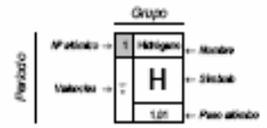


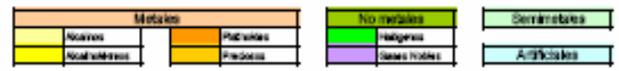
# Tabla Periódica de los elementos

IA																												VIIA (01)				
1	1	2																	18	19												
	H	He																	Ne	Ar												
2	3	4																	16	17												
	Li	Be																	Ne	Ar												
3	11	12																	14	15												
	Na	Mg																	Ar	Kr												
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36														
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr														
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54														
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe														
6	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn														
7	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
	Fr	Ra	Ac	Unq	Unp	Unh	Uns	Unc	Uue																							



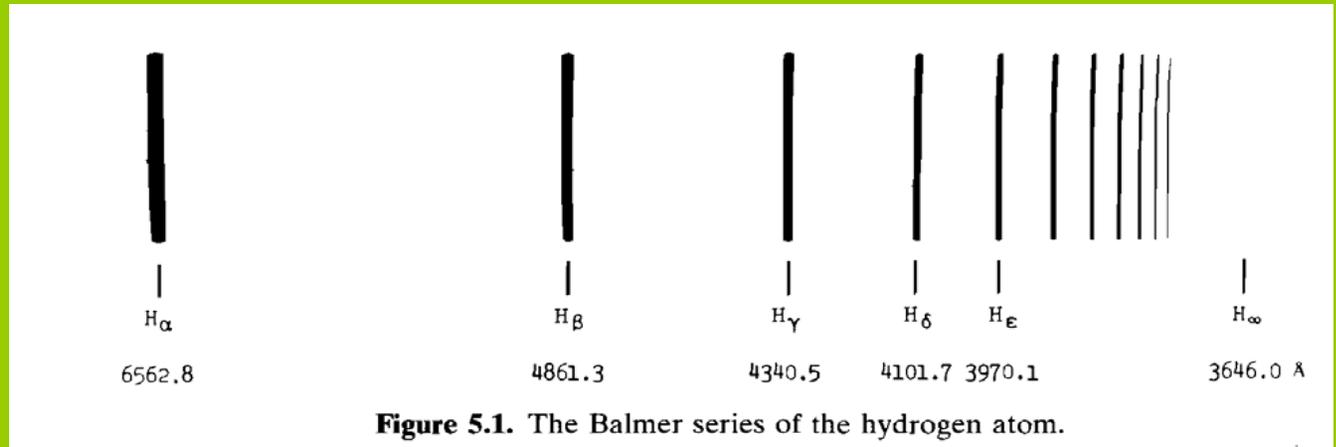
Tiempos Raras Ligeros (TRLA) Lantanidos		58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu					
		138.91	140.91	144.24	144.91	150.35	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.05	174.97					
Tiempos Raras Pesadas (TRP)		88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr					
		232.038	231.04	238.03	237.05	244.06	247.07	251.08	252.08	257.10	261.10	267.10	271.10	287.10	289.10					

\* Número atómico del isótopo más ligero.  
Peso atómico basado en <sup>12</sup>C



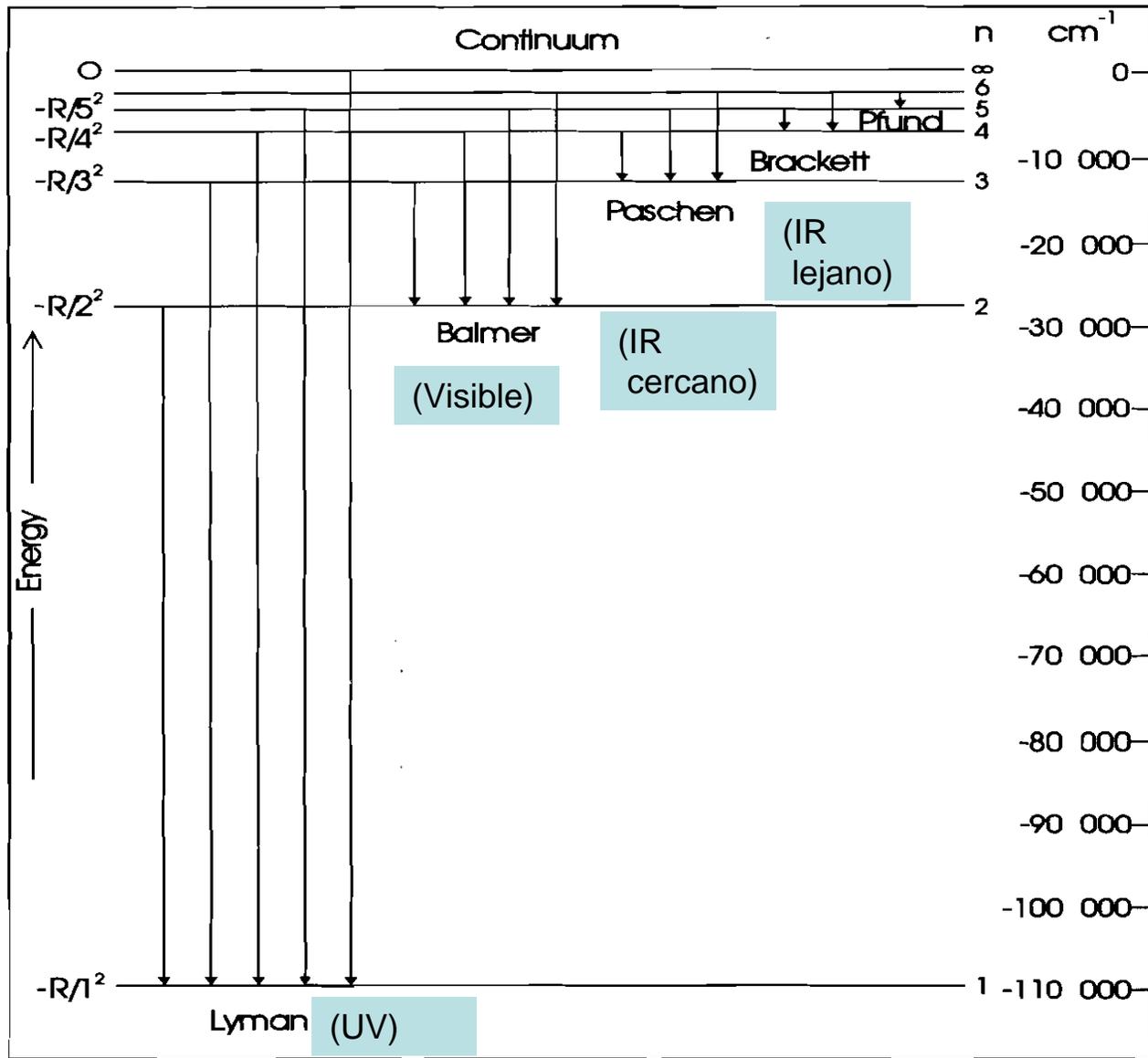
# ESPECTROS ATOMICOS

## SERIE DE BALMER



$$\tilde{\nu} = 109,678 \left( \frac{1}{2^2} - \frac{1}{n^2} \right) \text{ cm}^{-1}, \quad n = 3, 4, \dots$$

$$= R_H \left( \frac{1}{2^2} - \frac{1}{n^2} \right),$$



**Figure 5.2.** Energy levels of the hydrogen atom.

**S**=momento de spin electrónico

**Matrices de Pauli**

**ATOMO DE HIDRÓGENO-espectro de un electrón**

$$\frac{-\hbar^2}{2\mu} \nabla^2 \psi - \frac{Ze^2 \psi}{4\pi\epsilon_0 r} = E\psi.$$

$$\frac{-\hbar^2}{2mr^2} \frac{\partial}{\partial r} r^2 \frac{\partial \psi}{\partial r} + \frac{1}{2mr^2} \hat{L}^2 \psi - \frac{Ze^2 \psi}{4\pi\epsilon_0 r} = E\psi.$$

$$\psi = R_{nl}(r) Y_{lm}(\theta, \phi),$$

$$n = 1, 2, 3, \dots, \infty,$$

$$l = 0, 1, \dots, n - 1,$$

$$m = 0, \pm 1, \dots, \pm l.$$

$$E_n = \frac{-\mu Z^2 (e^2 / 4\pi\epsilon_0)^2}{2n^2 \hbar^2} = \frac{-R}{n^2}, \quad n = 1, 2, 3, \dots,$$

$$l = 0, 1, 2, 3, \dots \rightarrow s, p, d, f, \dots$$

$$R = R_H = 109,677,4212 \text{ cm}^{-1}$$

$$R_H = \frac{R_\infty}{1 + m_e/m_p},$$

## Momento angular

$$[\hat{L}_x, \hat{L}_y] = i\hbar\hat{L}_z, \quad [\hat{L}_y, \hat{L}_z] = i\hbar\hat{L}_x, \quad [\hat{L}_z, \hat{L}_x] = i\hbar\hat{L}_y,$$

$$[\hat{L}^2, \hat{L}_x] = [\hat{L}^2, \hat{L}_y] = [\hat{L}^2, \hat{L}_z] = 0,$$

$$\hat{L}^2 Y_{LM}(\theta, \phi) = \hbar^2 L(L+1) Y_{LM}(\theta, \phi),$$

$$\hat{L}_z Y_{LM}(\theta, \phi) = M\hbar Y_{LM}(\theta, \phi).$$

$$L_+ = L_x + iL_y$$

Funciones de spin:

$$|\alpha\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \left| \frac{1}{2}; +\frac{1}{2} \right\rangle$$

$$|\beta\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \left| \frac{1}{2}; -\frac{1}{2} \right\rangle$$

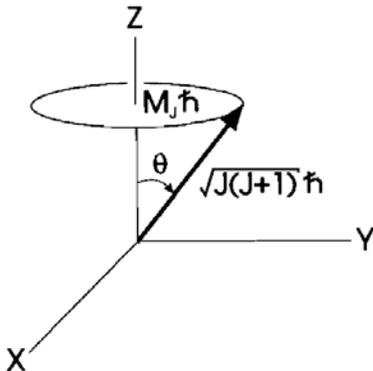
$$[\hat{H}, \hat{l}_z] = [\hat{H}, \hat{l}^2] = 0,$$

$$\hat{H}\psi_{nlm} = E_n\psi_{nlm},$$

$$\hat{l}^2\psi_{nlm} = l(l+1)\hbar^2\psi_{nlm},$$

$$\hat{l}_z\psi_{nlm} = m\hbar\psi_{nlm}.$$

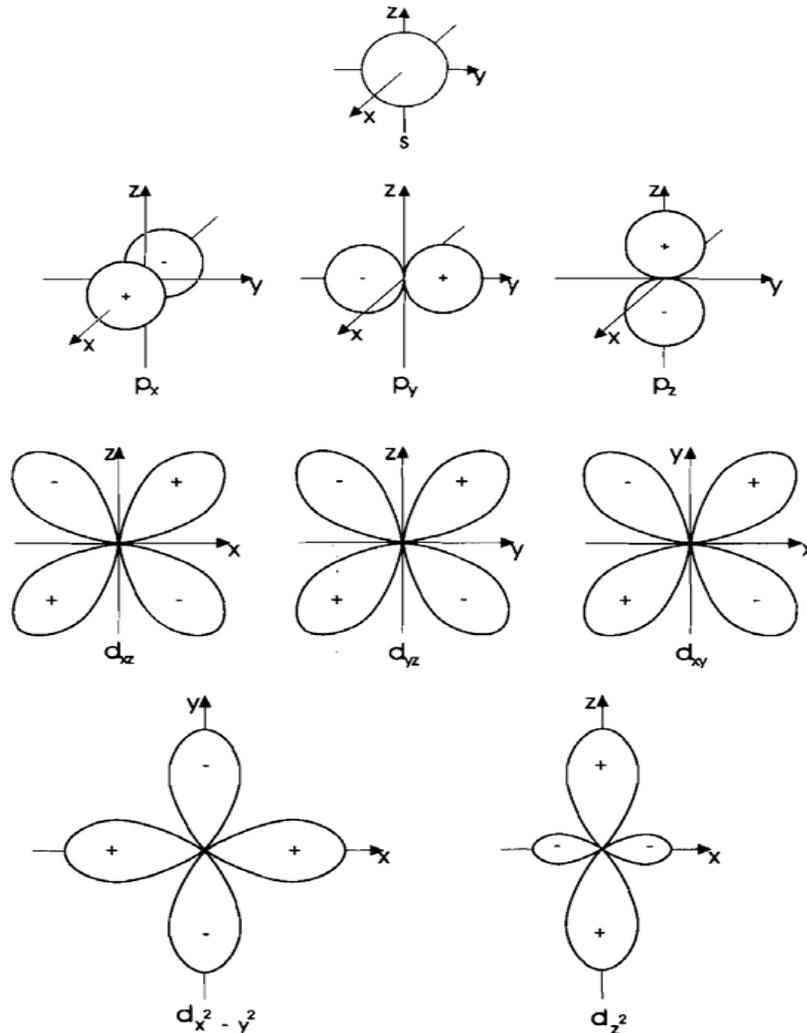
Para un momento angular  $J$



$M_J$ : Diferentes orientaciones Espaciales de  $J$

Degeneración  $(2J+1)$ , para un espacio isótropo (ausencia de campos externos)

# PARTE ANGULAR DE LOS ORBITALES 1s, 2p, 3d



$$\psi = R_{nl}(r)Y_{lm}(\theta, \phi),$$

# Acoplamiento spin órbita

(estructura fina)

e<sup>-</sup>(partícula cargada)



El movimiento orbital=corriente

$$\boldsymbol{\mu}_s = -g_e \mu_B \mathbf{S}$$

$$E = -\boldsymbol{\mu} \cdot \mathbf{B}$$

Campo en el e<sup>-</sup> proporcional al  
**momento angular l**

$$\hat{H}_{so} = \xi(r) \hat{\mathbf{l}} \cdot \hat{\mathbf{s}}.$$

$$\xi(r) = \frac{1}{2\mu^2 c^2} \frac{1}{r} \frac{\partial V}{\partial r} = \frac{1}{2\mu^2 c^2} \left( \frac{Ze^2}{4\pi\epsilon_0 r^3} \right)$$

$$V = -\frac{Ze^2}{4\pi\epsilon_0 r}$$

Atracción COULOMBIANA  
entre electrón y núcleos

$$[\hat{H}^{(0)} + \xi(r)\hat{\mathbf{l}} \cdot \hat{\mathbf{s}}]\psi = E\psi,$$

(derivación adecuada: EQR  
(electrodinámica cuántica relativista))

$l_z$  y  $s_z$  ya no conmutan con  $\mathbf{H}$

$\mathbf{j}$  conmuta con  $\mathbf{H}$

(cte de movimiento)

$$\mathbf{j} = \mathbf{l} + \mathbf{s}$$

$j^2$  y  $j_z$  **SI** conmutan con  $\mathbf{H}$

Ejemplo:  
electrones p

$$|l = 1, m_l = 1\rangle |s = \frac{1}{2}, m_s = \pm \frac{1}{2}\rangle,$$
$$|l = 1, m_l = 0\rangle |s = \frac{1}{2}, m_s = \pm \frac{1}{2}\rangle,$$

(Representación desacoplada:  
Producto de funciones angular  
y spin de un electrón: 6 funciones)

$$|l = 1, m_l = -1\rangle |s = \frac{1}{2}, m_s = \pm \frac{1}{2}\rangle.$$

## Representación en estados acoplados y desacoplados

$$\hat{H} = \hat{H}^{(0)} + \xi(r)\hat{\mathbf{l}} \cdot \hat{\mathbf{s}} = (\hat{H}^{(0)} + \xi(r)\hat{l}_z\hat{s}_z) + \frac{\xi(r)(\hat{l}_+\hat{s}_- + \hat{l}_-\hat{s}_+)}{2}$$

$$\begin{aligned} \langle l = 1, m_l | \langle s = \frac{1}{2}, m_s | \hat{H} | s = \frac{1}{2}, m_s \rangle | l = 1, m_l \rangle \\ = E_{2p}^{(0)} + \zeta_{2p} m_l m_s \end{aligned}$$

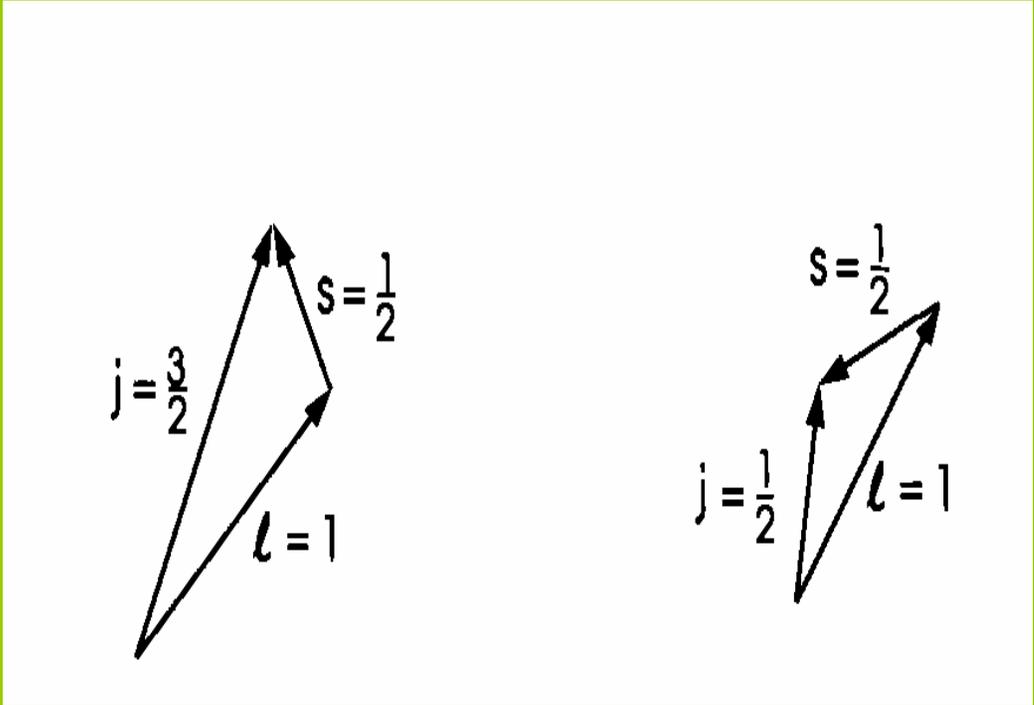
$$E_{2p}^{(0)} = -R_H/4$$

$$\zeta_{2p} = \hbar^2 \int R_{2p}^*(r) \xi(r) R_{2p}(r) r^2 dr.$$

$$\xi \hat{\mathbf{l}} \cdot \hat{\mathbf{s}} = \frac{\xi(\hat{j}^2 - \hat{l}^2 - \hat{s}^2)}{2}.$$

$$\hat{j}^2 = (\hat{\mathbf{l}} + \hat{\mathbf{s}}) \cdot (\hat{\mathbf{l}} + \hat{\mathbf{s}}) = \hat{\mathbf{l}}^2 + \hat{\mathbf{s}}^2 + 2\hat{\mathbf{l}} \cdot \hat{\mathbf{s}}$$

$J^2$  conmuta con H



$$|2p, j = \frac{3}{2}, m_j = \frac{3}{2}\rangle,$$

$$|2p, j = \frac{3}{2}, m_j = \frac{1}{2}\rangle,$$

$$|2p, j = \frac{3}{2}, m_j = -\frac{1}{2}\rangle,$$

$$|2p, j = \frac{3}{2}, m_j = -\frac{3}{2}\rangle,$$

$$|2p, j = \frac{1}{2}, m_j = \frac{1}{2}\rangle,$$

$$|2p, j = \frac{1}{2}, m_j = -\frac{1}{2}\rangle.$$

Los estados acoplados  $|J M_J\rangle$  están relacionados con los no acoplados  $|j_1 m_1\rangle |j_2 m_2\rangle$  por

$$|j_1, j_2 J, M_J\rangle = \sum_{m_1=-j_1}^{j_1} \sum_{m_2=-j_2}^{j_2} \langle j_1, j_2; m_1, m_2 | JM_J\rangle |j_1 m_1\rangle |j_2 m_2\rangle,$$

Aparecen los coeficientes de Glebsh Gordan

# SISTEMA DE MUCHOS ELECTRONES

$$\left( \frac{-\hbar^2}{2m_e} \sum_{i=1}^N \nabla_i^2 - \sum_{i=1}^N \frac{Ze^2}{4\pi\epsilon_0 r_i} + \sum_{i,j>i}^N \frac{e^2}{4\pi\epsilon_0 r_{ij}} \right) \psi = E\psi.$$

$$\hat{\mathbf{L}} = \hat{\mathbf{l}}_1 + \hat{\mathbf{l}}_2 + \dots + \hat{\mathbf{l}}_N = \sum_{i=1}^N \hat{\mathbf{l}}_i.$$

$$\hat{\mathbf{S}} = \sum_{i=1}^N \hat{\mathbf{s}}_i$$

$$\hat{\mathbf{J}} = \hat{\mathbf{L}} + \hat{\mathbf{S}}.$$

$$\hat{L}_z = \hat{l}_{z1} + \hat{l}_{z2} + \cdots + \hat{l}_{zN},$$

$$\hat{S}_z = \hat{s}_{z1} + \hat{s}_{z2} + \cdots + \hat{s}_{zN},$$

$$\hat{L}^2 = \hat{L}_x^2 + \hat{L}_y^2 + \hat{L}_z^2,$$

$$\hat{S}^2 = \hat{S}_x^2 + \hat{S}_y^2 + \hat{S}_z^2.$$

$$\hat{L}^2 \psi \approx L(L + 1)\hbar^2 \psi$$

$$[\hat{l}_{zi}, \hat{H}] \neq 0,$$

$$\hat{l}_{zi} \psi \neq m_{li} \hbar \psi,$$

$$\hat{L}_z \psi = M_L \hbar \psi,$$

$$M_L = m_{l1} + m_{l2} + \cdots + m_{lN}.$$

$$[\hat{L}_z, \hat{H}] = 0,$$

$$[\hat{L}_x, \hat{H}] = 0 \quad \text{and} \quad [\hat{L}_y, \hat{H}] = 0.$$

$$[\hat{L}_z^2, \hat{H}] = 0, \quad [\hat{L}_x^2, \hat{H}] = 0, \quad \text{and} \quad [\hat{L}_y^2, \hat{H}] = 0,$$

$$[\hat{L}^2, \hat{H}] = 0$$

**Table 5.4.** One-electron and Multi-electron Atoms

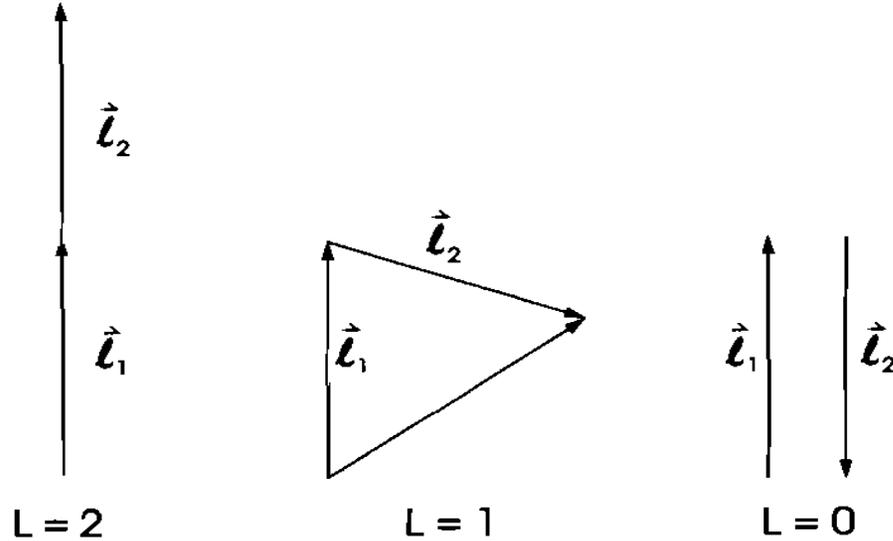
Multi-electron Atoms	One-electron Atoms
$\hat{L}^2\psi = L(L + 1)\hbar^2\psi$	$\hat{l}^2\psi = l(l + 1)\hbar^2\psi$
$\hat{L}_z\psi = M_L\hbar\psi$	$\hat{l}_z\psi = m_l\hbar\psi$
$\hat{S}^2\psi = S(S + 1)\hbar^2\psi$	$\hat{s}^2\psi = s(s + 1)\hbar^2\psi$
$\hat{S}_z\psi = M_S\hbar\psi$	$\hat{s}_z\psi = m_s\hbar\psi$
$L = 0, 1, 2, 3, 4, 5$	$l = 0, 1, 2, 3, 4, 5$
$S \quad P \quad D \quad F \quad G \quad H$	$s \quad p \quad d \quad f \quad g \quad h$

$$2S+1 L,$$

Degeneración  
→

$$g = (2L + 1)(2S + 1).$$

Ejemplo  $l_1=1, l_2=1$



Configuración  $2p^2$  del  
Átomo de carbono

2 electrones y  
6 spin orbitales

$$\chi_1 = p_1\alpha$$

$$\chi_2 = p_0\alpha;$$

$$\chi_3 = p_{-1}\alpha;$$

$$\chi_4 = p_1\beta;$$

$$\chi_5 = p_0\beta;$$

$$\chi_6 = p_{-1}\beta$$

15  
determinantes  
=  
15  
configuraciones

	$M_S = 1$	0	-1
$M_L = 2$	—	$ 1, \bar{1} $	—
$M_L = 1$	$ 1, 0 $	$ 1, \bar{0}   1, 0 $	$ \bar{1}, \bar{0} $
$M_L = 0$	$ 1, -1 $	$ 1, -\bar{1}   1, -1   0, \bar{0} $	$ \bar{1}, -\bar{1} $
$M_L = -1$	$ 0, -1 $	$ -1, \bar{0}   -\bar{1}, 0 $	$ \bar{0}, -\bar{1} $
$M_L = -2$	—	$ -1, -\bar{1} $	—

microestado

**15 configuraciones:** no todas spin adaptadas

**Notación**

$|1, \bar{0}|$

significa.

$$m_{l1} = 1, m_{s1} = \frac{1}{2}, m_{l2} = 0, m_{s2} = -\frac{1}{2}$$

# Acoplamiento Spin órbita

$$\hat{H}_{so} = \zeta \hat{\mathbf{L}} \cdot \hat{\mathbf{S}}.$$

Valores permitidos

$$J=L+S, L+S-1, \dots, |L-S|$$

$$\hat{J}^2 = (\mathbf{L} + \mathbf{S}) \cdot (\mathbf{L} + \mathbf{S}) = \hat{L}^2 + \hat{S}^2 + 2\mathbf{L} \cdot \mathbf{S}.$$

$$\mathbf{L} \cdot \mathbf{S} = \frac{\hat{J}^2 - \hat{L}^2 - \hat{S}^2}{2}$$

Las **componentes** de **L** y **S** no conmutan con H

$$\mathbf{J} = \mathbf{L} + \mathbf{S}$$

**J**, **L**<sup>2</sup> y **S**<sup>2</sup> conmutan con H

$$\begin{aligned} \langle H_{so} \rangle &= \zeta \langle \mathbf{L} \cdot \mathbf{S} \rangle = \zeta \langle nJM_JLS | \mathbf{L} \cdot \mathbf{S} | nJM_JLS \rangle \\ &= \frac{\zeta [J(J+1) - L(L+1) - S(S+1)]}{2}. \end{aligned}$$

$$\hat{H} = \hat{H}_0 + \hat{H}_{ee}$$

$$\hat{H} = \hat{H}_0 + \hat{H}_{ee} + \zeta \mathbf{L} \cdot \mathbf{S}$$

$$\hat{H} = \hat{H}_0 + \hat{H}_{ee} + \sum \xi(r_i) \mathbf{l}_i \cdot \mathbf{s}_i$$

$$\hat{H}\psi = E\psi$$

$$\hat{L}^2\psi = L(L+1)\hbar^2\psi$$

$$\hat{L}_z\psi = M_L\hbar\psi$$

$$\hat{S}^2\psi = S(S+1)\hbar^2\psi$$

$$\hat{S}_z\psi = M_S\hbar\psi$$

$$\hat{H}\psi = E\psi$$

$$\hat{L}^2\psi = L(L+1)\hbar^2\psi$$

$$\hat{S}^2\psi = S(S+1)\hbar^2\psi$$

$$\hat{J}^2\psi = J(J+1)\hbar^2\psi$$

$$\hat{J}_z\psi = M_J\hbar\psi$$

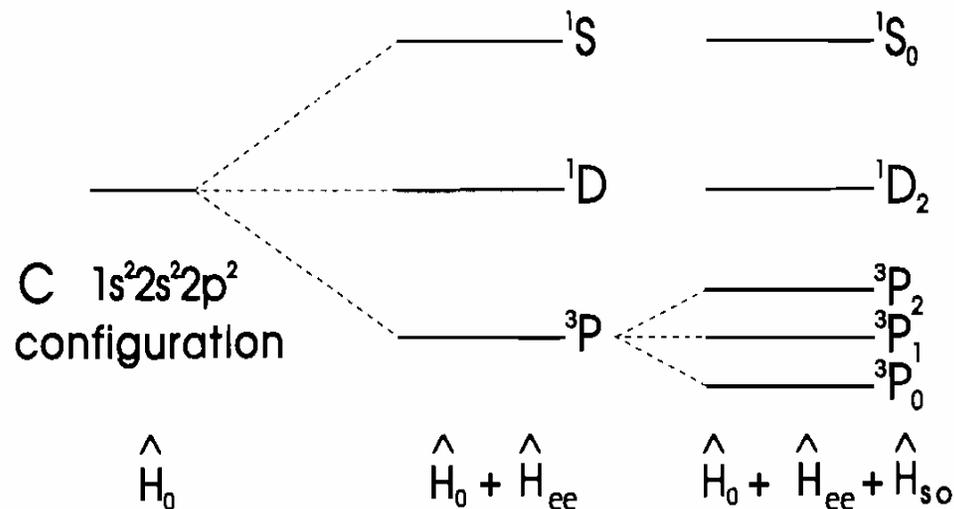
$$\hat{H}\psi = E\psi$$

$$\hat{L}^2\psi \approx L(L+1)\hbar^2\psi$$

$$\hat{S}^2\psi \approx S(S+1)\hbar^2\psi$$

$$\hat{J}^2\psi = J(J+1)\hbar^2\psi$$

$$\hat{J}_z\psi = M_J\hbar\psi$$



**Reglas de selección**

# Regla de Hund

- Al llenar orbitales de igual energía, los electrones prefieren acomodarse con spin paralelo

Ejemplo: 3 electrones en el orbital 2p;

$px^1 py^1 pz^1$  (vs)  $px^2 py^1 pz^0$

$(px^2 py^1 pz^0 = px^0 py^1 pz^2 = px^1 py^0 pz^2 = px^2 py^0$

$pz^1 = \dots)$

**1era. Regla:** mayor proyección de spin ( $2S+1$ ).

**2da. Regla** mayor Momento angular (L).

**3era. Regla** Acoplamiento spin órbita.

Cuando varios electrones están descritos por orbitales degenerados, la mayor estabilidad energética es aquella en donde los espines electrónicos están desapareados (correlación de espines):

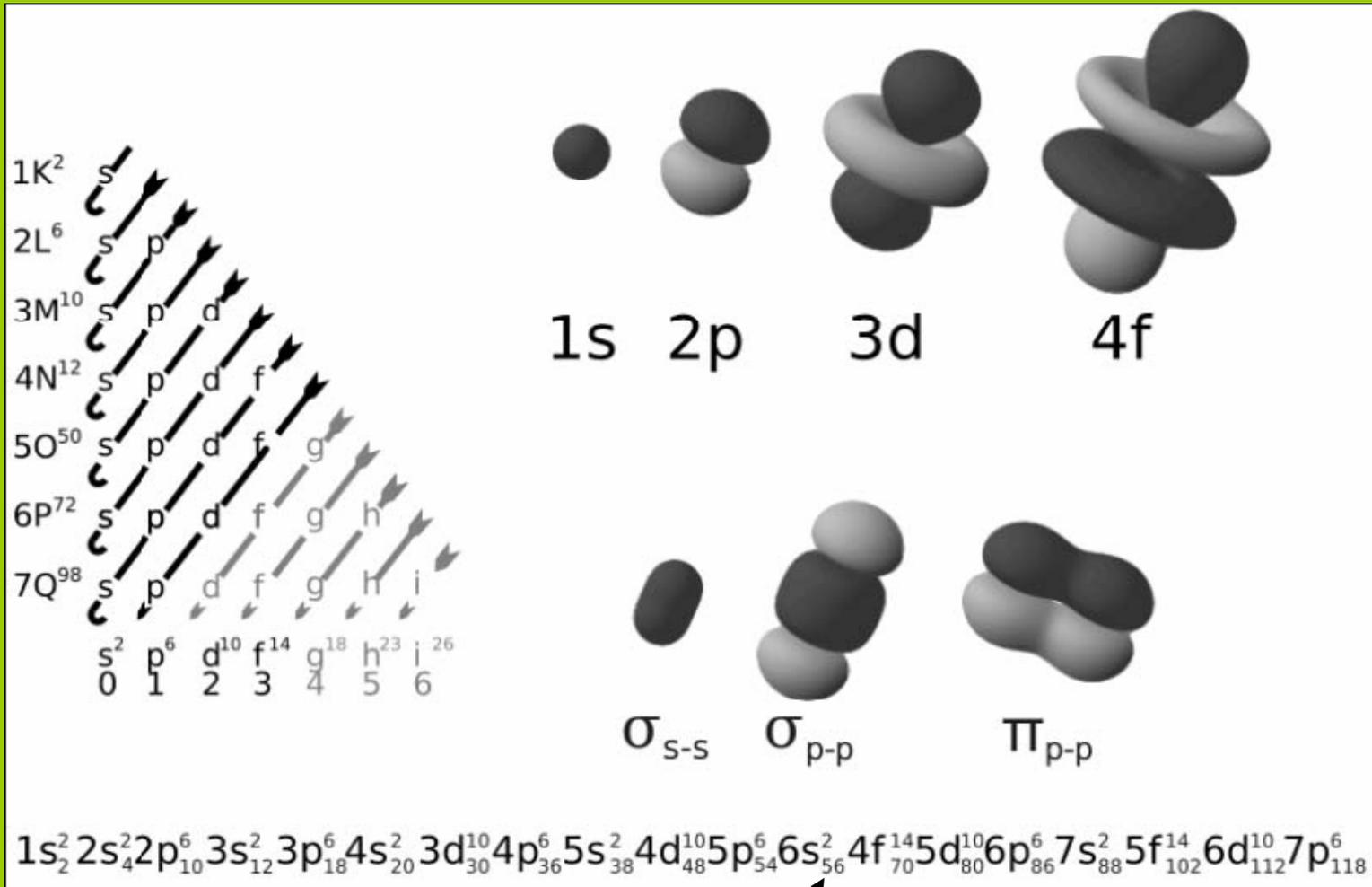
## principio de Aufbau

**subcapa 2p** tres niveles energéticos, 2px, 2py, 2pz.

orbital **2p** hasta seis electrones,

un electrón en cada uno antes que alguno llegue a tener dos.

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^2 5f^{14} 6d^{10} 7p^6$



Columna de gases nobles

REGLA DEL SERRUCHO: 1s → 2s → 2p → 3s → 3p → 4s → 3d → 4p → 5s -----

# Configuraciones atómicas $p^n$ y $d^n$

$p^1$ :  $^2P$

$p^2$ :  $^1S, ^1D, ^3P$

$p^3$ :  $^2P, ^2D, ^4S$

$p^4$ :  $^1S, ^1D, ^3P$

$p^5$ :  $^2P$

$d^1, d^9$ :  $^2D$

$d^2, d^8$ :  $^1S, ^1D, ^1G, ^3P, ^3F$

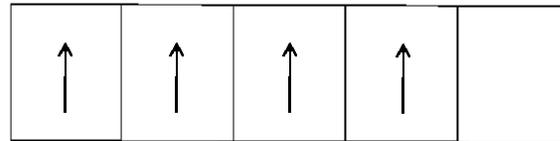
$d^3, d^7$ :  $^2P, ^2D$  (twice),  $^2F, ^2G, ^2H, ^4P, ^4F$

$d^4, d^6$ :  $^1S$  (twice),  $^1D$  (twice),  $^1F, ^1G$  (twice),  $^1I, ^3P$  (twice)

$^3D, ^3F$  (twice),  $^3G, ^3H, ^5D$

$d^5$ :  $^2S, ^2P, ^2D$  (three times),  $^2F$  (twice),  $^2G$  (twice),

$^2H, ^2I, ^4P, ^4D, ^4F, ^4G, ^6S$



$m_l$     2    1    0    -1    -2

Microestado  $d^4$ ;  $M_l=2$ ,  
 $M_s=2$

---

 $2S + 1$ 

Name

 $2S + 1$ Name

---

1

Singlet

6

Sextet

2

Doublet

7

Septet

3

Triplet

8

Octet

4

Quartet

9

Nonet

5

Quintet

10

Decet

---

$$\begin{aligned} \langle H_{\text{so}} \rangle &= \zeta \langle \mathbf{L} \cdot \mathbf{S} \rangle = \zeta \langle nJM_JLS | \mathbf{L} \cdot \mathbf{S} | nJM_JLS \rangle \\ &= \frac{\zeta [J(J+1) - L(L+1) - S(S+1)]}{2}. \end{aligned}$$

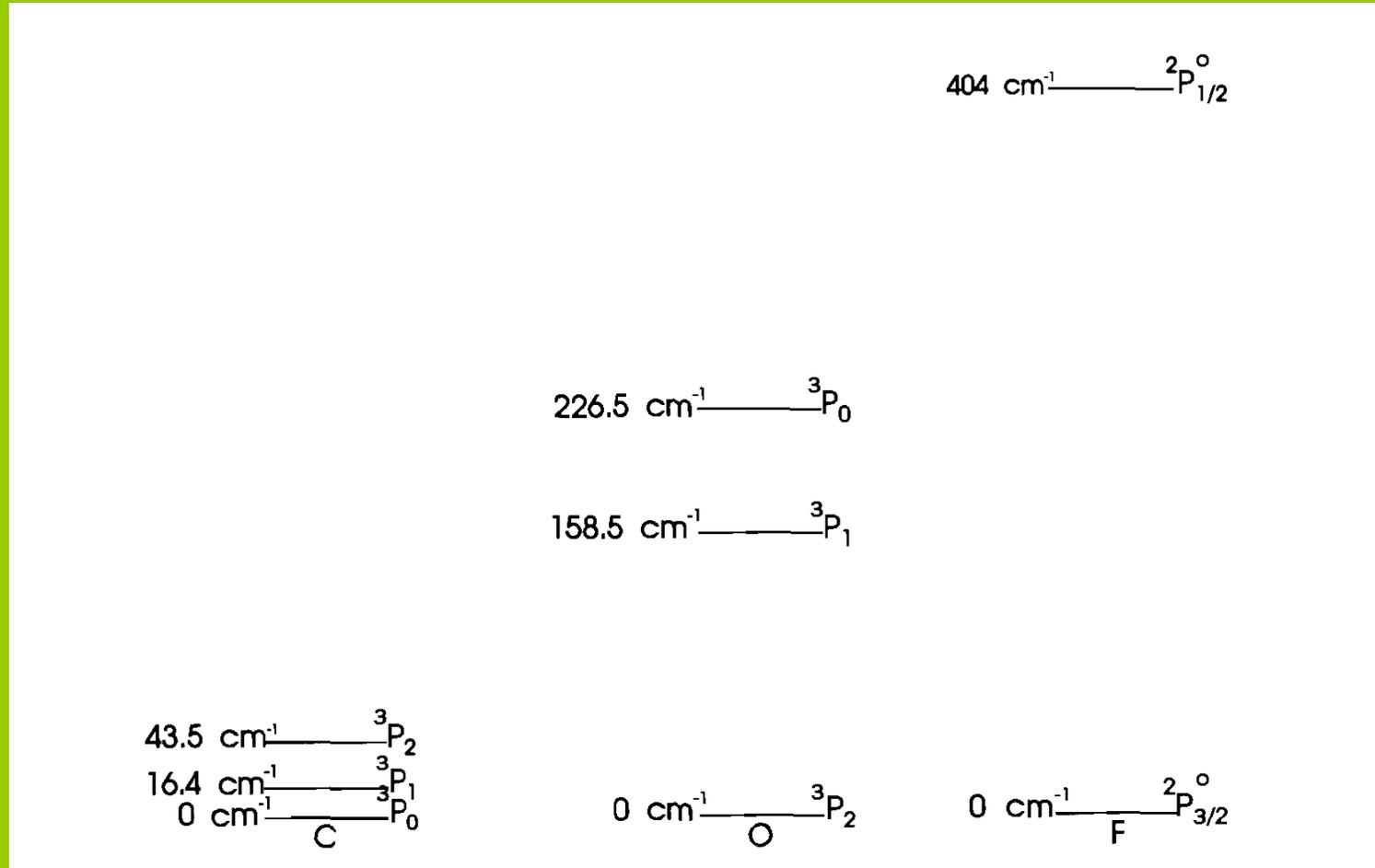
$$E_{J+1} - E_J = \frac{\zeta [(J+1)(J+2) - J(J+1)]}{2} = \zeta(J+1).$$

Intervalo de Landé



Valores permitidos de J: L+S, L+S-1, ..... | L-S|

# Splitting de los multipletes mas bajos de C, O, F (Landé)



C:  $1s^2, 2s^2 2p^2$

O:  $1s^2, 2s^2 2p^4$

F:  $1s^2, 2s^2 2p^5$

$2S+1L_J$

## Efecto Zeeman

$$\boldsymbol{\mu}_L = \gamma \mathbf{L}.$$

$$|\mathbf{L}| = [L(L + 1)]^{1/2} \hbar$$

$$|\boldsymbol{\mu}_L| = -\left(\frac{e\hbar}{2m_e}\right) \sqrt{L(L + 1)} = -\mu_B \sqrt{L(L + 1)},$$

$$\boldsymbol{\mu}_S = g_e \gamma \mathbf{S} = g_e \left(\frac{-\mu_B}{\hbar}\right) \mathbf{S},$$

$$g_e = 2.0023$$

Campo  $\mathbf{B}$  externo

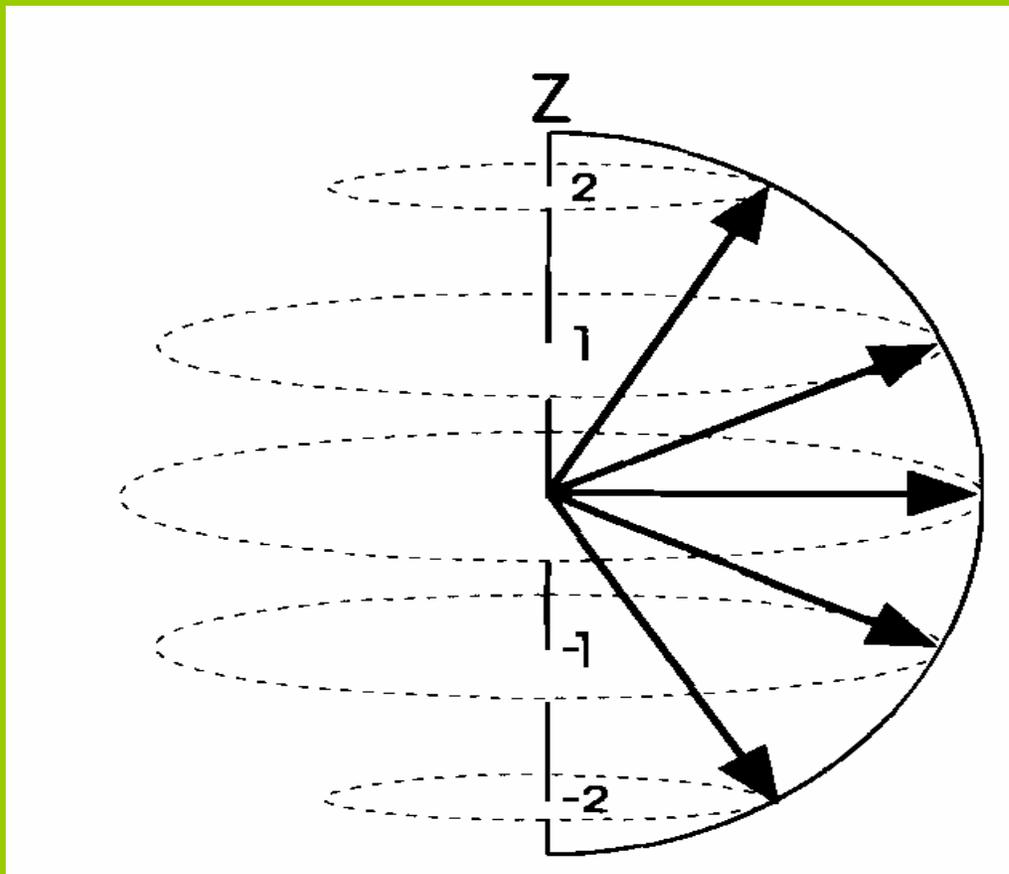
$$\hat{H}' = -\boldsymbol{\mu} \cdot \mathbf{B}$$

Momento magnético nuclear:

$$\boldsymbol{\mu}_I = \gamma_I \mathbf{I} = g_I \frac{\mu_N}{\hbar} \mathbf{I}$$

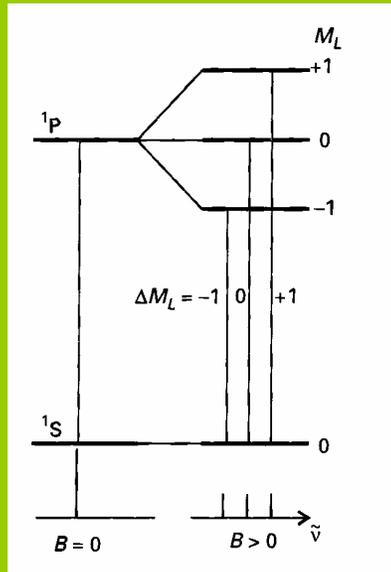
$$\mu_N = \frac{e\hbar}{2m_p}$$

$$\nu = \frac{\Delta(\boldsymbol{\mu} \cdot \mathbf{B})}{\hbar}$$



ZEEMAN normal (**singletes**)  
para sistema de muchos electrones

$$H^{(1)} = -m_z \mathcal{B} = -\gamma_e (l_{z1} + l_{z2} + \dots) \mathcal{B} = -\gamma_e L_z \mathcal{B}$$



$${}^1P \rightarrow {}^1S$$

Intervalo:  $\mu_L B$   
Independiente de L

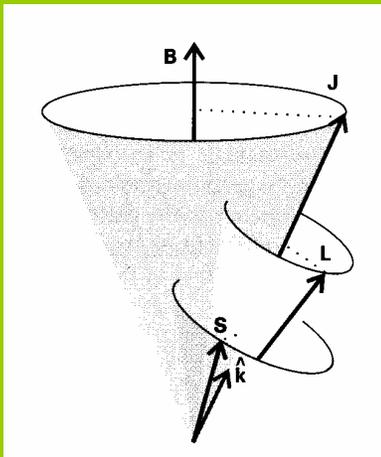
$$\Delta M_L = \pm 1$$

Luz polarizada perpend a **B**

$$\Delta M_L = 0$$

Luz polarizada paralela a **B**

## EFECTO ZEEMAN ANOMALO



$$H^{(1)} = -\mathbf{m}_{\text{orbital}} \cdot \mathbf{B} - \mathbf{m}_{\text{spin}} \cdot \mathbf{B} = -\gamma_e (\mathbf{L} + 2\mathbf{S}) \cdot \mathbf{B}$$

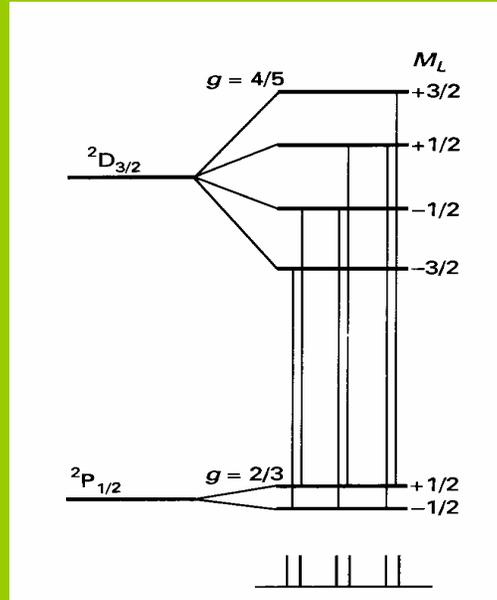
(el momento de **spin** es no nulo)

$$\begin{aligned}\boldsymbol{\mu}_J &= \left[ \boldsymbol{\mu}_S \cdot \frac{\mathbf{J}}{|\mathbf{J}|^2} + \frac{\boldsymbol{\mu}_L \cdot \mathbf{J}}{|\mathbf{J}|^2} \right] \mathbf{J} \\ &= \left[ \gamma(g_s \mathbf{S} + \mathbf{L}) \cdot \frac{\mathbf{J}}{|\mathbf{J}|^2} \right] \mathbf{J},\end{aligned}$$

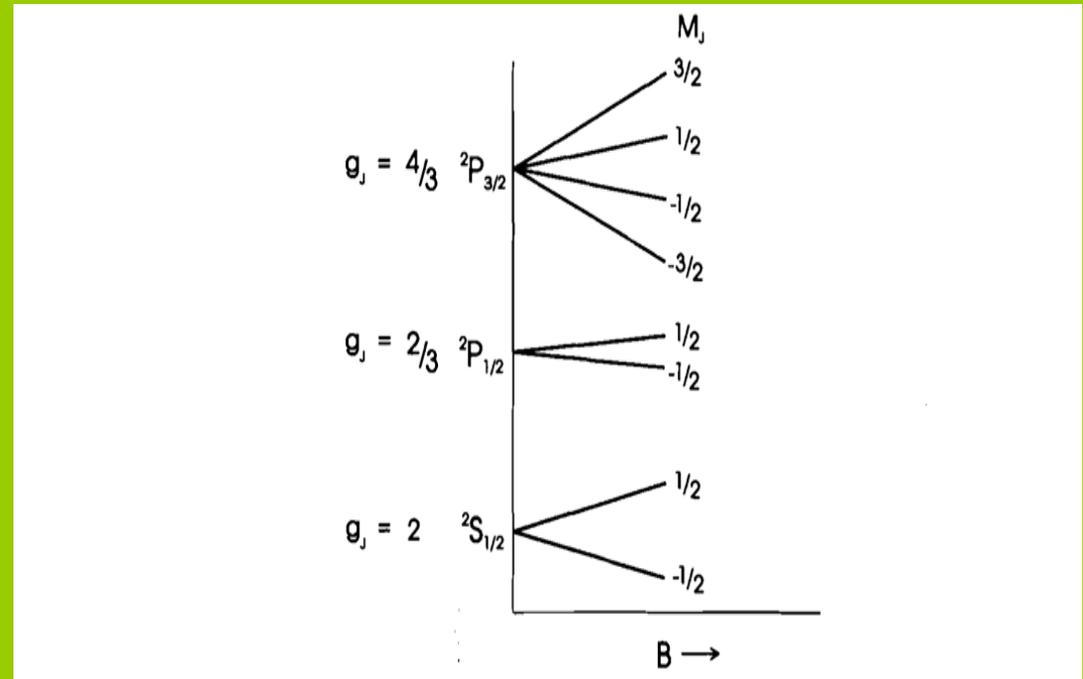
$$H^{(1)} = -g_J \gamma_e \mathbf{J} \cdot \mathbf{B}$$

$$\begin{aligned}H^{(1)} &= -\gamma_e (\mathbf{L} + 2\mathbf{S}) \cdot \mathbf{B} \\ &= -\gamma_e \left\{ 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)} \right\} \mathbf{J} \cdot \mathbf{B}\end{aligned}$$

## Zeeman normal



## Zeeman (anómalo) para los primeros 3 estados de un alcalino



$$\nu_L = \frac{\mu_B B}{h}$$

$$E_{M_J} = \langle \hat{H}' \rangle = -\langle \mu_J \cdot B \rangle = g_J \frac{\mu_B}{\hbar} \langle \mathbf{J} \cdot \mathbf{B} \rangle = g_J \frac{\mu_B B}{\hbar} \langle J_z B_z \rangle = g_J \mu_B M_J B,$$

Poca utilidad en espectroscopía atómica pq depende de J