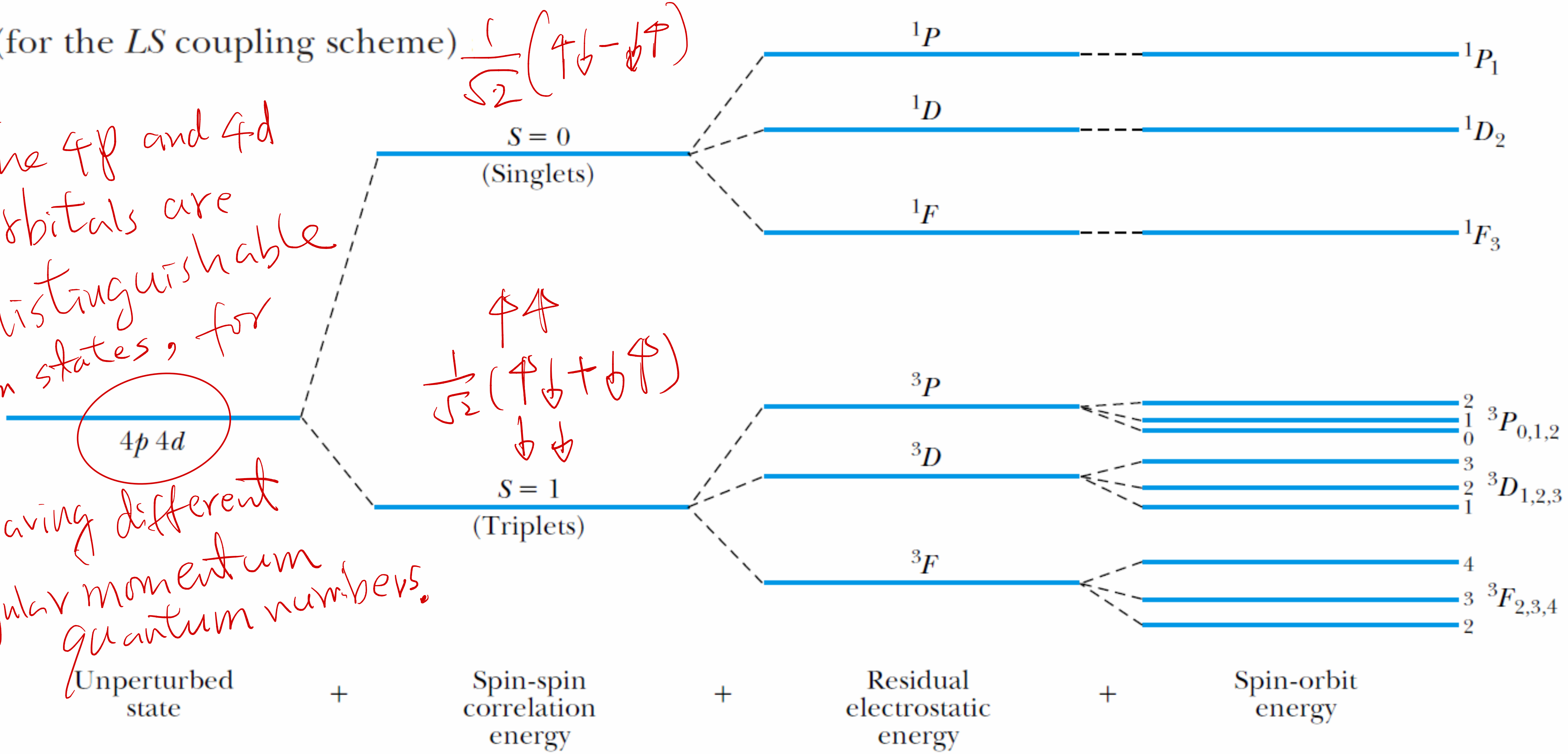
The Atomic states

(for the LS coupling scheme) $\frac{1}{\sqrt{2}}(\uparrow\downarrow - \downarrow\uparrow)$



The 4p and 4d orbitals are distinguishable quantum states, for having different angular momentum quantum numbers.

$\uparrow\uparrow$

$\frac{1}{\sqrt{2}}(\uparrow\downarrow + \downarrow\uparrow)$

$\downarrow\downarrow$

Figure 8.9 Schematic diagram indicating the increasing fine-structure splitting due to different effects. This case is for an atom having two valence electrons, one in the $4p$ and the other in the $4d$ state. The energy is not to scale. *From R. B. Leighton,* Principles of Modern Physics, *New York: McGraw-Hill (1959), p. 261. Used with permission.*

Transition Matrix element

$\langle f | H_{int} | i \rangle$

$= \langle f | (-e\vec{r}\cdot\vec{E}) | i \rangle$

for the electric dipole interaction

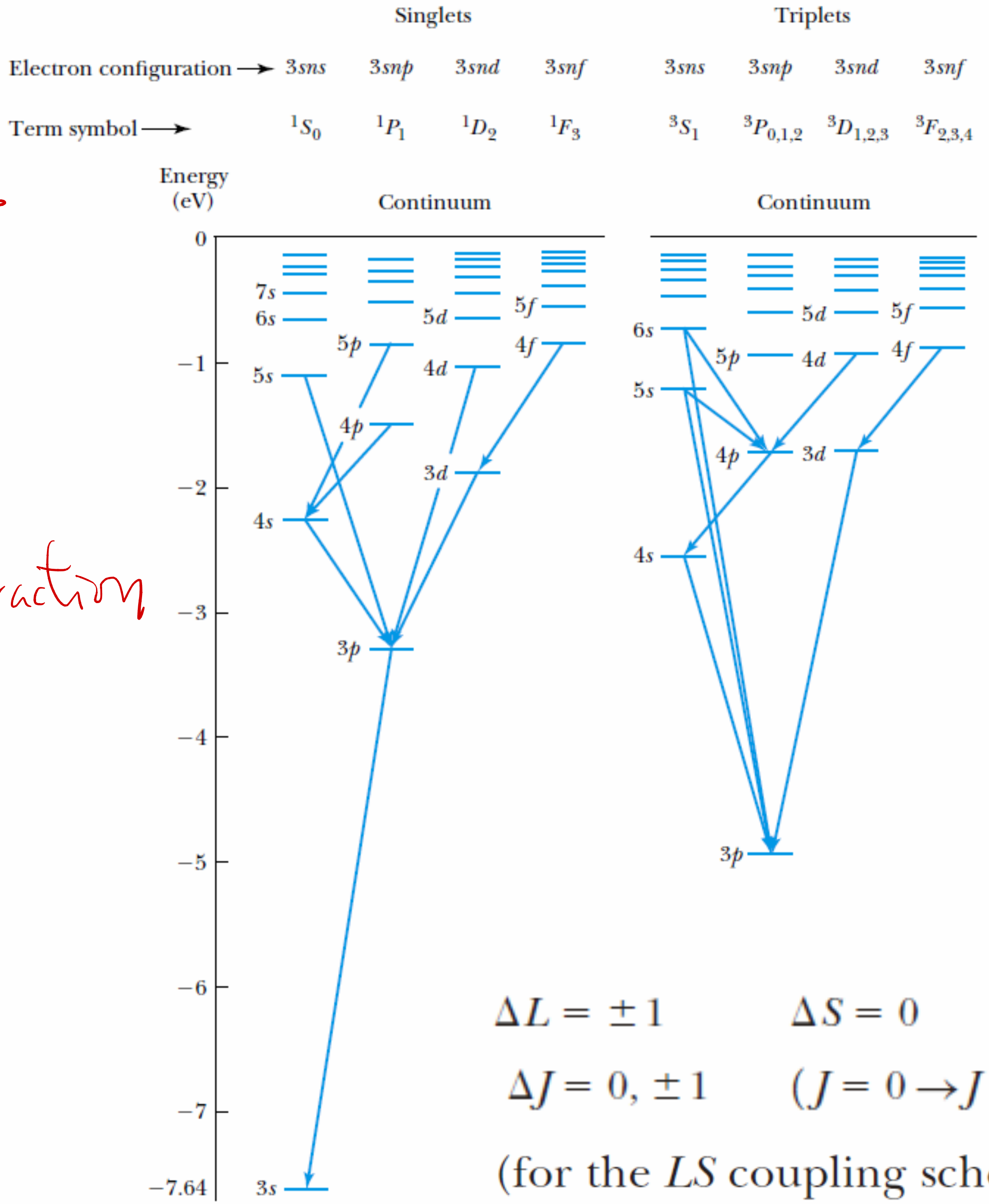


Figure 8.10 Energy-level diagram for magnesium (two-electron atom) with one electron in the 3*s* subshell and the other electron excited into the $n\ell$ subshell indicated. The singlet and triplet states are separated, because transitions between them are not allowed by the $\Delta S = 0$ selection rule. Several allowed transitions are indicated.

$\Delta L = \pm 1 \qquad \Delta S = 0$

$\Delta J = 0, \pm 1 \qquad (J = 0 \rightarrow J = 0 \text{ is forbidden})$

(for the *LS* coupling scheme)

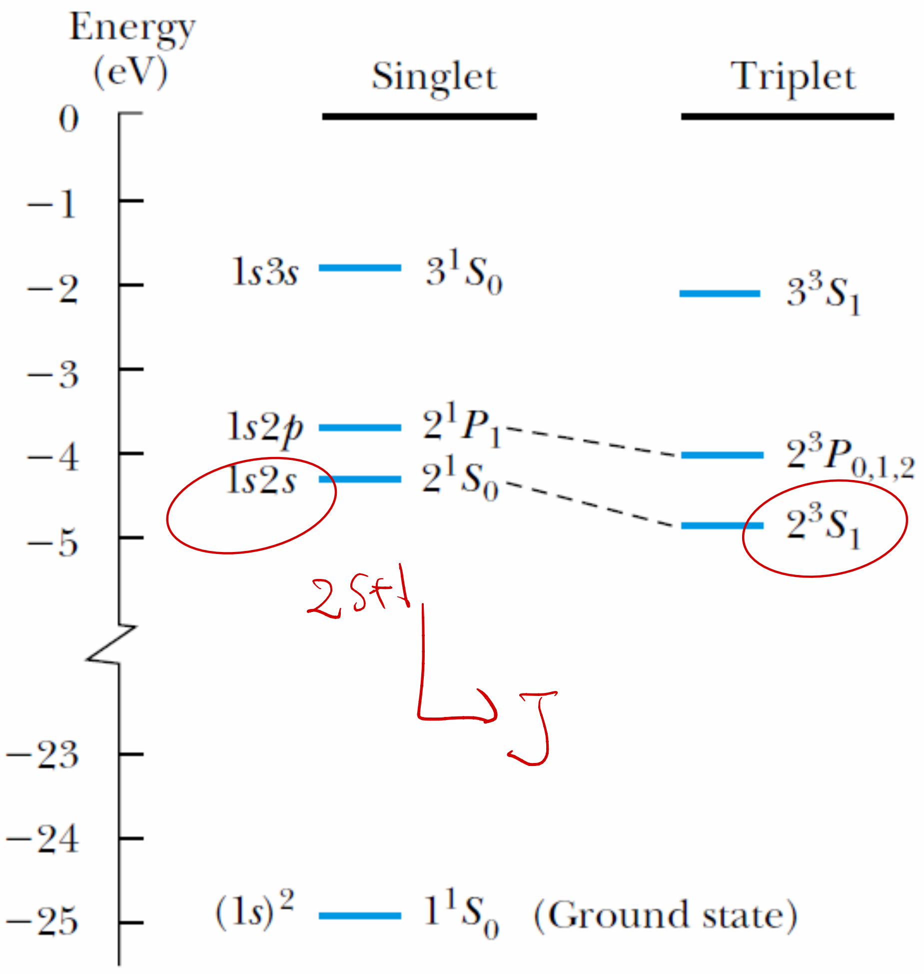


Figure 8.13 The low-lying atomic states of helium are shown. The ground state ($^1S_0$) is some 20 eV below the grouping of the lowest excited states. The level indicated by $^3P_{0,1,2}$ is actually three states ($^3P_0$, $^3P_1$, $^3P_2$), but the separations are too small to be indicated.

2^3S_1 is allowed because 1s and 2s are in different n shells, so that they are is distinguishable states.

Two electrons 1s2s

① $l_1 = 0$, $s_1 = \frac{1}{2}$

② $l_2 = 0$, $s_2 = \frac{1}{2}$

$\Rightarrow \vec{L} = \vec{L}_1 + \vec{L}_2$; $\vec{S} = \vec{S}_1 + \vec{S}_2$

($l = 0$) ($S = 0, 1$)

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

($J = 0, 1$)

$\Rightarrow$ 2^1S_0 & 2^3S_1

What are the possible energy states for atomic carbon?

Strategy The element carbon has two $2p$ subshell electrons outside the closed $2s^2$ subshell. Both electrons have $\ell = 1$, so we have $L = 0$, 1, or 2 using the LS coupling scheme. The spin angular momentum is $S = 0$ or 1.

$S=0$ (antisymmetric) $\frac{1}{\sqrt{2}}(\uparrow\downarrow - \downarrow\uparrow)$

$S=1$ (symmetric) $\uparrow\downarrow$, $\frac{1}{\sqrt{2}}(\uparrow\downarrow + \downarrow\uparrow)$, $\downarrow\downarrow$

spin wave function

Spatial (orbital) wave function

$$(-1)^L = \begin{cases} -1, & \text{antisymmetric} \\ 1, & \text{symmetric} \end{cases}$$

$^{2S+1}L_J$

S	L	J	Spectroscopic Notation	
0	0	0	$^1S_0$	
	1	1	$^1P_1$	$S=0$, $L=1$ Not allowed
	2	2	$^1D_2$	
1	0	1	$^3S_1$	$S=1$, $L=0$ Not allowed
	1	0, 1, 2	$^3P_{0,1,2}$	
	2	1, 2, 3	$^3D_{1,2,3}$	$S=1$, $L=2$ Not allowed

For fermions (such as electrons),

Total wave function

$\equiv$ (spin wave func.) $*$ (spatial, orbital wave func.)

$=$ anti-symmetric

(Pauli Exclusion Principle)

$\Rightarrow$ Require $\boxed{(-1)^{S+1} \cdot (-1)^L = -1}$