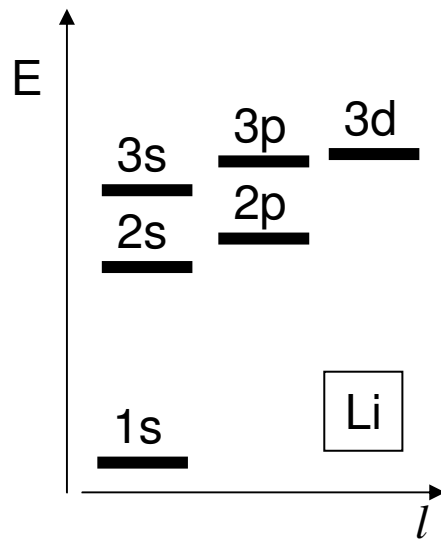


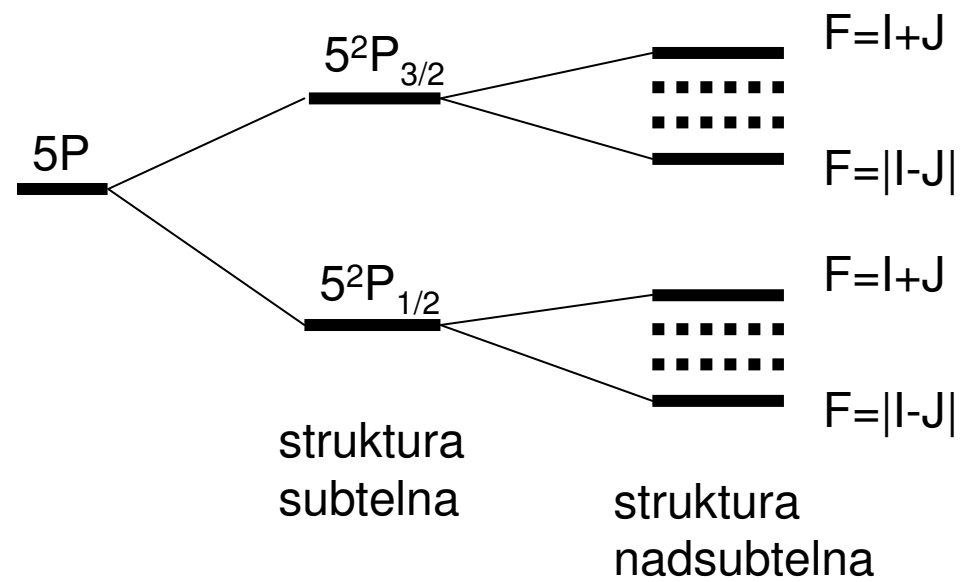
Atom ze spinem i jądrem

Powtórzenie



Ruch w polu ekranowym
znosi degenracje ze względu na l

Powtórzenie



Efekt Zeemana

$$H_B = \frac{\mu_B}{\hbar} (g_S \vec{S} + g_L \vec{L} + g_I \vec{I}) \cdot \vec{B}$$

$\begin{matrix} \nearrow \\ \sim 2 \end{matrix} \quad \begin{matrix} \uparrow \\ \sim 1 \end{matrix} \quad \begin{matrix} \nwarrow \\ \sim 0 \end{matrix}$

$$H_{IJ} \propto \hat{\vec{J}} \cdot \hat{\vec{I}}$$

Efekt Zeemana

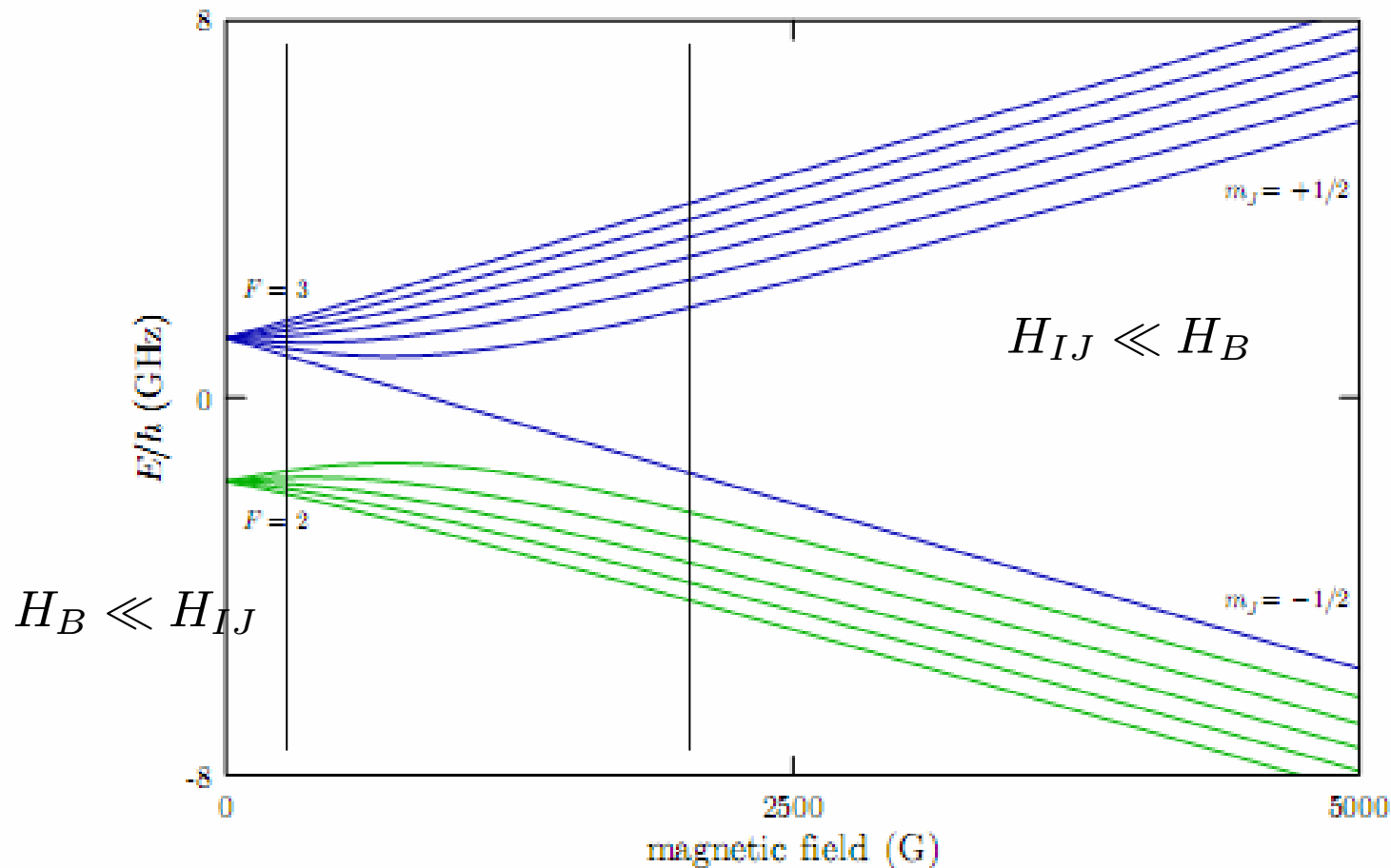
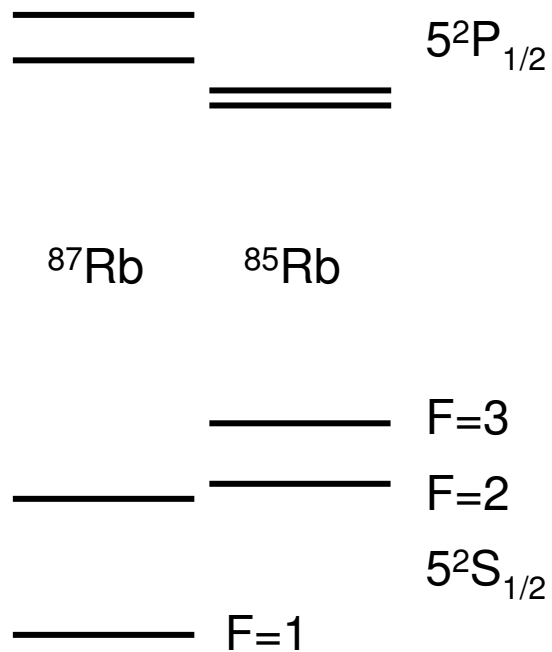
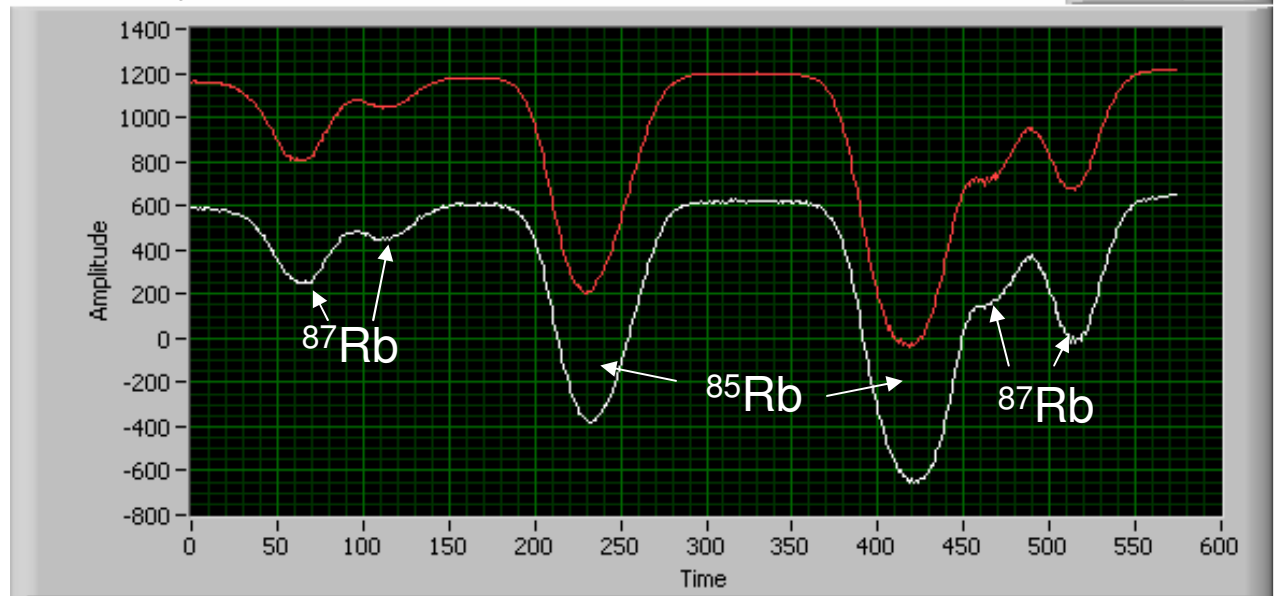


Figure 4: Rubidium 85 $5^2S_{1/2}$ (ground) level hyperfine structure in an external magnetic field. The levels are grouped according to the value of F in the low-field (Zeeman) regime and m_J in the strong-field (hyperfine Paschen-Back) regime.

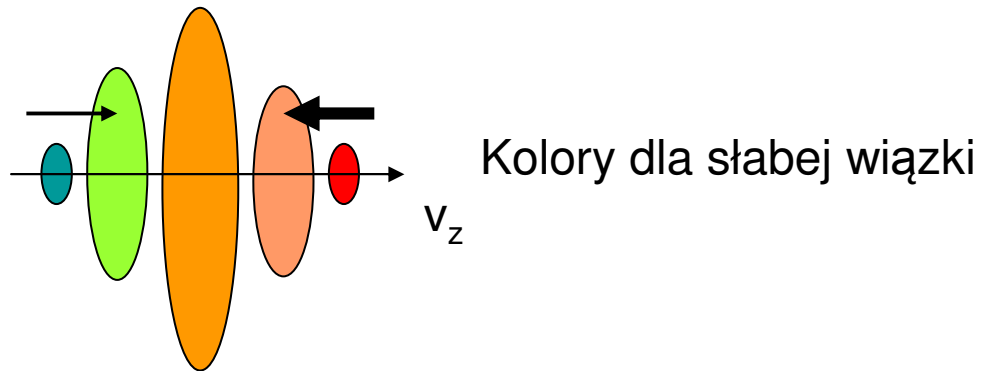
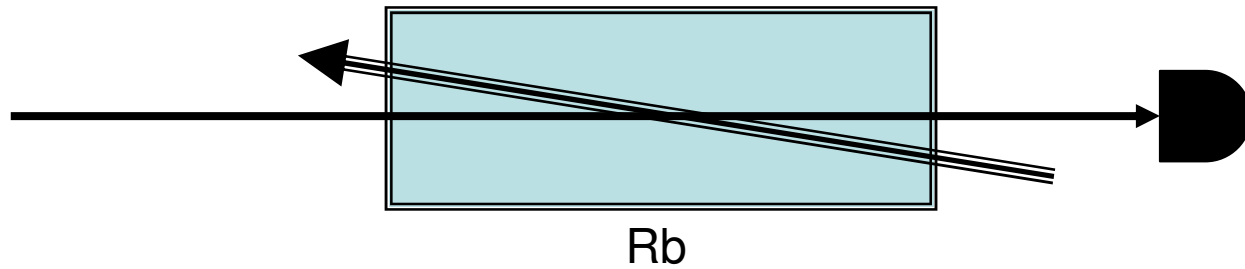
Przykład: spektroskopia atomowa



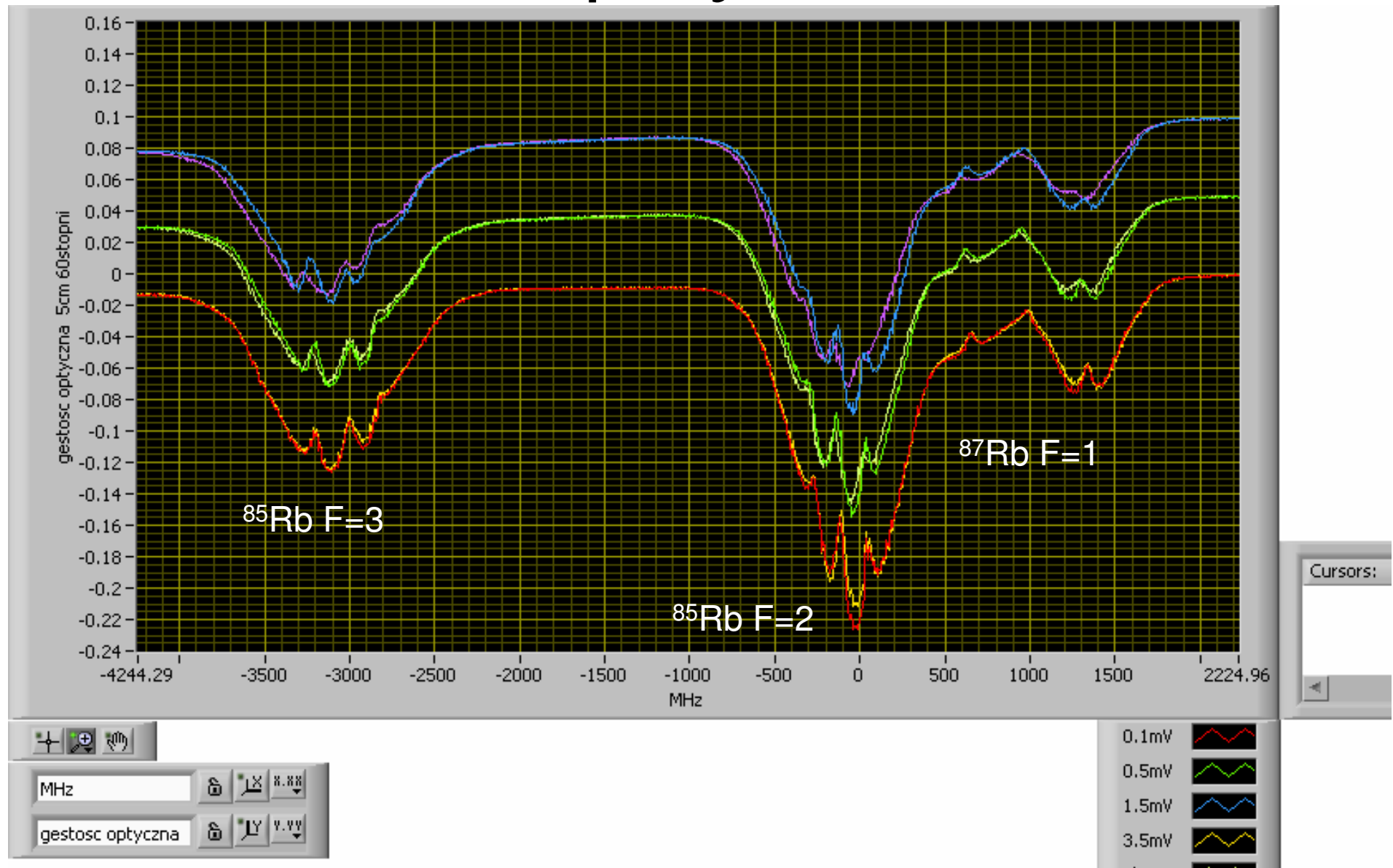
Waveform Graph



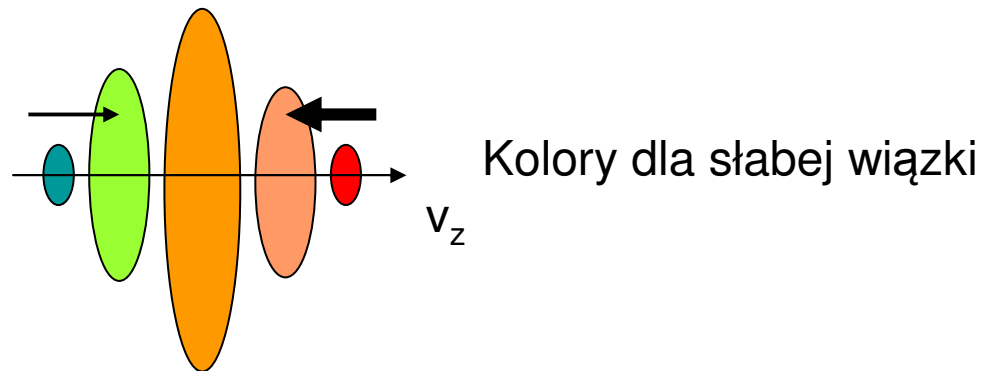
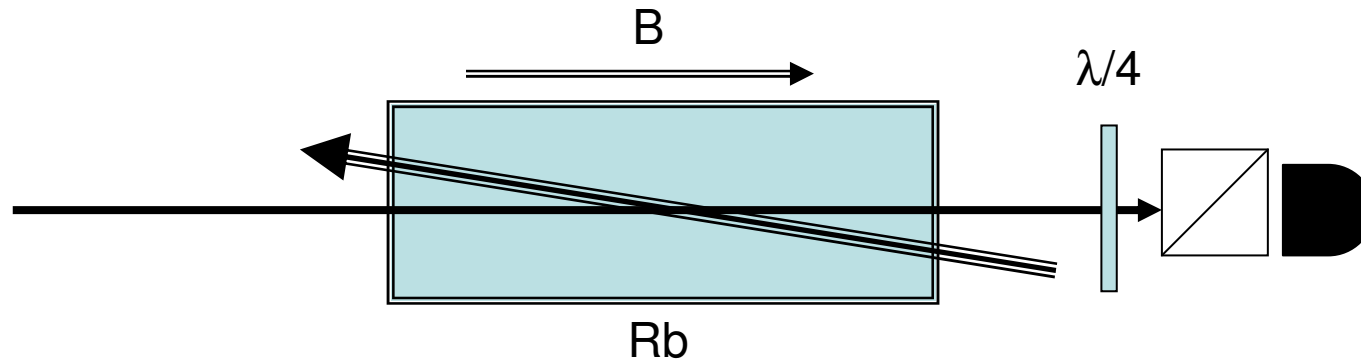
Nasycenie absorpcji



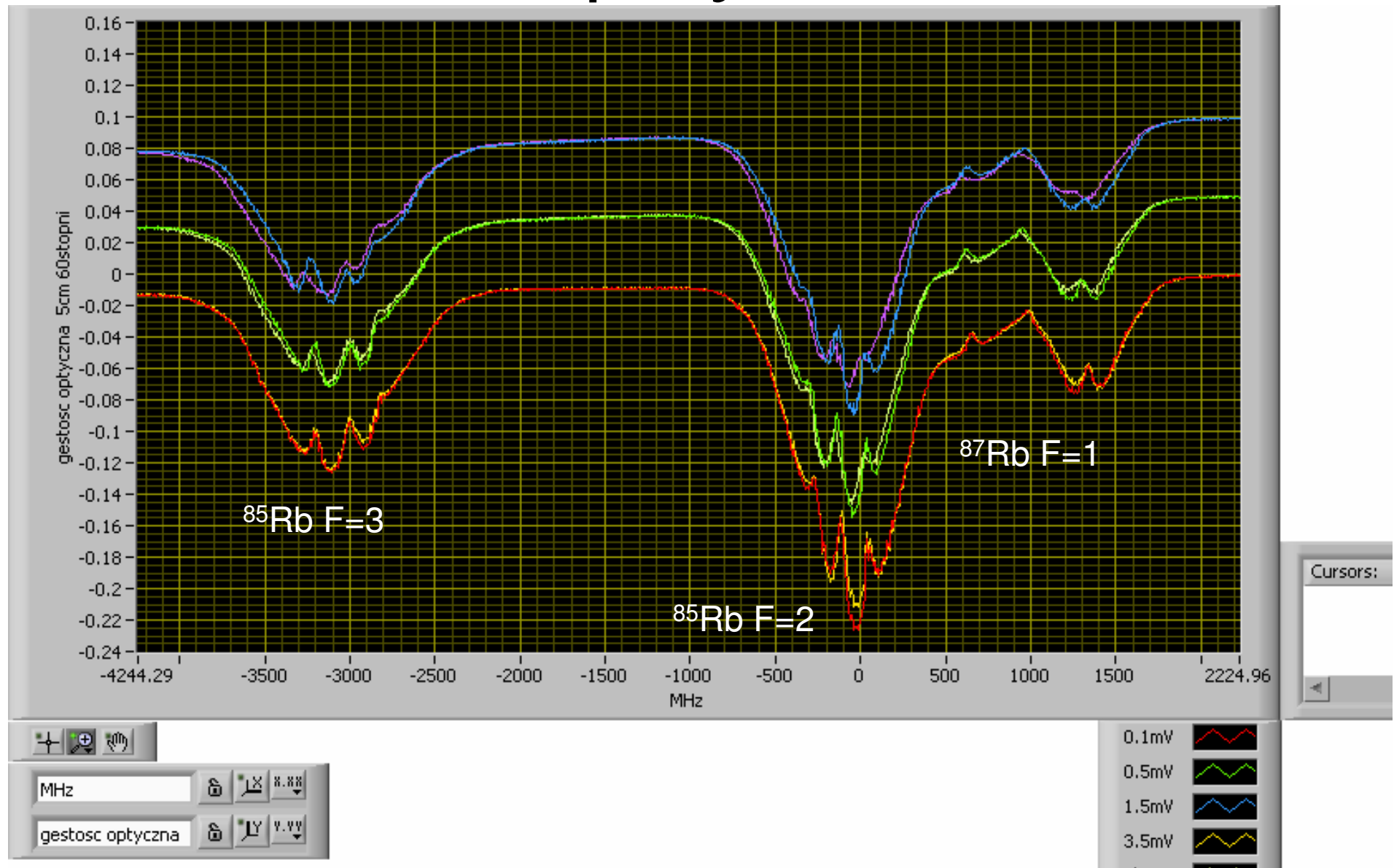
Eksperyment



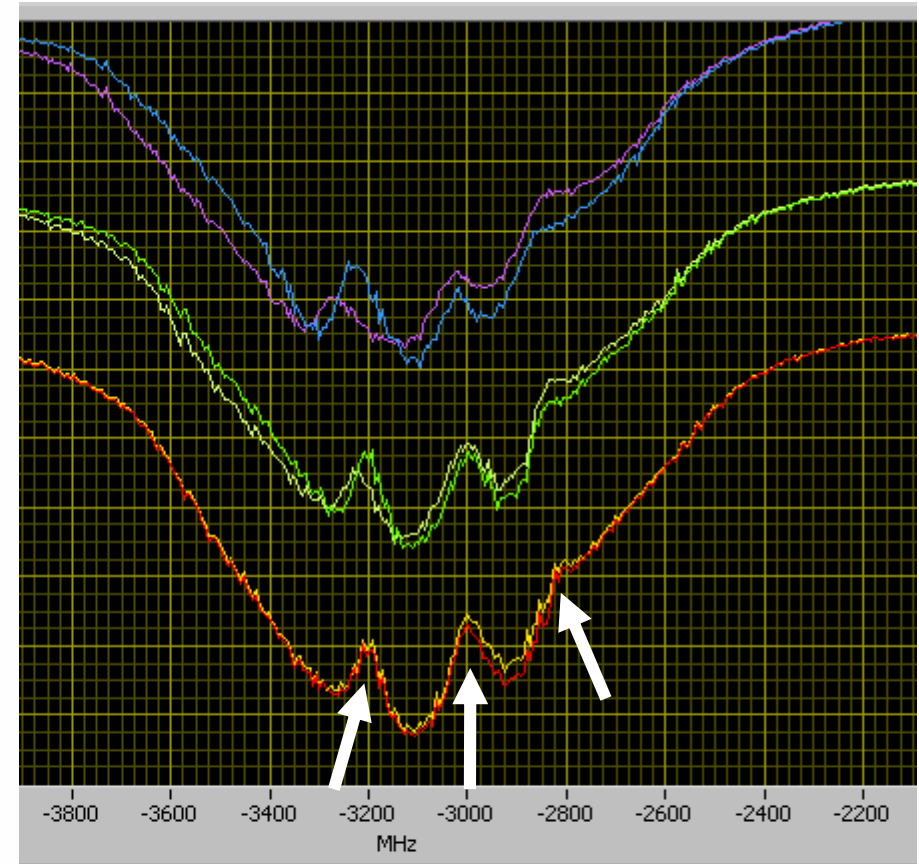
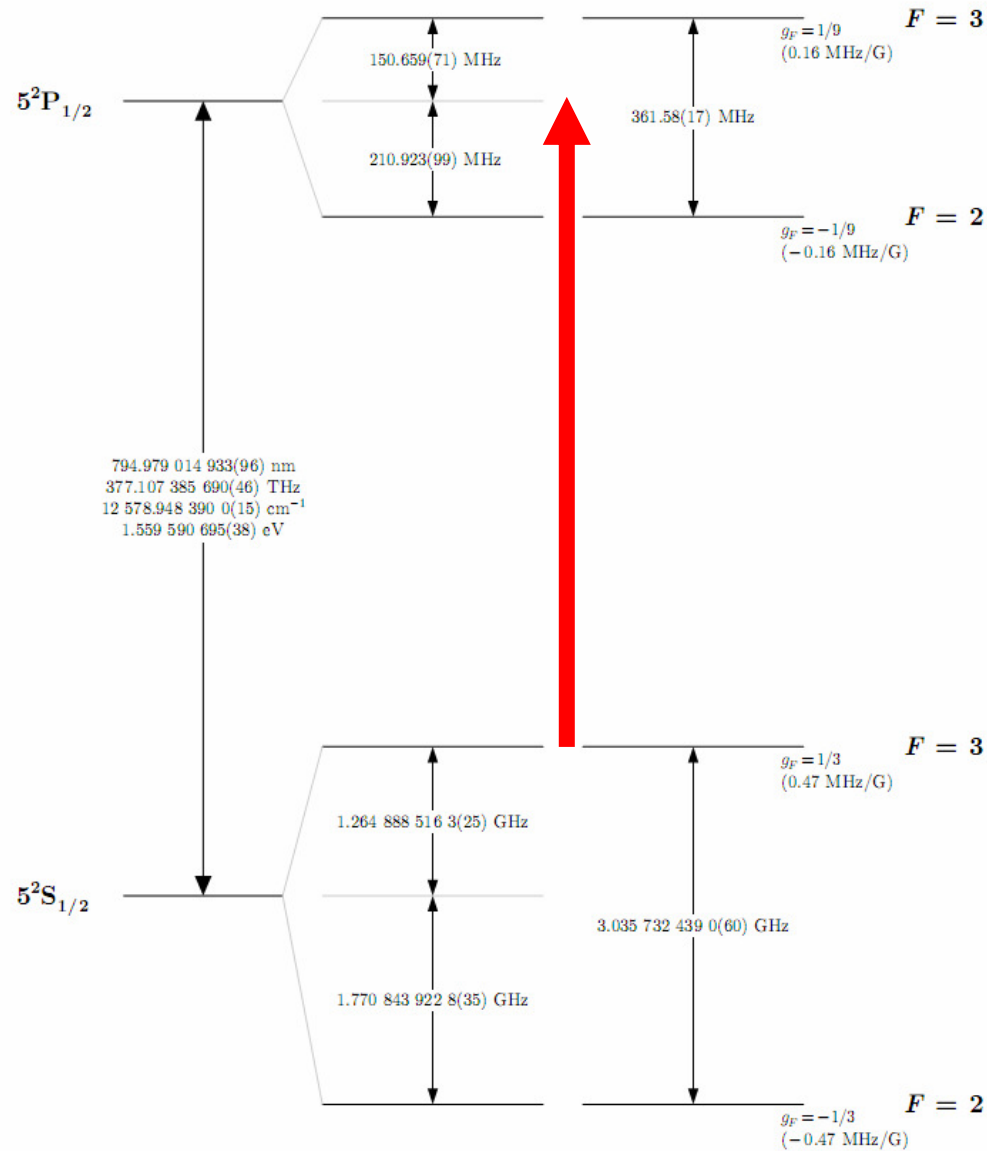
i efekt Zeemana



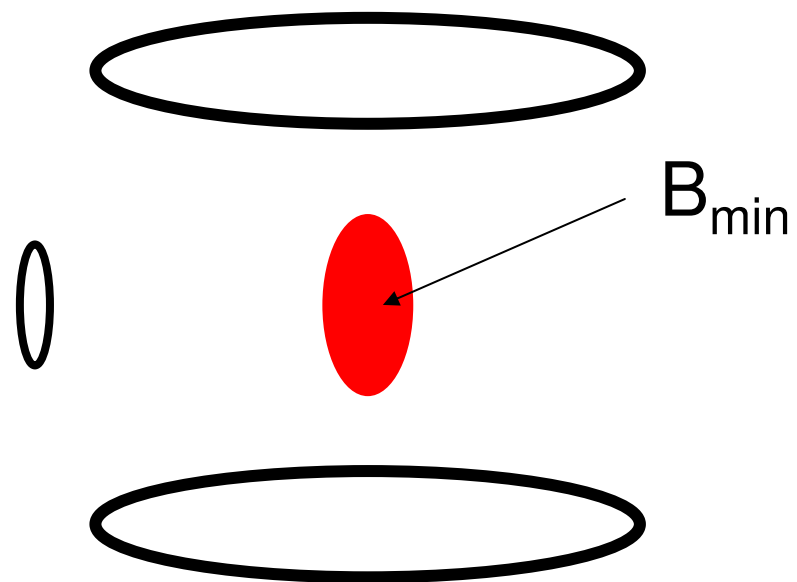
Eksperyment



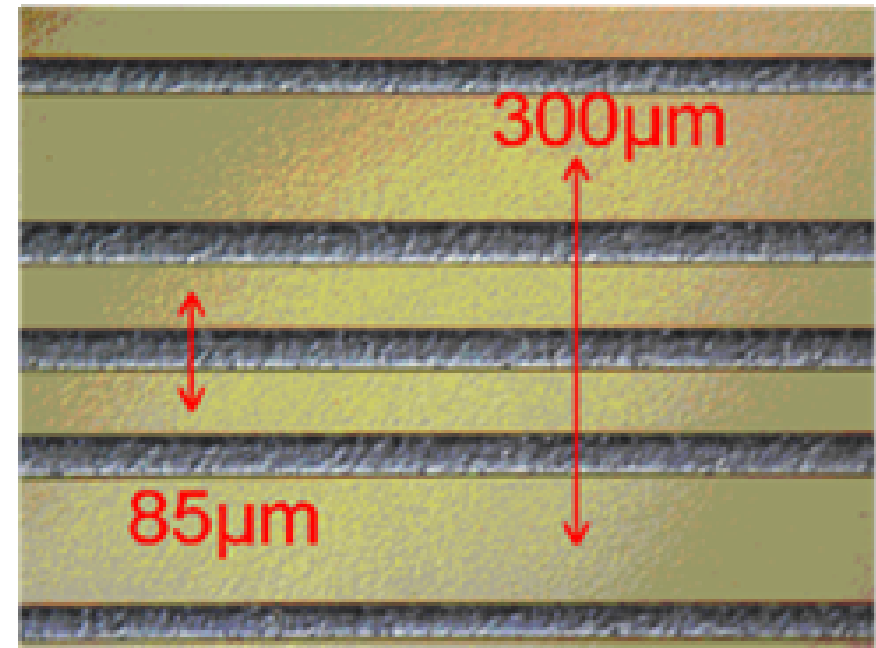
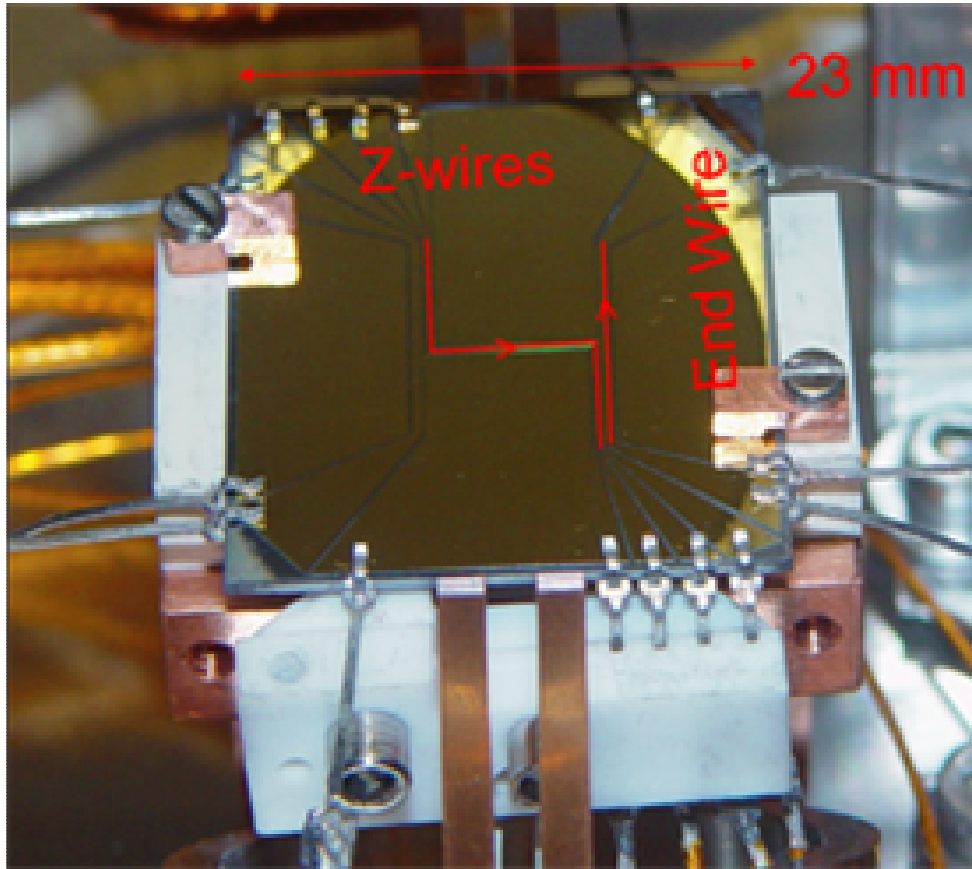
Zagadka do domu



Pułapka magnetyczna

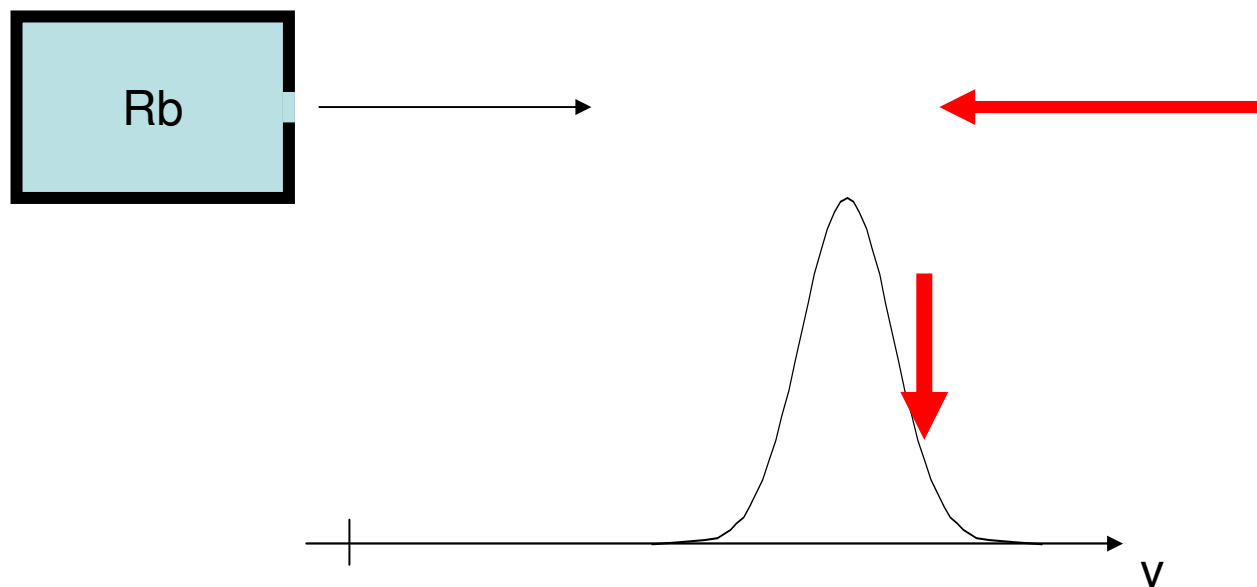


Atom chip

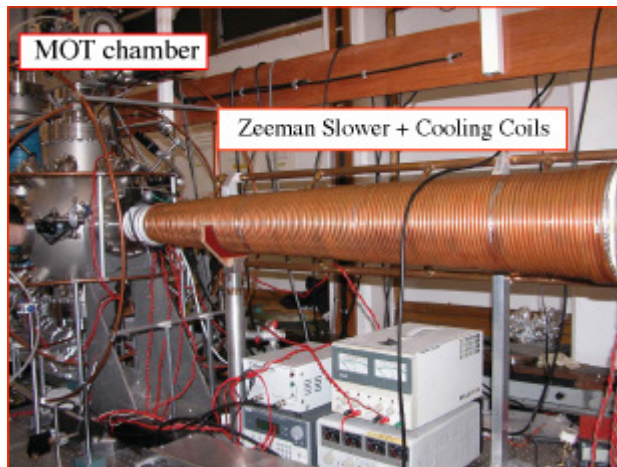
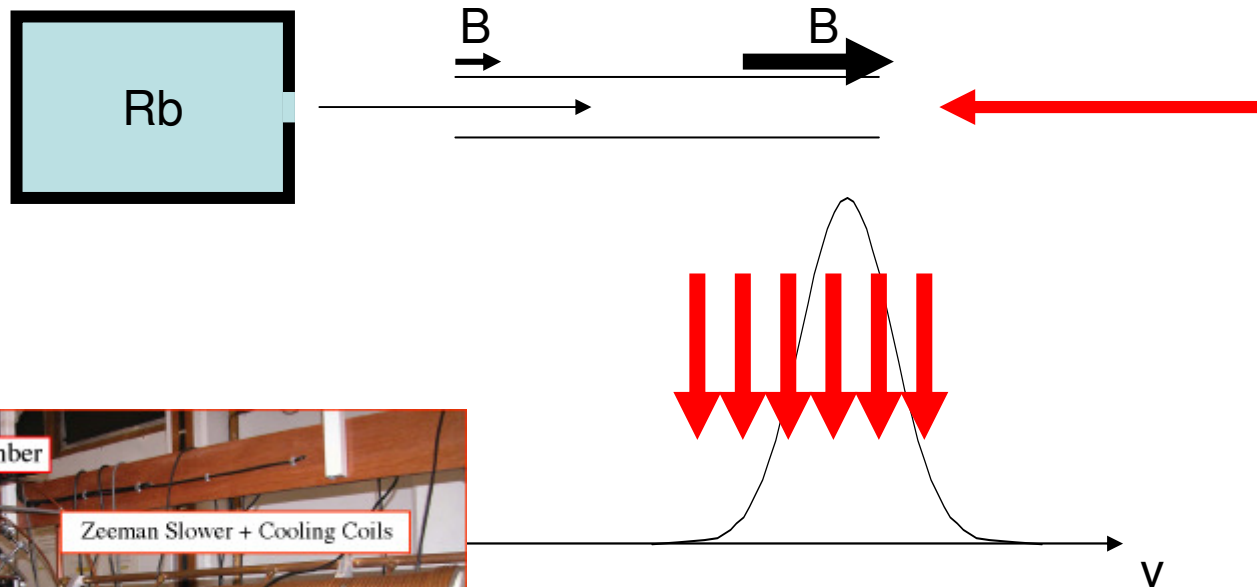


<http://www3.imperial.ac.uk/ccm/research/coldatoms/interferometer>

Spowalnianie atomów

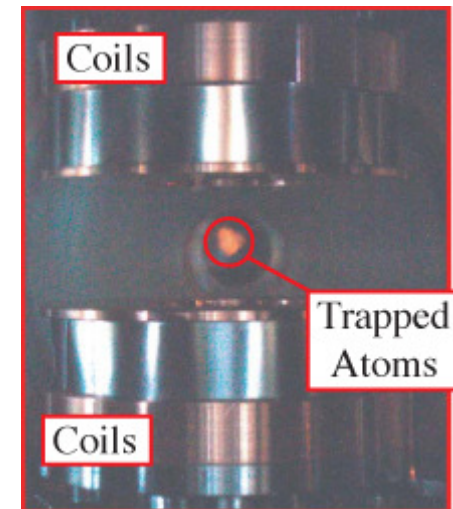
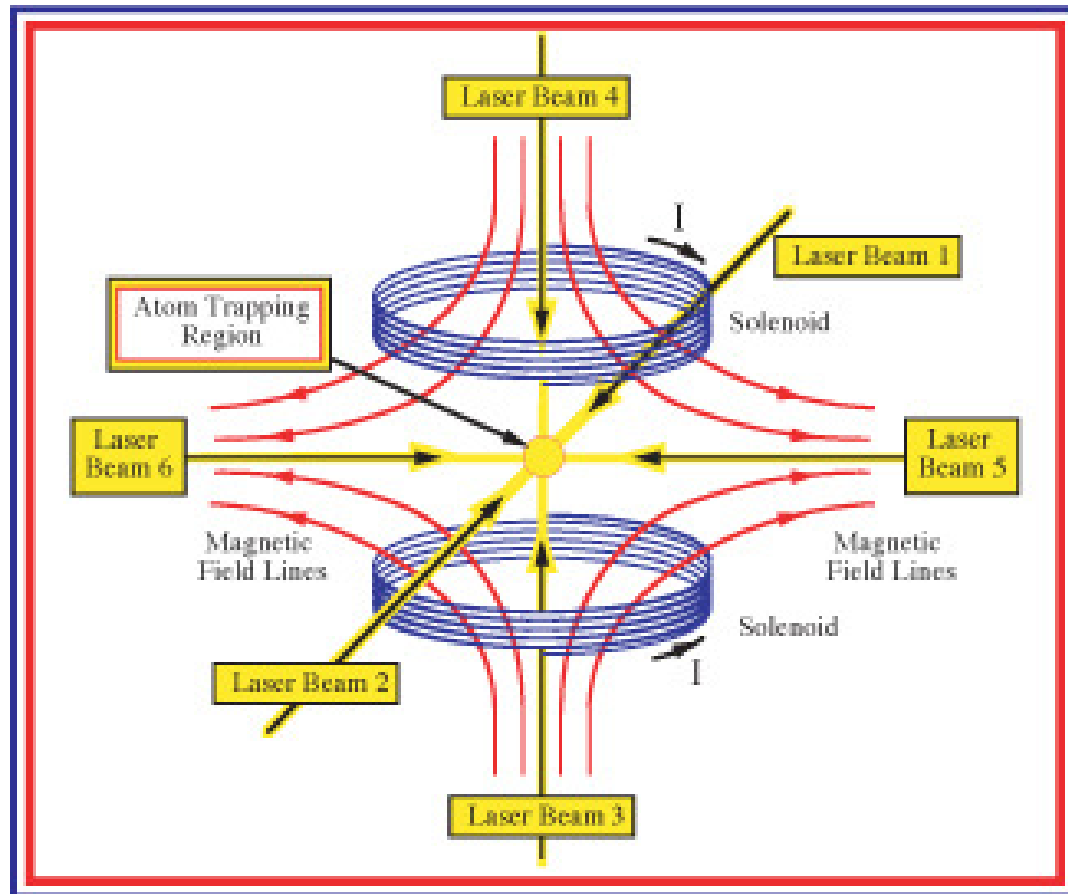


Zeeman slower



<http://es1.ph.man.ac.uk/AJM2/Atomtrapping/Atomtrapping.htm>

Magneto Optical Trap



<http://es1.ph.man.ac.uk/AJM2/Atomtrapping/Atomtrapping.htm>

Domieszki w ciałach stałych

pole krystaliczne
o określonej symetrii

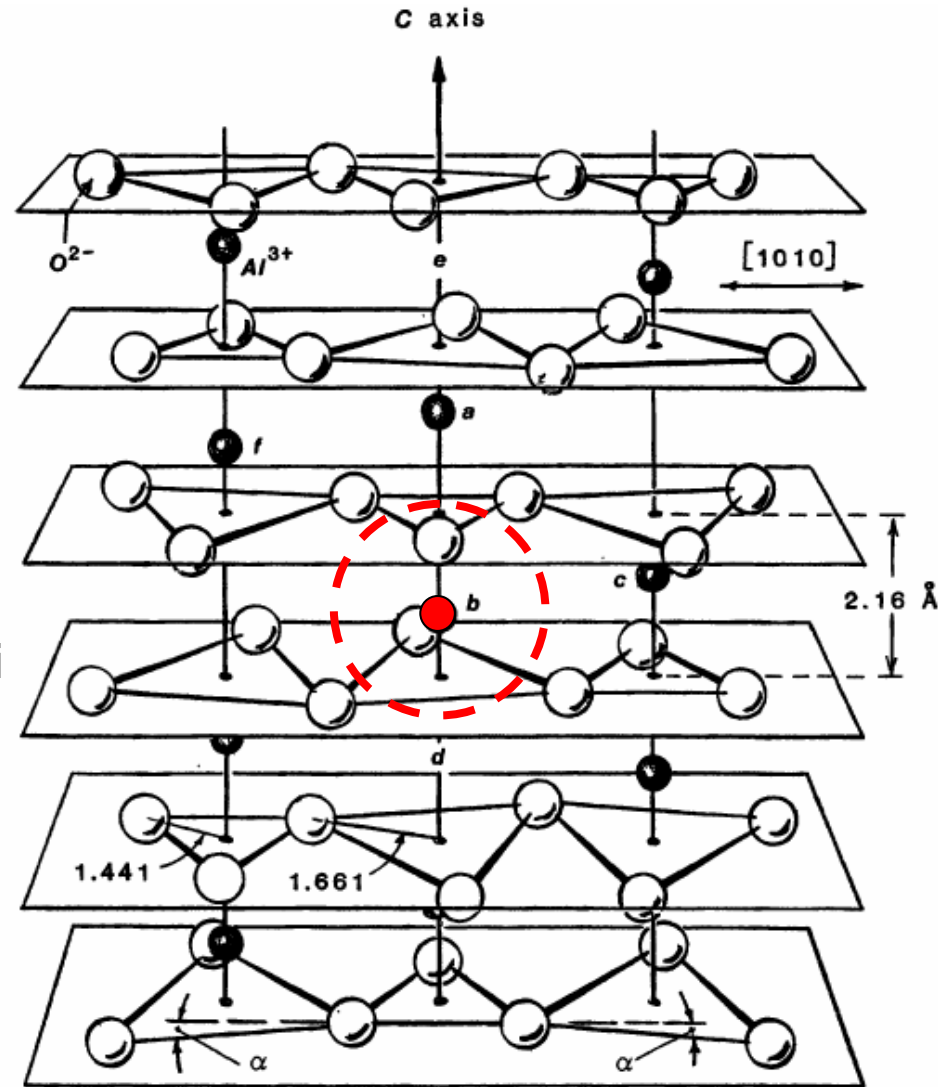


FIGURE 1.9
Sapphire crystal lattice.

Symetrie i funkcje falowe

atomy swobodne

SO(3)

domieszki

grupy punktowe

pod działaniem obrotów
 $E = \text{const}$

S ($L=0$) - nienaruszone

P ($L=1$) – jak wektory

D ($L=2$) – jak tensory

itd.

funkcje falowe transformują się
zgodnie z reprezentacjami
macierzowymi grupy

Przykład: $\text{Cr}^{3+}:\text{Al}_2\text{O}_3$

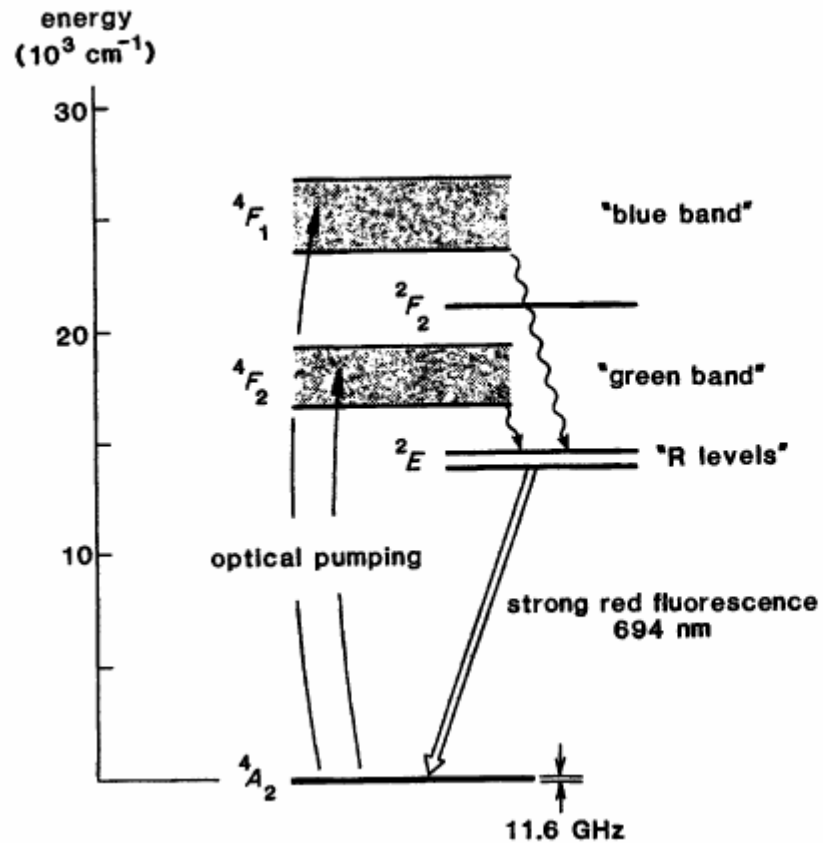
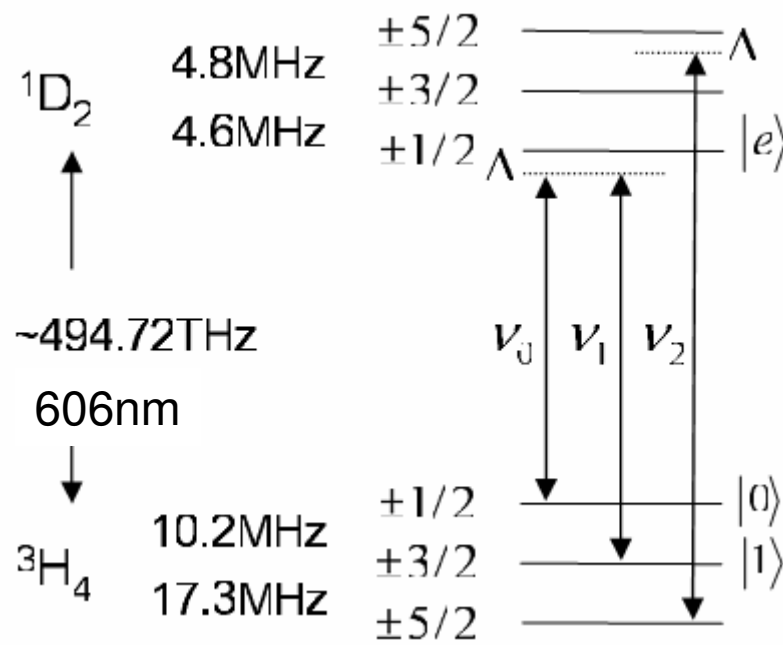


FIGURE 1.10
Quantum-mechanical energy
levels of the Cr^{3+} ions in a ruby
crystal.

Pr³⁺:YSO



$T_1 \sim 1$ ms
 $T_2 \sim 200$ ps

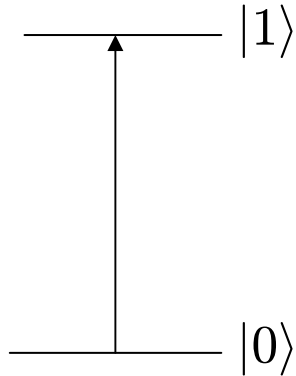
Efekty wielofotonowe:
polaryzacja nieliniowa

Rachunek zaburzeń w obrazie oddziaływania

$$i\hbar \frac{d}{dt} |\psi_I(t)\rangle = H_{int}(t) |\psi_I(t)\rangle$$

$$\begin{aligned} |\psi_I(T)\rangle &= |\psi_I(0)\rangle + \int_0^T dt \frac{H_{int}(t)}{i\hbar} |\psi_I(0)\rangle \\ &\quad + \int_0^T dt \int_0^t dt' \frac{H_{int}(t)}{i\hbar} \frac{H_{int}(t')}{i\hbar} |\psi_I(0)\rangle \end{aligned}$$

Duže odstrojenje



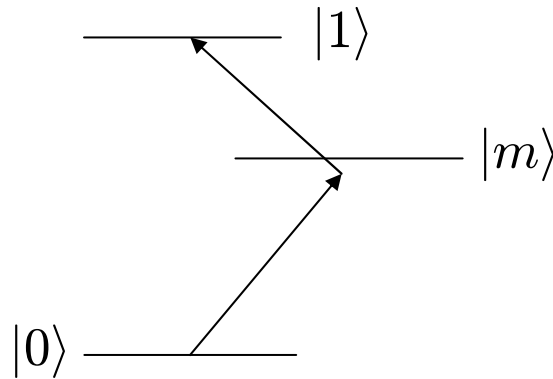
$$H_{int} = \frac{Ed_{1,0}}{2} e^{-i\omega t} \tilde{\sigma}_+ e^{i\omega_{10}t} + H.c.$$

$$|\psi_I(t)\rangle = |\psi_I(0)\rangle + \int_0^t dt H_{int}(t') |\psi_I(0)\rangle$$

$$\simeq |0\rangle + c_1 |1\rangle$$

$$c_1 \simeq \frac{E(\omega)d_{1,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{10})t} - 1}{\omega - \omega_{10}}$$

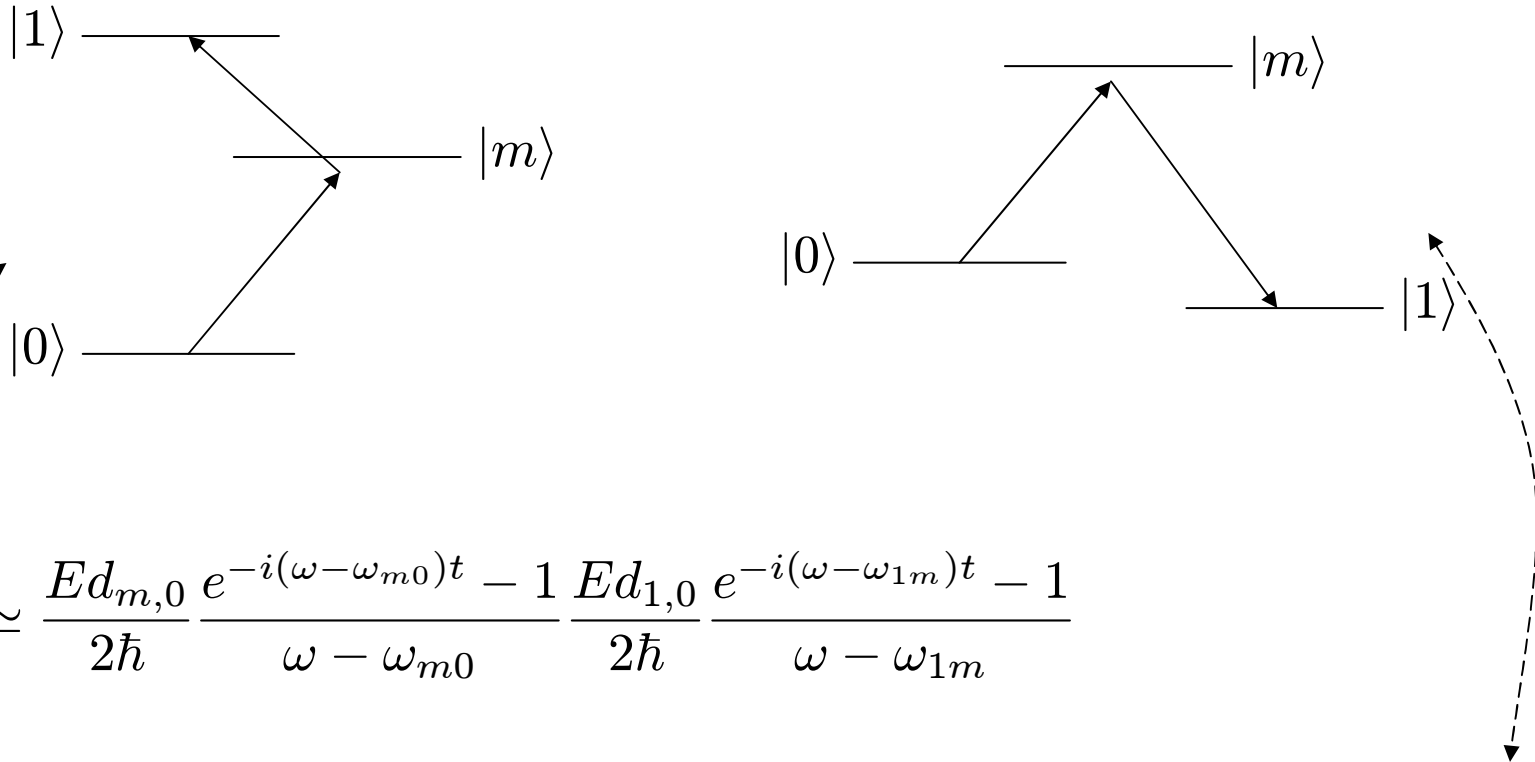
Przejścia wielofotonowe



$$H_{int} = \frac{Ed_{m,0}}{2} e^{-i\omega t} \tilde{\sigma}_{+0m} e^{i\omega_{m0}t} + \frac{Ed_{1,m}}{2} e^{-i\omega t} \tilde{\sigma}_{+m1} e^{i\omega_{1m}t} + H.c.$$

$$\langle 1|\psi_I\rangle \simeq \frac{Ed_{m,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{m0})t} - 1}{\omega - \omega_{m0}} + \frac{Ed_{1,m}}{2\hbar} \frac{e^{-i(\omega-\omega_{1m})t} - 1}{\omega - \omega_{1m}}$$

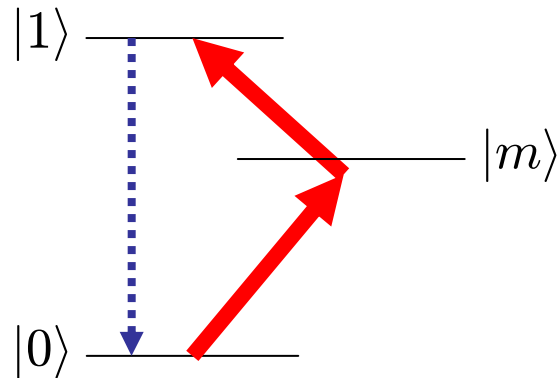
Przejścia wielofotonowe



$$\langle 1 | \psi_I \rangle \simeq \frac{Ed_{m,0}}{2\hbar} \frac{e^{-i(\omega - \omega_{m0})t} - 1}{\omega - \omega_{m0}} \frac{Ed_{1,0}}{2\hbar} \frac{e^{-i(\omega - \omega_{1m})t} - 1}{\omega - \omega_{1m}}$$

$$\langle 1 | \psi_I \rangle \simeq \frac{Ed_{m,0}}{2\hbar} \frac{e^{-i(\omega - \omega_{m0})t} - 1}{\omega - \omega_{m0}} \left(\frac{Ed_{1,0}}{2\hbar} \frac{e^{-i(\omega - \omega_{1m})t} - 1}{\omega - \omega_{1m}} \right)^*$$

Podatność wielofotonowa



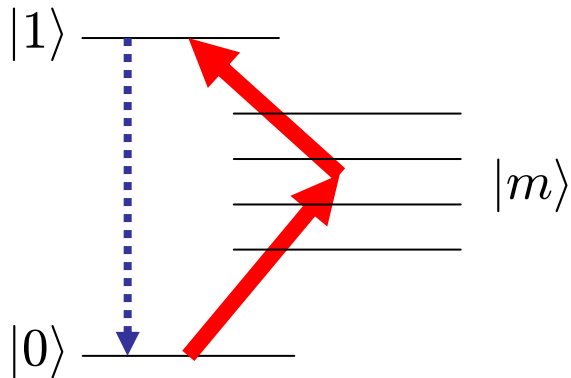
$$|0\rangle \longrightarrow |0\rangle + c_1|1\rangle + \dots$$

$$c_1 \simeq \frac{Ed_{m,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{m0})t} - 1}{\omega - \omega_{m0}} \frac{Ed_{1,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{1m})t} - 1}{\omega - \omega_{1m}}$$

$$\langle \vec{d} \rangle = \dots + \Re d_{01} c_1 e^{-i\omega_{1,0}t}$$

$$P = \dots + \chi^{(2)} E E e^{-i(\omega+\omega)t}$$

Mnożenie poziomów



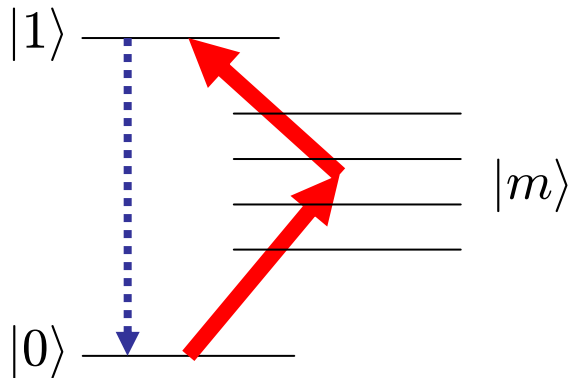
$$|0\rangle \longrightarrow |0\rangle + c_1|1\rangle + \dots$$

$$c_1 \simeq \sum_m \frac{Ed_{m,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{m0})t} - 1}{\omega - \omega_{m0}} \frac{Ed_{1,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{1m})t} - 1}{\omega - \omega_{1m}}$$

$$\langle \vec{d} \rangle = \dots + \Re d_{01} c_1 e^{-i\omega_{1,0}t}$$

$$P = \dots + \chi^{(2)} E E e^{-i(\omega+\omega)t}$$

Mnożenie poziomów



$$\sum_i \sum_f$$

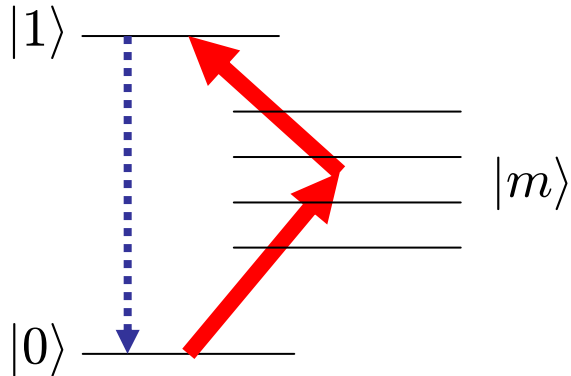
$$|0\rangle \longrightarrow |0\rangle + c_1|1\rangle + \dots$$

$$c_1 \simeq \sum_m \frac{Ed_{m,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{m0})t} - 1}{\omega - \omega_{m0}} \frac{Ed_{1,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{1m})t} - 1}{\omega - \omega_{1m}}$$

$$\langle \vec{d} \rangle = \dots + \Re d_{01} c_1 e^{-i\omega_{1,0}t}$$

$$P = \dots + \chi^{(2)} E E e^{-i(\omega+\omega)t}$$

Množenie pól



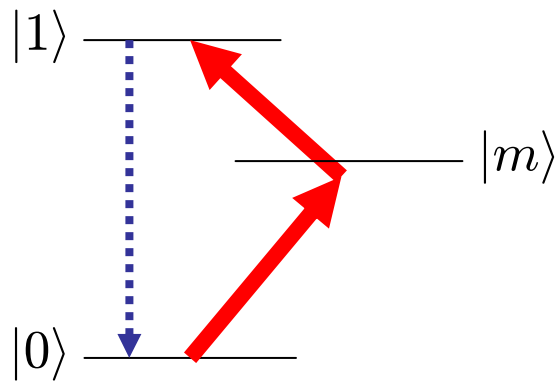
$$|0\rangle \longrightarrow |0\rangle + c_1|1\rangle + \dots$$

$$c_1 \simeq \sum_{\omega} \frac{E(\omega)d_{m,0}}{2\hbar} \frac{e^{-i(\omega-\omega_{m0})t} - 1}{\omega - \omega_{m0}} \sum_{\omega'} \frac{E(\omega')d_{1,0}}{2\hbar} \frac{e^{-i(\omega'-\omega_{1m})t} - 1}{\omega' - \omega_{1m}}$$

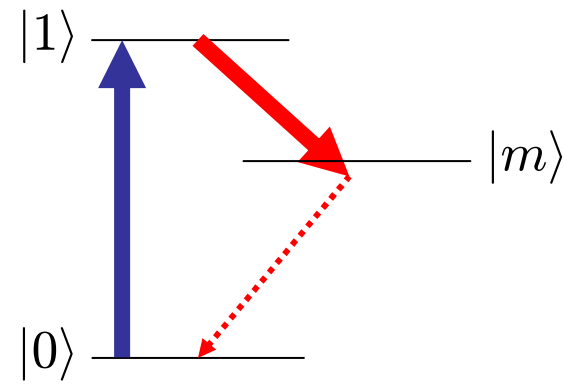
$$\langle \vec{d} \rangle = \dots + \Re \vec{d}_{01} c_1 e^{-i\omega_{1,0}t}$$

$$P = \dots + \sum_{\omega, \omega'} \chi^{(2)} E(\omega) E(\omega') e^{-i(\omega + \omega')t}$$

Różne konfiguracje



SHG
SFG



DFG
PDC



Dopasowanie fazowe

$$P^{NL}(\vec{x}, t) = \chi^{(2)} E_1(\vec{x}, t) E_2(\vec{x}, t) \\ \propto e^{i(k_1 + k_2)\vec{x} - i(\omega_1 + \omega_2)t}$$

Kiedy taka polaryzacja ośrodka może “nadać” falę?

$$|k_3| \simeq \frac{n\omega_3}{c}$$

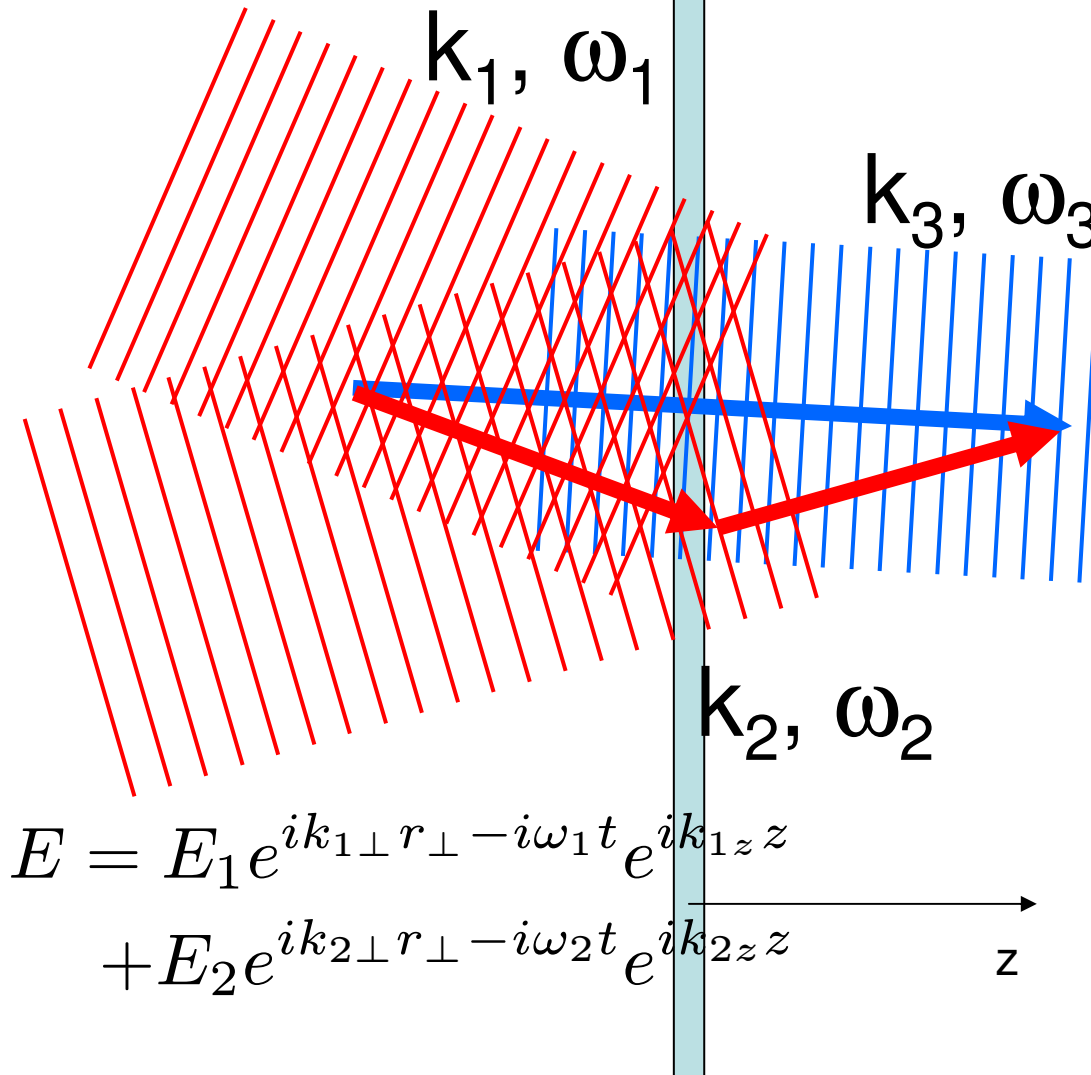
Jakie może być maksymalne niedopasowanie?

$$(k_{1z} + k_{2z} - k_{3z})L_z < 2\pi$$

$$(\omega_1 + \omega_2 - \omega_3)T < 2\pi$$

Cienki plasterek

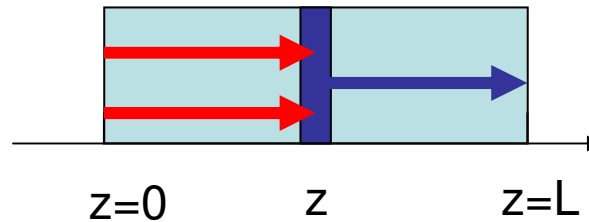
$$P^{NL} \propto E^2$$



$$\omega_3 = \omega_1 + \omega_2$$

$$k_{3\perp} = k_{1\perp} + k_{2\perp}$$

Wkład od plasterka



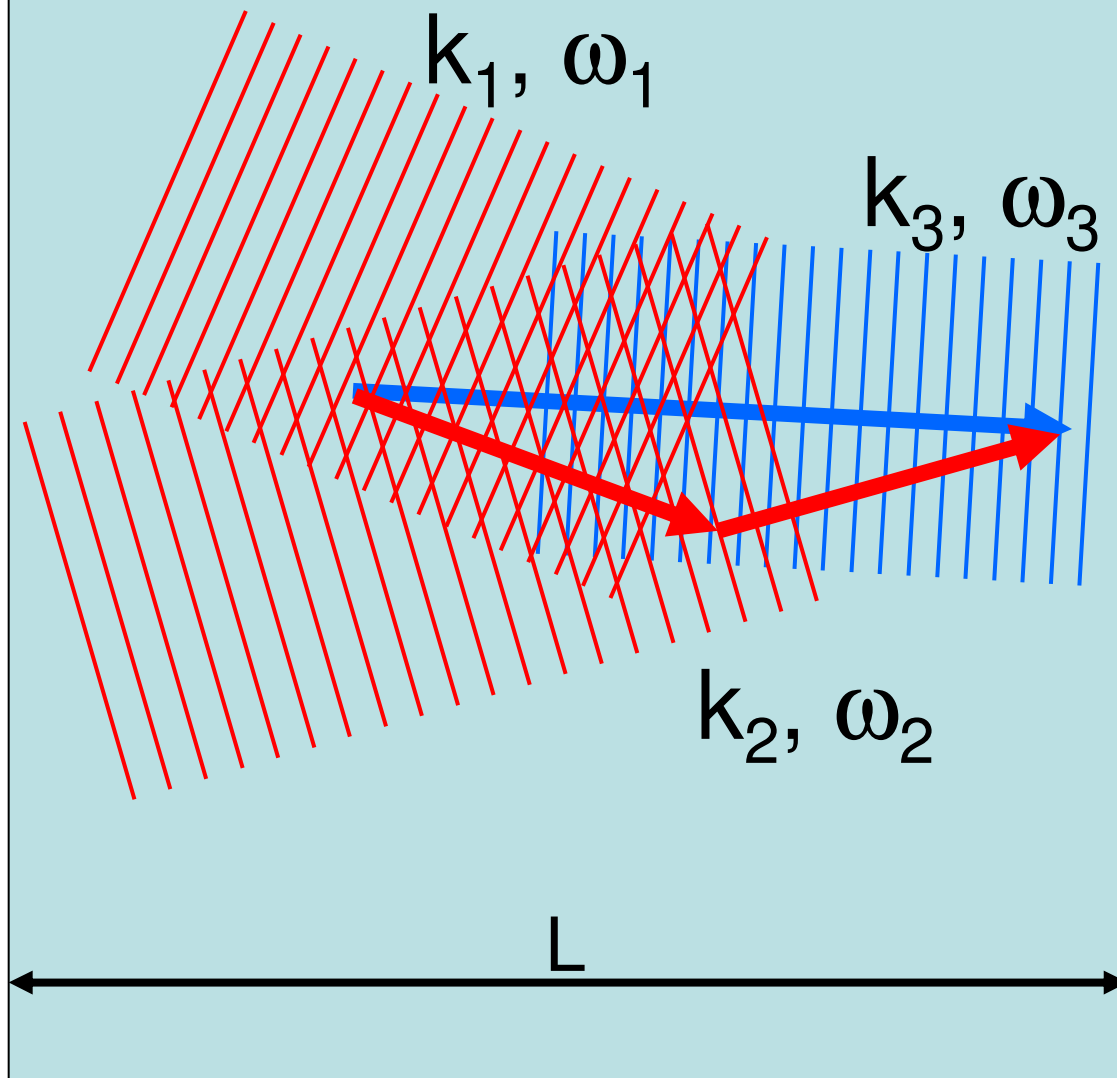
$$E = E_1 e^{ik_{1\perp} r_{\perp} - i\omega_1 t} e^{ik_{1z} z} \\ + E_2 e^{ik_{2\perp} r_{\perp} - i\omega_2 t} e^{ik_{2z} z}$$

$$P^{NL}(z) \propto E_1 E_2 e^{i(k_{1\perp} + k_{2\perp}) r_{\perp} - i(\omega_1 + \omega_2) t} e^{i(k_{1z} + k_{2z}) z} + \dots$$

$$E_3(z = L) = \frac{P^{NL}(z)}{\epsilon_0} e^{ik_{3z}(L-z)}$$

zależność od z: $\propto e^{i(k_{1z} + k_{2z} - k_{3z}) z}$

3Wave Mixing



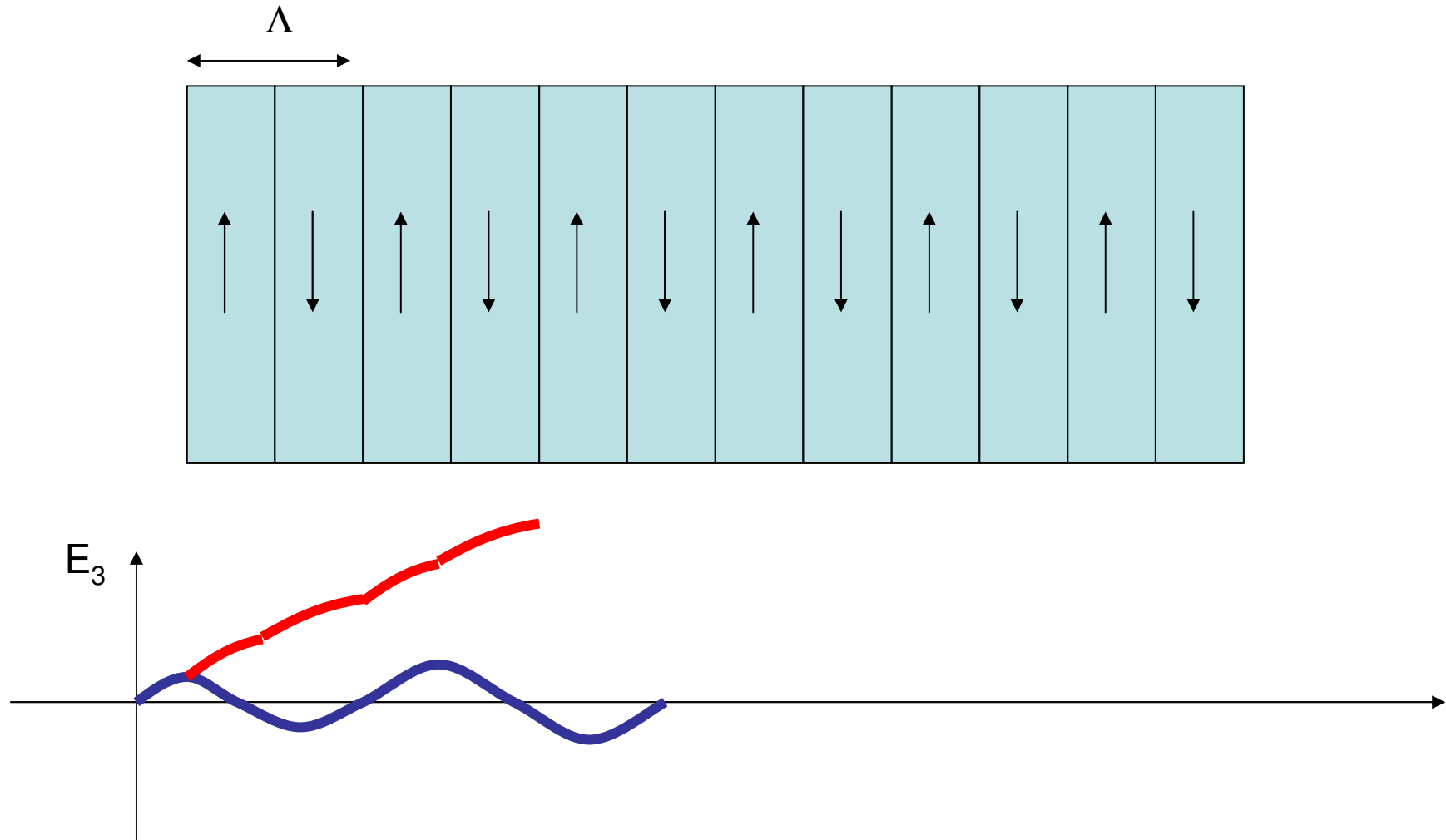
$$\omega_3 = \omega_1 + \omega_2$$

$$k_{3\perp} = k_{1\perp} + k_{2\perp}$$

sprawność
 $\sim \text{sinc}^2[\Delta k L / 2]$

$$\Delta k = k_{3z} - k_{1z} - k_{2z}$$

Periodically Poled Crystals



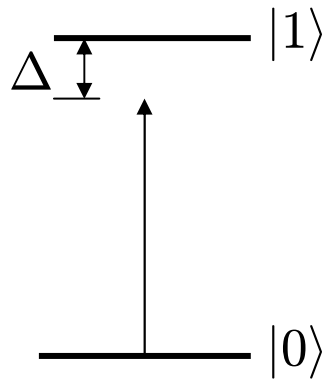
W domu

1. wyjaśnić pochodzenie wszystkich linii w eksperymentalnym obrazie absorpcji nasyconej
2. Jaki jest optymalny okres przestrzenny odwrócenia domen Λ do mieszania 3 fal z pewnym Δk_z ?

Efekty wielofotonowe: życie atomów

AC stark shift. Raman. EIT.

Lightshift (AC Stark shift)



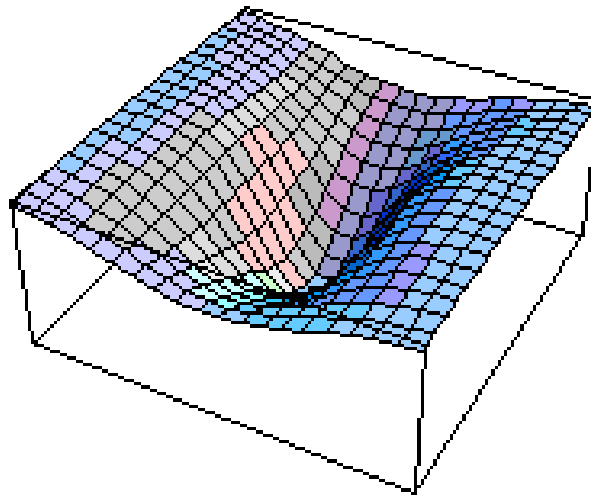
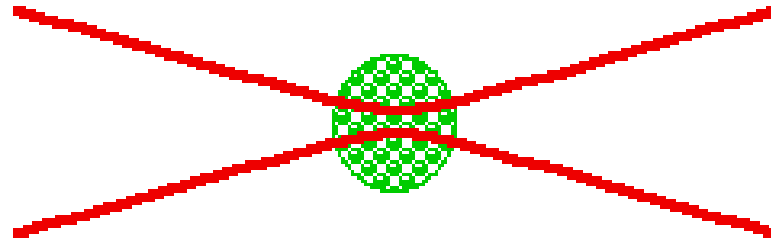
$$\tilde{H}_{int} = -\frac{\hbar}{2} \begin{pmatrix} 0 & \Omega \\ \Omega & -2\Delta \end{pmatrix}$$

Potraktujmy to jako stałe zaburzenie...

$$E_0 = E_0^{(0)} + \underbrace{\langle 0|V|0\rangle}_{=0} + \sum_{m \neq 0} \frac{|\langle 0|V|m\rangle|^2}{\Delta_m}$$

$$\sum_{m \neq 0} \frac{|Ed_{m0}|^2}{\omega_{m0} - \omega}$$

Pułapka dipolowa



Optical Lattice

