/Paramagneto/Diamagneto
- Magnetismo itinerante
- Hamiltoniano de Hubbard y Criterio de Stoner



# Programa de la materia

- Red cristalina y red recíproca ✓
- Difracción de rayos X ✓
- Cohesión en sólidos ✓
- Vibraciones, fonones y propiedades térmicas ✓
- Electrones en sólidos ✓
- Semiconductores ✓
- Introducción a magnetismo ✓

