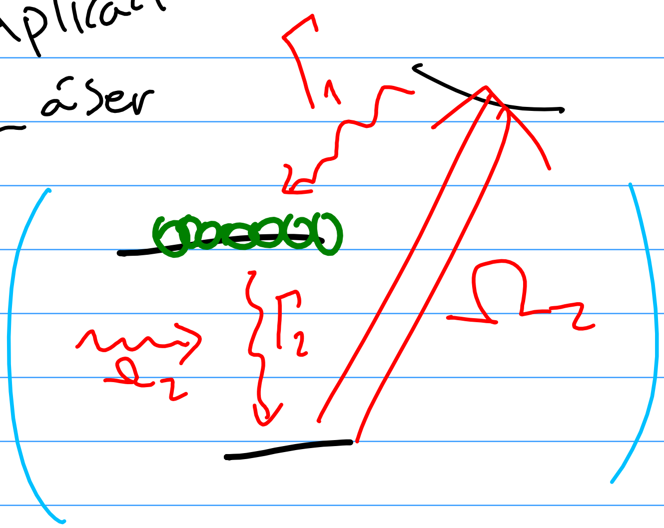
Átomo de 3 niveles

Aplicación.

Láser

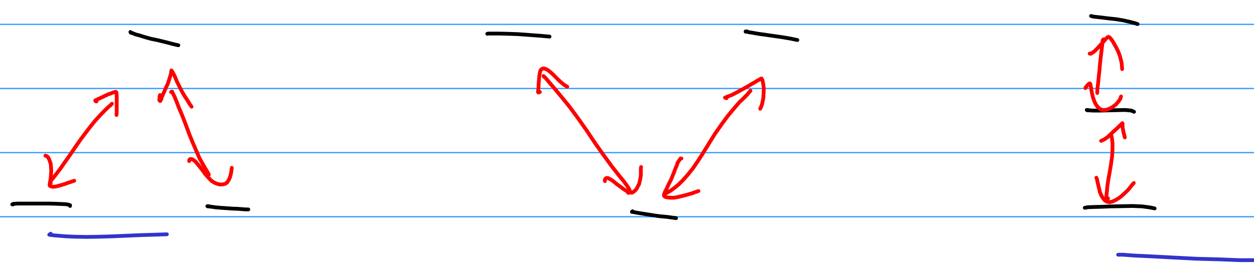


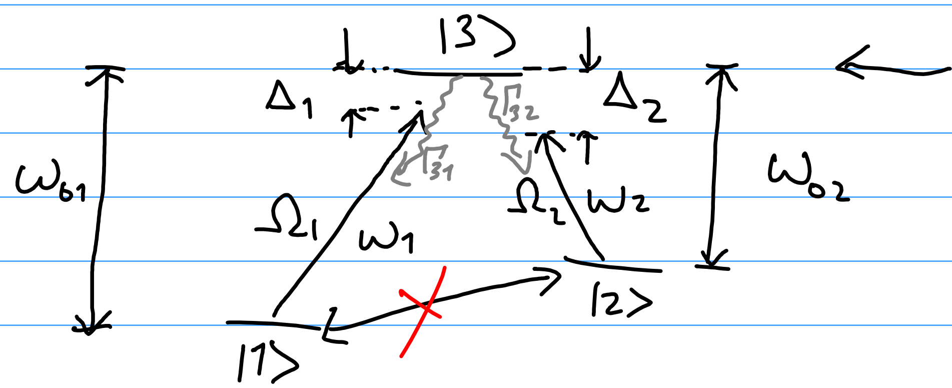
En átomo de 2 niveles.

$$\rho_{ee}(t\to\infty) = \frac{\Omega^2/\Gamma^2}{1+\left(\frac{2\delta}{\Gamma}\right)^2+2\left(\frac{\Omega}{\Gamma}\right)^2}$$

Cuando $\Omega\to\infty$ $\rho_{ee}\to\frac{1}{2}$

Hay 3 tipos: Λ V I





$$\vec{\mathcal{E}}(\vec{r},t) = \hat{\epsilon}_1\mathcal{E}_{01}\cos(\vec{k}_1\cdot\vec{r}-\omega_1 t)+\hat{\epsilon}_2\mathcal{E}_{02}\cos(\vec{k}_2\cdot\vec{r}-\omega_2 t)$$
$$= \mathcal{E}^{(+)}(\vec{r},t) + \mathcal{E}^{(-)}(\vec{r},t)$$

$$\vec{\mathcal{E}}^{(\pm)}(\vec{r},t) = \frac{1}{2}\left(\hat{\epsilon}_1\mathcal{E}_{01}e^{\pm i\vec{k}_1\cdot\vec{r}}e^{\mp i\omega_1 t}+\hat{\epsilon}_2\mathcal{E}_{02}e^{\pm i\vec{k}_2\cdot\vec{r}}e^{\mp i\omega_2 t}\right)$$

$$H_A = -\hbar\omega_{01}|1\rangle\langle 1| - \hbar\omega_{02}|2\rangle\langle 2|$$

$$H_{AF} = -\vec{d}\cdot\vec{\mathcal{E}} \overset{RWA}{\simeq} -\vec{d}^{(+)}\cdot\vec{\mathcal{E}}^{(-)} - \vec{d}^{(-)}\cdot\vec{\mathcal{E}}^{(+)}$$

$$\vec{d} = \mathbb{1}\,\vec{d}\,\mathbb{1} = \left(|1\rangle\langle 1| + |2\rangle\langle 2| + |3\rangle\langle 3|\right)\vec{d}\left(|1\rangle\langle 1| + |2\rangle\langle 2| + |3\rangle\langle 3|\right)$$

$$= \langle 1|\vec{d}|3\rangle \underbrace{|1\rangle\langle 3|}_{\sigma_{13}} + \langle 2|\vec{d}|3\rangle \underbrace{|2\rangle\langle 3|}_{\sigma_{23}} + \langle 3|\vec{d}|1\rangle \underbrace{|3\rangle\langle 1|}_{\sigma_{13}^{+}} + \langle 3|\vec{d}|2\rangle \underbrace{|3\rangle\langle 2|}_{\sigma_{23}^{+}}$$

$$\Omega_\alpha = -\frac{\langle \alpha|\hat{\varepsilon}_\alpha\cdot\vec{d}|3\rangle}{\hbar}\mathcal{E}_{0\alpha} \qquad \alpha = 1, 2$$

$$H_{AF} \overset{RWA}{=} \frac{\hbar\Omega_1}{2}\left(\sigma_{13}e^{-i\vec{k}_1\cdot\vec{r}}e^{i\omega_1 t} + \sigma_{13}^{+}e^{i\vec{k}_1\cdot\vec{r}}e^{-i\omega_1 t}\right) + \frac{\hbar\Omega_2}{2}\left(\sigma_{23}e^{-i\vec{k}_2\cdot\vec{r}}e^{i\omega_2 t} + \sigma_{23}^{+}e^{i\vec{k}_2\cdot\vec{r}}e^{-i\omega_2 t}\right)$$

Cambio al marco rotante

Para el átomo de dos niveles usamos

$$U = e^{i\omega t|e\rangle\langle e|} = \begin{array}{cc} |g\rangle & |e\rangle \end{array} \begin{pmatrix} 1 & 0 \\ 0 & e^{i\omega t} \end{pmatrix}$$

$$\tilde{H} = U^{+}HU + i(\partial_t U)U^{+}$$

$$\hbar\begin{pmatrix} 0 & \frac{\Omega}{2}e^{i\omega t} \\ \frac{\Omega}{2}e^{-i\omega t} & \omega_0 \end{pmatrix} \longrightarrow \hbar\begin{pmatrix} 0 & \frac{\Omega}{2} \\ \frac{\Omega}{2} & \omega_0 - \omega \end{pmatrix}$$

Para 3 niveles

$$U = \begin{array}{c} \begin{matrix} |1\rangle & |2\rangle & |3\rangle \end{matrix} \\ \begin{pmatrix} e^{-i\omega_1 t} & 0 & 0 \\ 0 & e^{-i\omega_2 t} & 0 \\ 0 & 0 & 1 \end{pmatrix} \end{array}$$

Calculando $\tilde{H} = U^{+} H U + i(\partial_t U) U^{+}$

$$\tilde{H} = \hbar\Delta_1 |1\rangle\langle 1| + \hbar\Delta_2 |2\rangle\langle 2|$$
$$+ \frac{\hbar}{2}\Omega_1\left(\sigma_{13} e^{-i\vec{k}_1\cdot\vec{r}} + \sigma_{13}^{+} e^{i\vec{k}_1\cdot\vec{r}}\right) + \frac{\hbar\Omega_2}{2}\left(\sigma_{23} e^{-i\vec{k}_2\cdot\vec{r}} + \sigma_{23}^{+} e^{-i\vec{k}_2\cdot\vec{r}}\right)$$

$$\dot{\rho}_{AF} = \frac{1}{i\hbar}\left[\tilde{H}_{AF}^{\text{completo}}, \rho_{AF}\right]$$

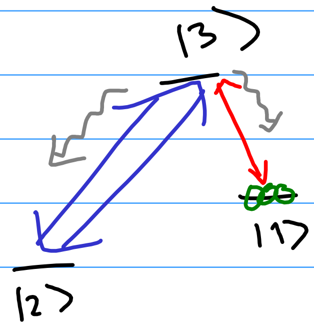
Trazando sobre grados de libertad atómicos

Operador de Lindblad
$\mathcal{L}[A]\rho = A\rho A^{+} - \frac{1}{2}(A^{+}A\rho + \rho A A^{+})$

$$\dot{\rho}_A = \frac{1}{i\hbar}\left[\tilde{H}, \rho_A\right] + \Gamma_{31}\mathcal{L}[\sigma_{13}]\rho_A$$
$$+ \Gamma_{32}\mathcal{L}[\sigma_{32}]\rho_A$$
$$+ \gamma_{2dec}\mathcal{L}[\sigma_{22}]\rho_A$$
$$+ \gamma_{1dec}\mathcal{L}[\sigma_{11}]\rho_A$$
$$+ \gamma_{3dec}\mathcal{L}[\sigma_{33}]\rho_A$$

Ecuación maestra.

Caso de láser de prueba débil:



Usando $\rho_{11} \approx 1$ podemos encontrar la respuesta óptica

Respuesta óptica

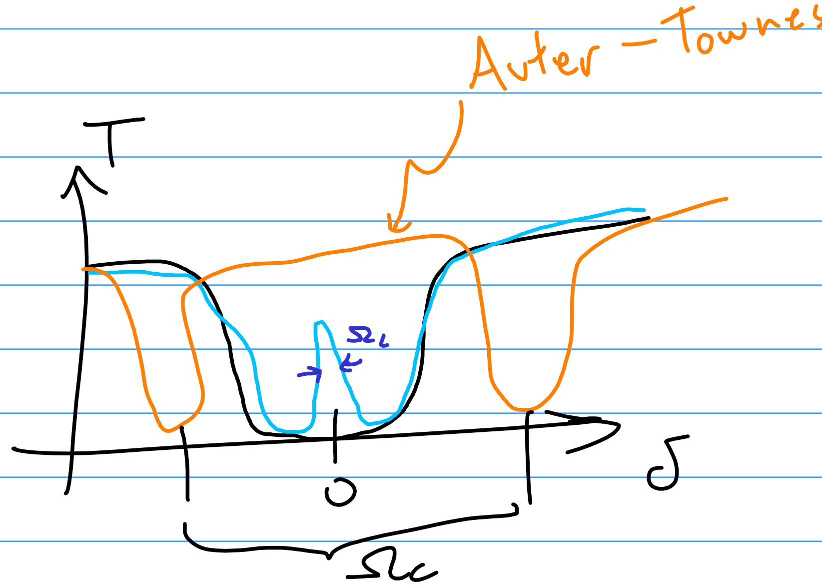
$$\langle P^{(+)} \rangle = n \langle \vec{d}^{(+)} \rangle$$

densidad numerica de átomos

$$P^{(+)} = \epsilon_0 \chi(\omega) \mathcal{E}^{(+)}$$

$$n_{refracción} = \sqrt{\epsilon_r \mu_r} \simeq \sqrt{\epsilon_r} = \sqrt{1+\chi}$$


Ω_c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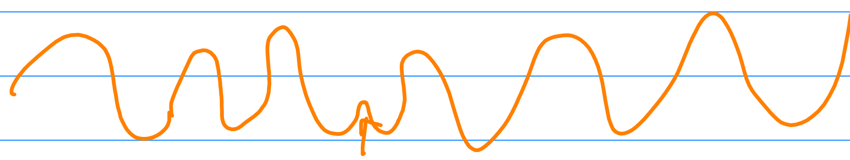

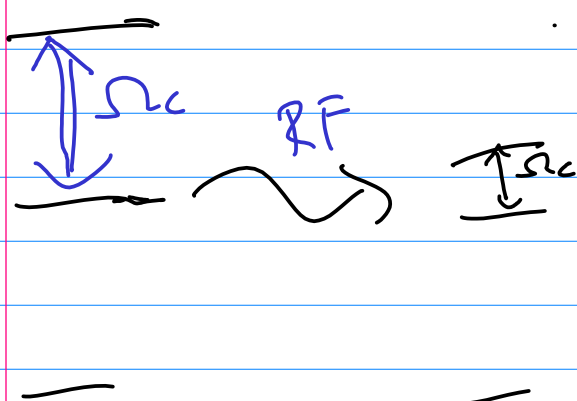
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