$$|\psi(t)\rangle = \sum_n \underset{!!}{c_n(t)} \{ \underbrace{e^{-iE_n^0 t/\hbar} |\phi_n\rangle} \} \quad , \quad H = H_0 + H'$$

$$i\hbar \dot{c}_m = \sum_n c_n(t)\, e^{i(E_m^0-E_n^0)t/\hbar} \underbrace{\langle\phi_m|H'(t)|\phi_n\rangle}_{H'_{mn}}$$

$$c_m(t) = c_m(0) - \frac{i}{\hbar}\sum_n \int_0^t c_n(t')\, e^{i(E_m^0-E_n^0)t'/\hbar} H'_{mn}(t')\, dt' \quad ,$$

Pert. periódica $H'(t) = M e^{i\omega t} + M^\dagger e^{-i\omega t}$

$$c_m(t) = c_m(0) - \frac{i}{\hbar}\sum_n \int_0^t c_n(t')\, e^{i(E_m^0-E_n^0)t'/\hbar} \left(M_{mn} e^{i\omega t'} + M^\dagger_{mn} e^{-i\omega t'}\right) dt'$$

absorción resonante $M^\dagger$, $E_m^0 \simeq E_n^0 + \hbar\omega$

emisión resonante M, $E_m^0 \simeq E_n^0 - \hbar\omega$

Considerar $c_n(t=0) = \delta_{nk}$, k único nivel ocupado. $P_{k\to m}(t) = |c_m(t)|^2 = |\langle\phi_m|\psi\rangle|^2$

Integramos a 1er orden, en forma iterativa, en $\underline{\underline{H'}}$

$$c_m(t) = c_m(0) - \frac{i}{\hbar}\sum_n \int_0^t c_n(0)\, e^{i(E_m^0-E_n^0)t'/\hbar} \left(M_{mn} e^{i\omega t'} + M^\dagger_{mn} e^{-i\omega t'}\right) dt' \quad ,$$ iteración a 1er orden

Sol. iterando a primer orden

$$c_m(t) = c_m(0) - \frac{i}{\hbar}\sum_n c_n(0) \left\{ M_{mn} \frac{e^{i(E_m^0-E_n^0+\omega\hbar)t/\hbar} - 1}{(E_m^0-E_n^0+\hbar\omega)/\hbar} + (M_{nm})^* \frac{e^{i(E_m^0-E_n^0-\hbar\omega)t/\hbar} - 1}{E_m^0-E_n^0-\hbar\omega} \right\}$$

$$c_n(0) = \delta_{nk}$$

$$c_m(t) = -\frac{i}{\hbar}\left\{ M_{mk}\,\frac{e^{i(E_m^0-E_k^0+\hbar\omega)t/\hbar}-1}{(E_m^0-E_k^0+\hbar\omega)/\hbar} + (M_{km})^*\,\frac{e^{i(E_m^0-E_k^0-\hbar\omega)t/\hbar}-1}{(E_m^0-E_k^0-\hbar\omega)/\hbar}\right\}$$

$m \neq k$

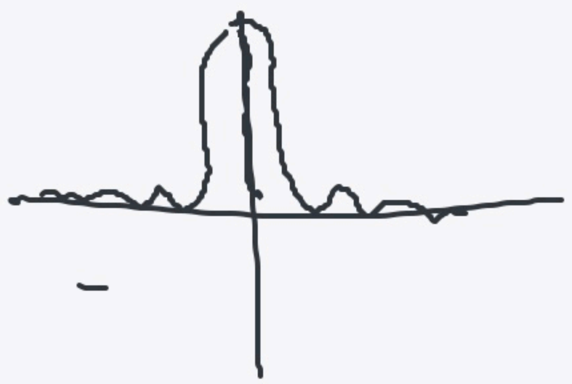
$c_m(0) = 0$

Resonante $E_m^0 \approx E_k^0 \pm \hbar\omega$

crecimiento lineal en t

Consideremos la absorción: $E_m^0 \approx E_k^0 + \hbar\omega$, $\quad c_m(t) = -\frac{i}{\hbar}(M_{km})^* \dfrac{e^{i(E_m^0-E_n^0-\hbar\omega)t/\hbar}-1}{(E_m^0-E_n^0-\hbar\omega)/\hbar}$

$$|c_m(t)|^2 = 4|M_{km}|^2 \frac{\operatorname{sen}^2[(E_m^0-E_n^0-\hbar\omega)t/2\hbar]}{((E_m^0-E_n^0-\hbar\omega)/\hbar)^2}$$



Tiempos grandes: $\dfrac{2\hbar}{\pi t}\dfrac{\operatorname{sen}^2 xt/2\hbar}{x^2} \xrightarrow[t\to\infty]{} \delta(x)$

$$P_{k\to m}(t) = |c_m(t)|^2 = 4\,|M_{km}|^2 \frac{\pi t}{2\hbar}\,\delta(E_k^0+\hbar\omega-E_m^0) \quad \text{absorción}$$

$$\Gamma_{k\to m} = \frac{P_{k\to m}(t)}{t} = \frac{dP_{k\to m}(t)}{dt} = |c_m(t)|^2 = \frac{2\pi}{\hbar}|M_{km}|^2\,\delta(E_k^0+\hbar\omega-E_m^0) \quad \text{absorción}$$

$$\frac{2\pi}{\hbar}|M_{mk}|^2\,\delta(E_k^0-\hbar\omega-E_m^0) \quad \text{emisión}$$

$\psi_{e,\text{continuo}} = L^{-3/2} e^{i\vec{k}\cdot\vec{r}}$, $\hbar\vec{k}$ momento

$k_x = 2\pi n_x/L$, no estados en el rango dk_x, dk_y, dk_z es $\left(\frac{L}{2\pi}\right)^3 dk_x\, dk_y\, dk_z$

y

z

$E_k = E_0 + \hbar\omega$, $\frac{\hbar^2 k^2}{2\mu} = -\frac{\mu e^4}{2\hbar^2} + \hbar\omega$, $\mu \simeq m_e$, $|\vec{k}|$ fijo

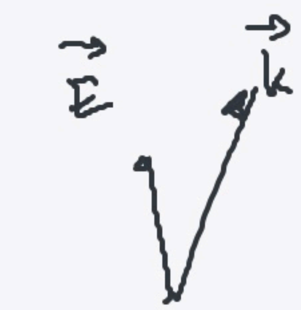
final (inicial, estado mínima energía

$dE_k = d\left(\frac{\hbar^2 k^2}{2\mu}\right) = \frac{\hbar^2}{2\mu} 2k\, dk$

sen θ dθ dφ

$\vec{k} : \theta, \varphi$, $d^3k = k^2 dk\, \text{sen}\,\theta\, d\theta\, d\varphi$

$\rho(E_k) dE_k = \left(\frac{L}{2\pi}\right)^3 d^3k = \left(\frac{L}{2\pi}\right)^3 k^2 dk\, \text{sen}\,\theta\, d\theta\, d\varphi$, $\rho(E_k)\frac{\hbar^2}{\mu} k\, dk = \frac{L^3 k^2}{8\pi^3} dk\, d\Omega_k$



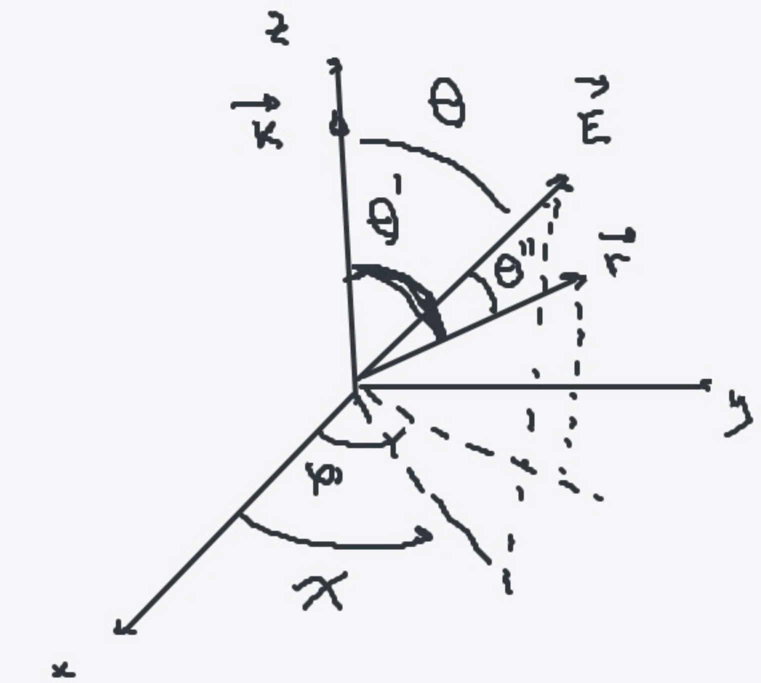
$\rho(E_k) = \frac{\mu L^3}{8\pi^3 \hbar^2} k\, d\Omega_k$

$\langle k | H' | 0 \rangle = \int d^3r\, (\pi a_0^3)^{-1/2} e^{-r/a_0} L^{-3/2} e^{-i\vec{k}\cdot\vec{r}}\, 2E_0 \,\text{sen}\,\omega t\, \hat{E}\cdot\vec{r}\, e$

$\theta' = \widehat{\vec{r},k}$, $\theta'' = \widehat{E,k}$ r: θ', φ'

E: θ, χ

$\hat{E}\cdot\vec{r} = r\cos\theta''$ $\vec{k}\cdot\vec{r} = kr\cos\theta'$



Grabando... | Está colaborando en esta pizarra | Cerrar Pizarra | Vista

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$$\langle k|H'|0\rangle = 2eE_0 \operatorname{sen}\omega t \,(\pi a_0^3 L^3)^{-1/2} \int d^3r\, e^{-r/a_0} e^{-ikr\cos\theta'} r\cos\theta''$$

θ'' : $\hat{E}\cdot\hat{r} = \cos\theta'' = s\theta s\theta' \cos(\varphi'-\chi) + c\theta c\theta'$

$d^3r = r^2 dr\, d\cos\theta'\, d\varphi'$

$\hookrightarrow$ integro en $2\pi \Rightarrow \int_0^{2\pi} d\varphi' \ldots \cos(\varphi'-\chi) = 0$

$\hat{r} = (s\theta' c\varphi', s\theta' s\varphi', c\theta')$

$\hat{E} = (s\theta c\chi, s\theta s\chi, c\theta)$

$\begin{cases} c = \cos \\ s = \operatorname{sen} \end{cases}$

$$\langle k|H'|0\rangle = 2eE_0 \operatorname{sen}\omega t\,(\pi a_0^3 L^3)^{-1/2}\, 2\pi \int dr\, d\theta'\, r^3 e^{-r/a_0} e^{-ikr\cos\theta'} \underline{\cos\theta} \cos\theta' \operatorname{sen}\theta'$$

$$\left\{ \begin{array}{l} \int_0^{\pi} d\theta'\, e^{\alpha\cos\theta'} \cos\theta' \operatorname{sen}\theta' = \int_{-1}^{1} du\, e^{\alpha u} u = \\ \quad \cos\theta' = u \\ \int d^3r \ldots \end{array} \right.$$

$$\langle k|H'|0\rangle = -\frac{64\pi i E_0 k a_0^5 \cos\theta}{(\pi a_0^3 L^3)^{1/2} (1+k^2 a_0^2)^3} \longrightarrow \text{fuerza sobre } e\,!$$

$$\Gamma = \frac{2\pi}{\hbar} \rho |H'|^2$$

Fórmula de Fermi : $\underline{d\Gamma}$ = prob. de transición p.u. de tiempo en la dir, $d\Omega = \dfrac{256\,\mu k^3 e^2 E_0^2 a_0^7 \cos^2\theta\, d\Omega_k}{\pi\hbar^3 (1+k^2a_0^2)^6}$

$$\boxed{\frac{d\Gamma}{d\Omega_k} = \frac{256\,\mu k^3 e^2 E_0^2 a_0^7}{\pi\hbar^3 (1+k^2 a_0^2)^6} \cos^2\theta}$$

NEW

100%

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