Problem 1.

a) Hund's rule 1. Consider partially filled shells

$\Longrightarrow 4d^4$, 4 equivalent d electrons.

Hund's rule 2. Highest spin possible.

with 4 electrons ($s=\frac{1}{2}, m_s=\frac{1}{2}, -\frac{1}{2}$).

highest $M_S = 4 \times (m_s=\frac{1}{2}) = 2 \Longrightarrow$ highest $S=2$.

Hund's rule 3: highest L value for highest S

$M_L = \Sigma m_\ell$; m_ℓ's must differ because all m_s equal. possible m_ℓ $-2,-1,0,1,2$.

highest 4 m_ℓ's $\Rightarrow M_L = 2+1+0-1 = 2. \Rightarrow L=2$.

$\Longrightarrow$ ground term ^5D

Hund's rule 4: shell less than half-filled $\Rightarrow$ lowest J value is ground level.

$J = 0,1,2,3,4. \Longrightarrow$ ground level $\boxed{^5D_0}$

b) idem $4d^5 \Longrightarrow S' = \frac{5}{2}$ $L=0$

$5s \Longrightarrow S=\frac{1}{2}$ $\ell=0$

sum $\Longrightarrow$ $\boxed{S' = 2,3 \quad \& \quad L=0}$

highest spin 3 $\Longrightarrow$ $\boxed{^7S_3}$

c) $\vec{F} = \vec{I} + \vec{J}$ $I = 7/2$, $J=3$.

$\Longrightarrow F = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \frac{7}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}$.

number of states $= \sum_F \# m_f = \sum_F (2F+1)$

$= (2I+1)(2J+1) = 8 \times 7 = 56.$

Problem 2

a) $1s2s^2 2p^6 \Longrightarrow 1s^2 2s^2 2p^5 + h\nu$ $\Delta\ell = \pm 1$ for radiative decay

b) $1s2s^2 2p^6 \Longrightarrow 1s^2 2p^6$ in Auger decay, the transition with the smallest ΔE prevails

[note: $1s^2 2p^6 \longrightarrow 1s^2 2s 2p^4$ if Auger decay is possible

$1s^2 2s^2 2p^4$ radiative

or $1s^2 2s^2 2p^4$ in 2 radiative decays]

2c) For low-Z elements Auger decay is more likely than radiative decay.
$\Longrightarrow$ thus Auger decay.

Problem 3

check whether the wavefunctions can be constructed as products of $(\alpha|0\rangle + \beta|1\rangle)(\gamma|0\rangle + \delta|1\rangle)$.

a) no $\Longrightarrow$ entangled

b) yes $\Longrightarrow$ $\alpha = \beta = \gamma = \delta = 1$

2d $\frac{80}{3} = 13.6 \frac{Z_{eff}^2}{n^4}$
$\Longrightarrow Z_{eff} = 5.6$

2e full shielding by $1s^2 2s^2 \Rightarrow Z = 10 \Rightarrow 6$
$\Delta Z_{eff} = 0.4$ from 2 el. thus 0.2/el

2f $Ne^{3+} \rightarrow Ne^{4+}$ $1s^2 2s^2 2p^2$
$E^{4+} = \left(13.6 \frac{5.8^2}{16}\right) \times 2 =$ 57.2 eV.
$80 - 57.2 = 22.8\,eV$

Problem 4

$\psi(t=0) = |2\rangle$.

a) R_1 resonant with $|2\rangle \leftrightarrow |1\rangle$.

$\psi(t\tfrac{\pi}{2}) = \cos\frac{\pi}{4}|2\rangle - i\sin\frac{\pi}{4}|1\rangle$.

$= \frac{1}{2}\sqrt{2}|2\rangle - i\frac{1}{2}\sqrt{2}|1\rangle$

b) R? resonant with $|2\rangle \leftrightarrow |3\rangle$.

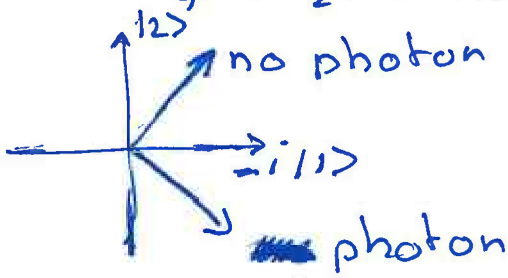
if photon $\xrightarrow{2\pi \text{ pulse}}$ $|2\rangle = \cos\pi|2\rangle = -|2\rangle$.

$\psi = -\frac{1}{2}\sqrt{2}|2\rangle - \frac{1}{2}i\sqrt{2}|1\rangle$.

no photon

$\psi = \frac{1}{2}\sqrt{2}|2\rangle - \frac{1}{2}i\sqrt{2}|1\rangle$

c

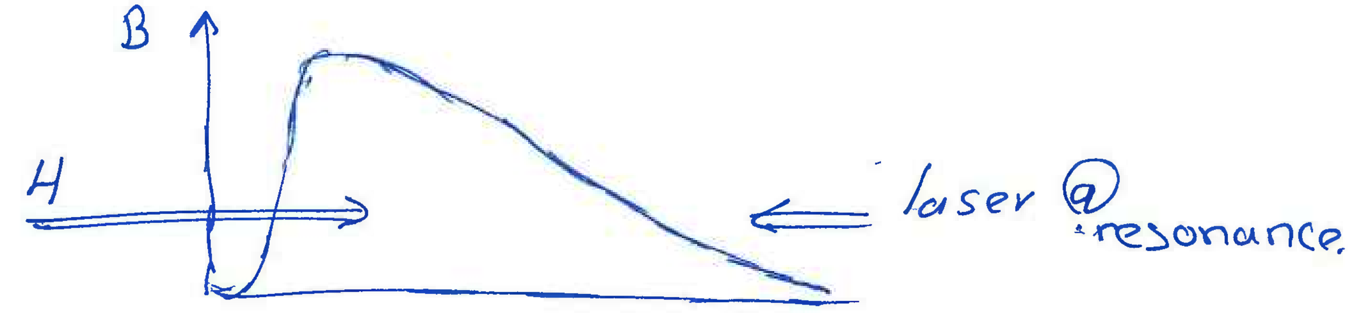


R_2 resonant with $|2\rangle \leftrightarrow |1\rangle$.

add another $\frac{\pi}{2}$ pulse to end up in either $-i|1\rangle$ or $-|2\rangle$.

Problem 5

a)



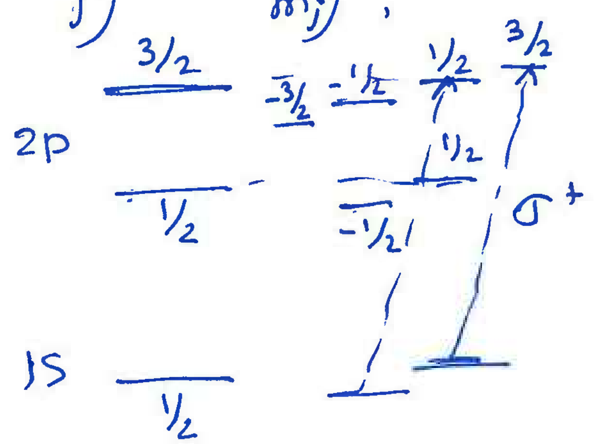
B field induces Zeeman shift in atom which should exactly compensate the Doppler shift along the ~~p~~ r direction.

b) no nuclear spin.

1s $\ell = 0$, $s = \frac{1}{2} \Rightarrow j = \frac{1}{2}$; $m_j = \pm\frac{1}{2}$

2p $\ell = 1$, $s = \frac{1}{2} \Rightarrow j = \frac{1}{2}, \frac{3}{2}$ $m_j = \pm\frac{1}{2}$ $m_j = \pm\frac{1}{2}, \pm\frac{3}{2}$.

$|j\rangle$ $|m_j\rangle$,



σ^+ laser light between 1s $j = \frac{1}{2}$ and 2p $j = \frac{3}{2}$ after a few pump cycles only the $(j=\frac{1}{2})\ m_j = \frac{1}{2} \leftrightarrow m_j = \frac{3}{2} (j = \frac{3}{2})$ remains

c) $v_r = \dfrac{h}{\lambda m} = 3.3\ m/s$

$\dfrac{2250\ m/s}{3.3\ m/s} \simeq 680$ photons

d) cycling rate $2 \times 1.6\ ns \Rightarrow 3.2\ ns$, 680 photons $\Big\} \Rightarrow 2.176\ \mu s = t$

$v = v_0 - at$ $v = 0$ (stopped) $\Rightarrow a = -v_0/t = 1 \times 10^9\ m/s^2$.

$L = v_0 t - \frac{1}{2} a t^2 \Rightarrow L = 5\ mm$

e) atom will ~ 2 photons/pulse (~6.5 m/s) and then travels for 20 ms (appr. 40 m) before the next pulse.

$\Longrightarrow$ laser is <u>not</u> suitable.