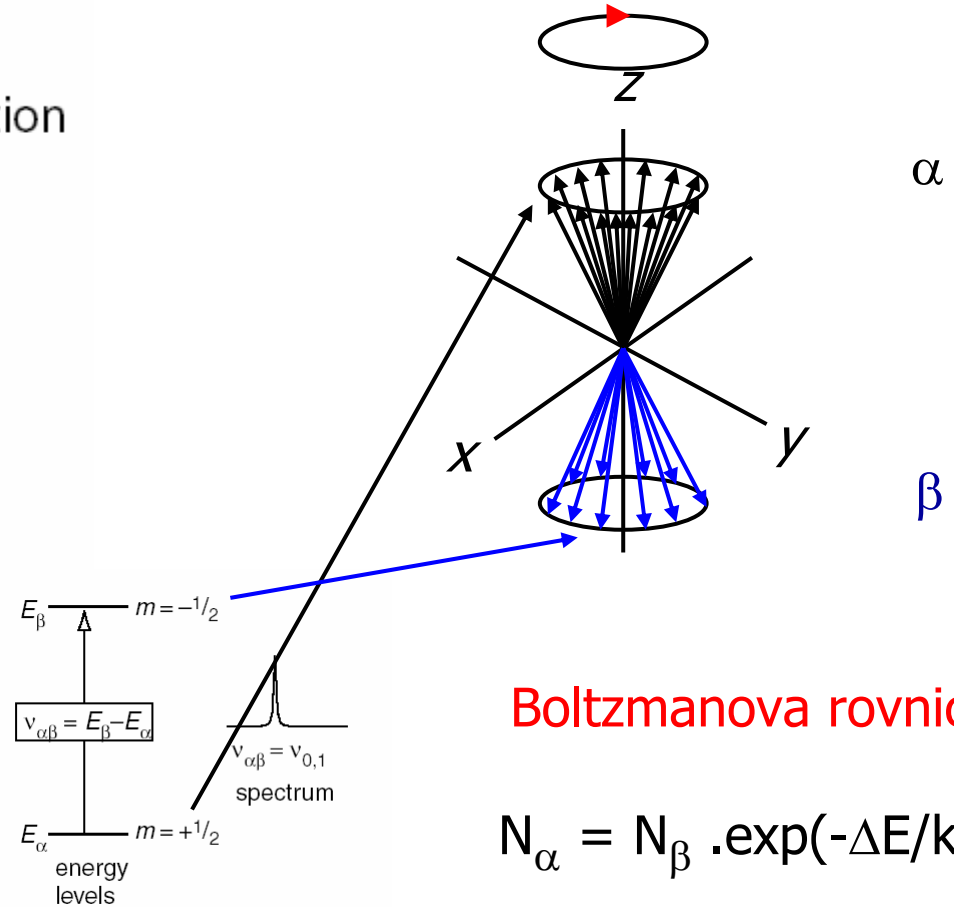
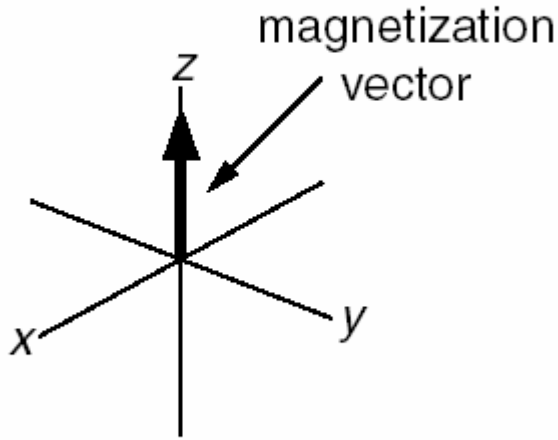


Vektorový model NMR

Makroskopická magnetizace

Směr rotace je negativní!!

magnetic field



Boltzmanova rovnice

$$N_{\alpha} = N_{\beta} \cdot \exp(-\Delta E/kT)$$



Vektorový model NMR

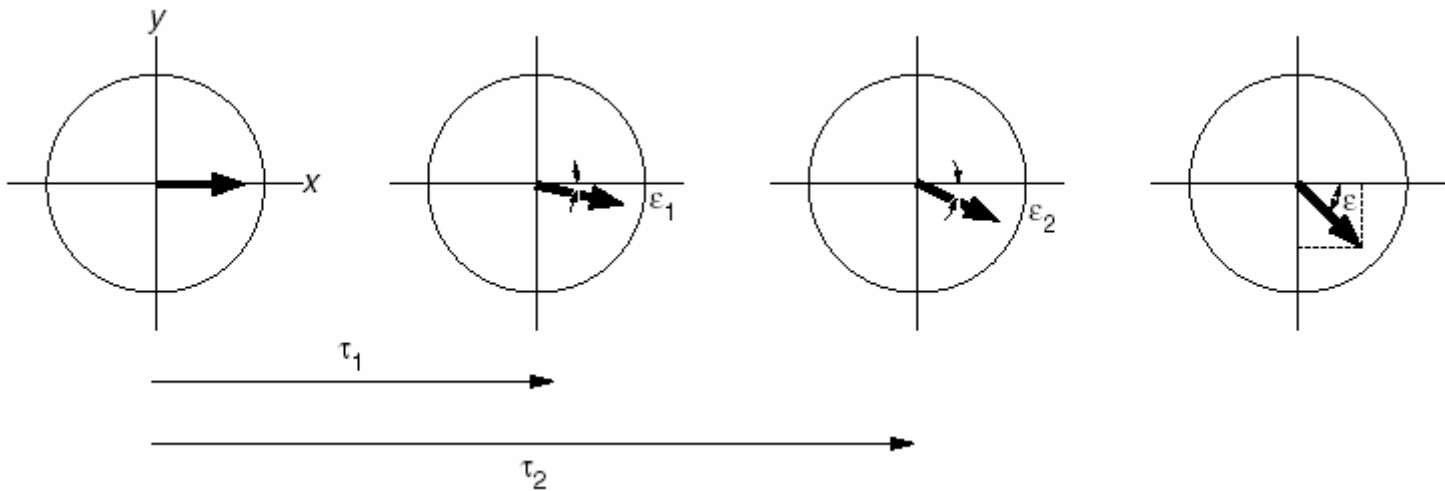
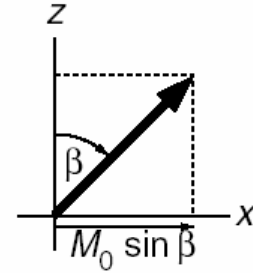
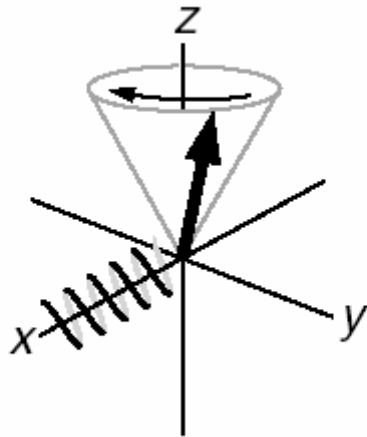
Larmorova precesní frekvence

$$\omega_0 = -\gamma B_0$$

$$\nu_0 = -\frac{1}{2\pi}\gamma B_0$$

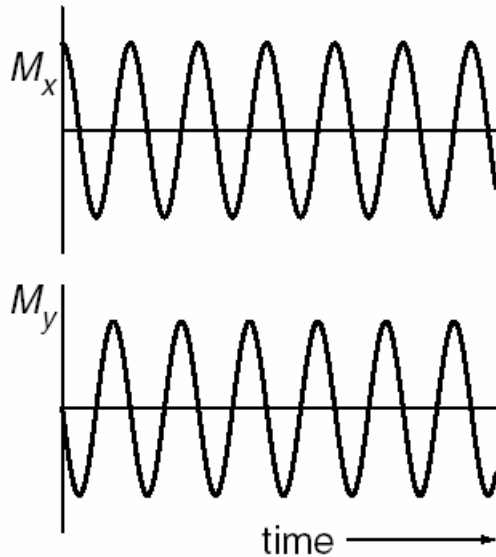
Vektorový model NMR

Detekce



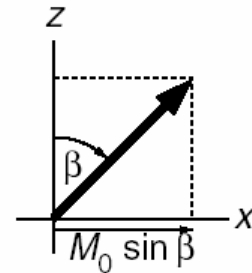
Vektorový model NMR

Detekce



$$M_x = M_0 \sin \beta \cos(\omega_0 t)$$

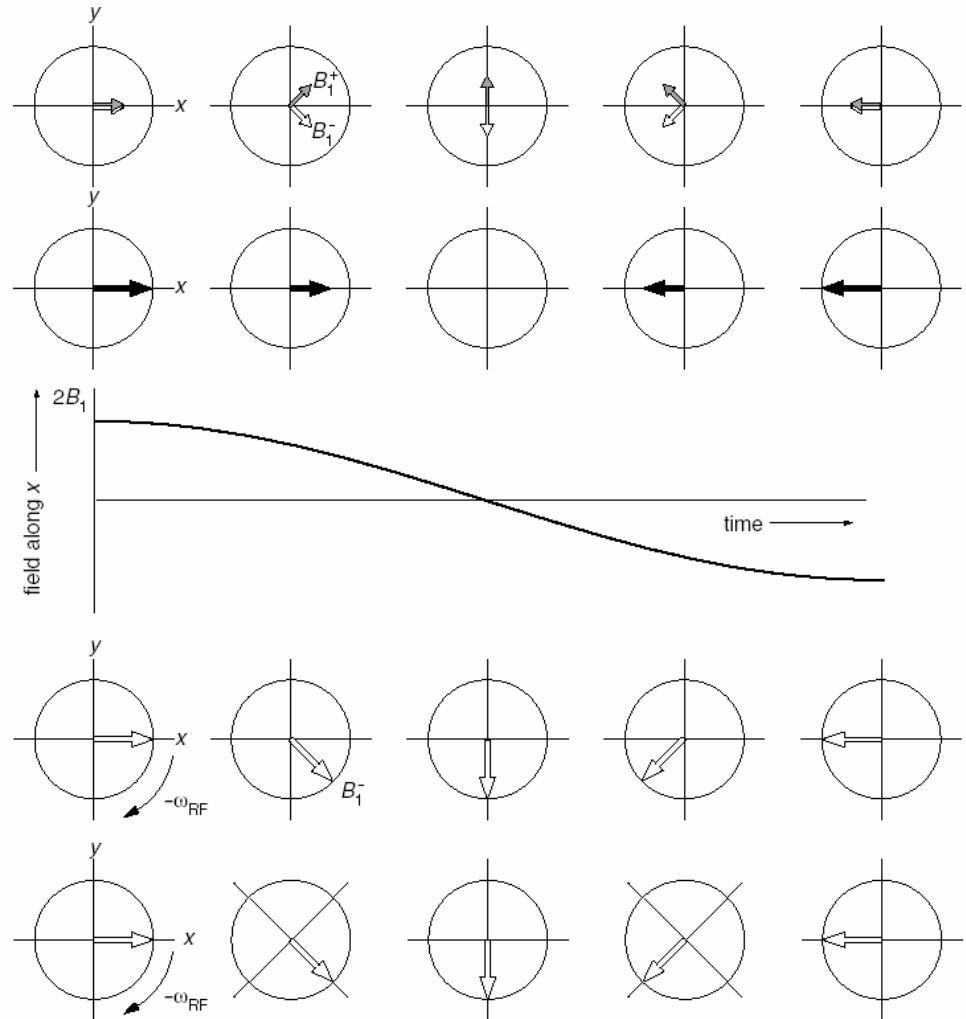
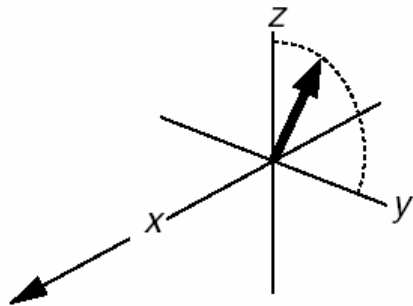
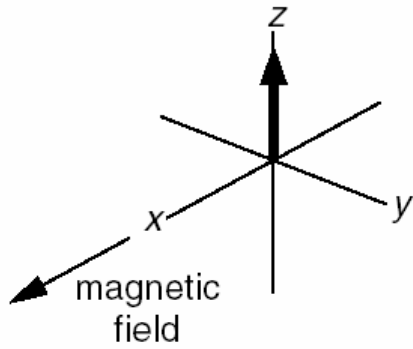
$$M_y = -M_0 \sin \beta \sin(\omega_0 t).$$



Vektorový model NMR

Rotující souřadná soustava

RF pulzy



Vektorový model NMR

Larmorova frekvence v rotující souřadné soustavě – efektivní pole

Offset $\Omega = \omega_0 - \omega_{\text{rot. fram.}}$

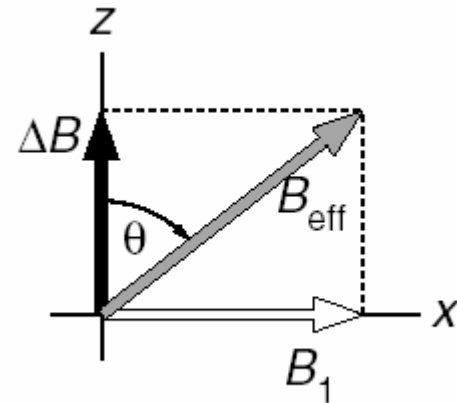
$$\omega = -\gamma B.$$

$$\Omega = -\gamma \Delta B$$

$$\Delta B = -\frac{\Omega}{\gamma}$$

$$\Omega = \omega_0 - (-\omega_{\text{RF}})$$

$$= \omega_0 + \omega_{\text{RF}}.$$



$$B_{\text{eff}} = \sqrt{B_1^2 + \Delta B^2}.$$

$$\omega_{\text{eff}} = \gamma B_{\text{eff}}$$

$$\sin \theta = \frac{B_1}{B_{\text{eff}}} \quad \cos \theta = \frac{\Delta B}{B_{\text{eff}}} \quad \tan \theta = \frac{B_1}{\Delta B}.$$

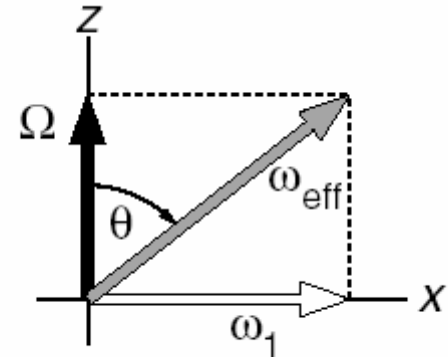
Vektorový model NMR

Larmorova frekvence v rotující souřadné soustavě – efektivní pole

$$\Omega = -\gamma \Delta B.$$

$$\omega_1 = \gamma B_1$$

$$\omega_{\text{eff}} = \gamma B_{\text{eff}}.$$

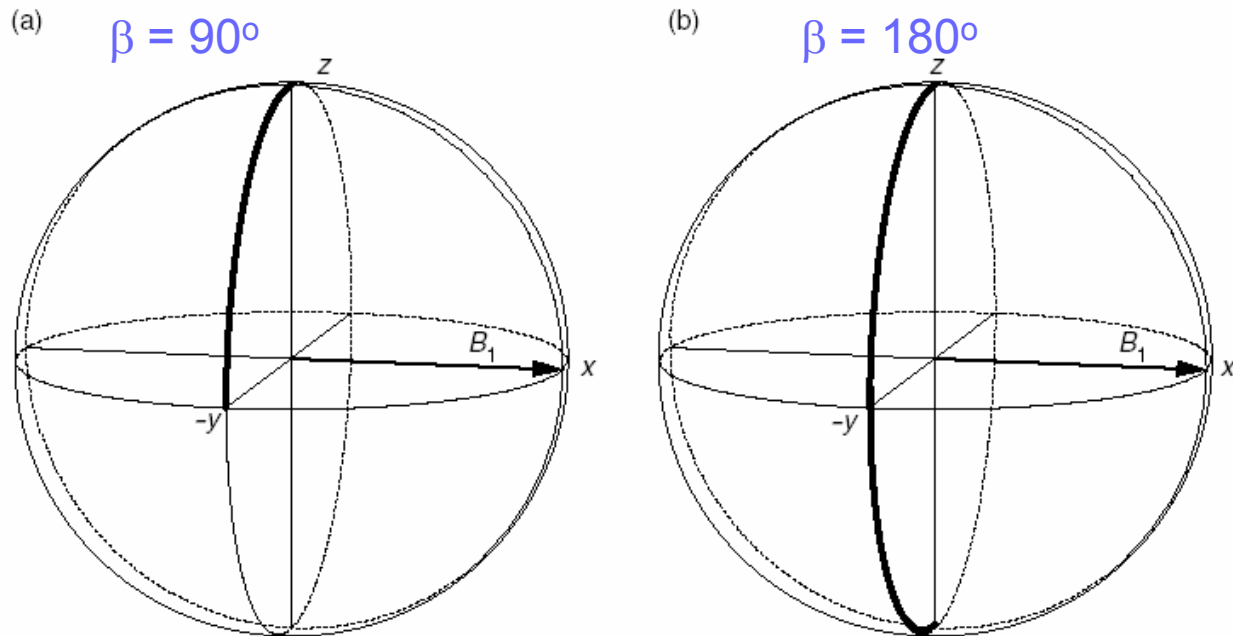


$$\omega_{\text{eff}} = \sqrt{\omega_1^2 + \Omega^2}.$$

$$\sin \theta = \frac{\omega_1}{\omega_{\text{eff}}} \quad \cos \theta = \frac{\Omega}{\omega_{\text{eff}}} \quad \tan \theta = \frac{\omega_1}{\Omega}.$$

Vektorový model NMR

RF pulzy – působení v rezonanci – offset $\Omega = \Delta B = 0$

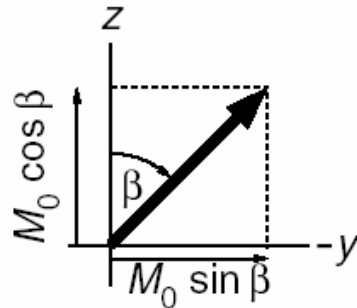


$$\beta = \omega_1 t_p$$

$$M_z = M_0 \cos \beta \quad M_y = -M_0 \sin \beta;$$

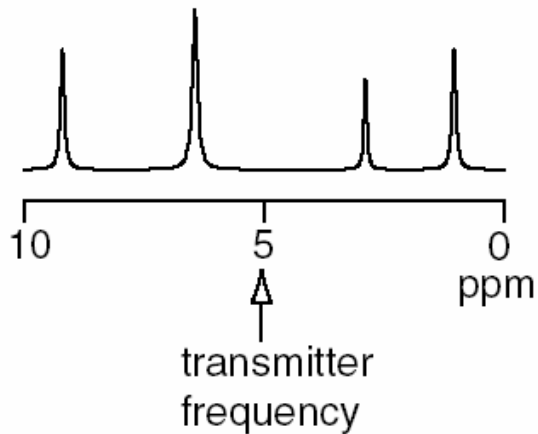
Vektorový model NMR

RF pulzy – 'tvrdé pulzy'



$$\beta = \omega_1 t_p \text{ hence } \omega_1 = \frac{\beta}{t_p}.$$

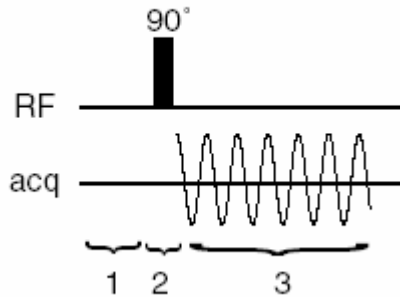
Je-li $\beta = 90^\circ$ pro $t_p = 12 \mu\text{s}$ potom



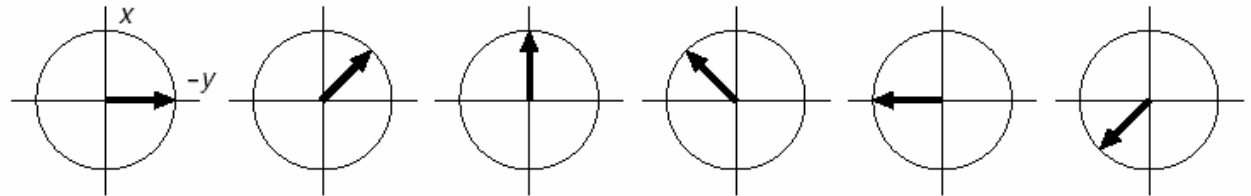
$$\begin{aligned} \omega_1 &= \frac{\pi/2}{12 \times 10^{-6}} \\ &= 1.3 \times 10^5 \text{ rad s}^{-1}. \end{aligned}$$

Vektorový model NMR

Detekce v rotující souřadné soustavě

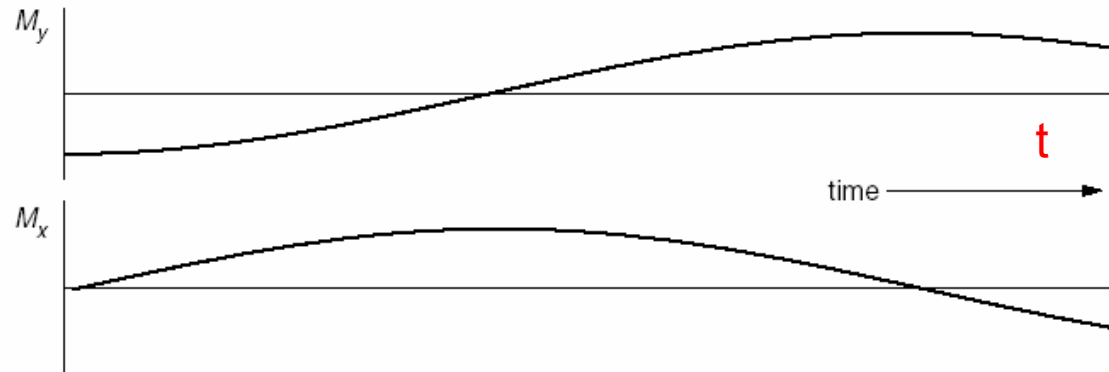


$$\varphi = \Omega t$$



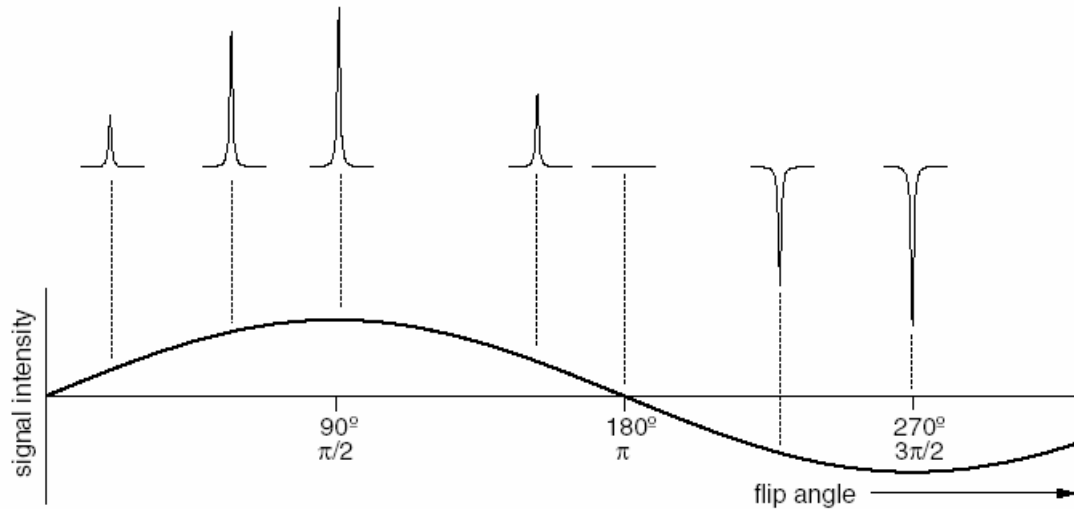
$$M_y = -M_0 \cos(\Omega t)$$

$$M_x = M_0 \sin(\Omega t).$$



Vektorový model NMR

Kalibrace rf pulzů



$$\pi = \omega_1 t_{180}$$
$$\omega_1 = \frac{\pi}{t_{180}}$$

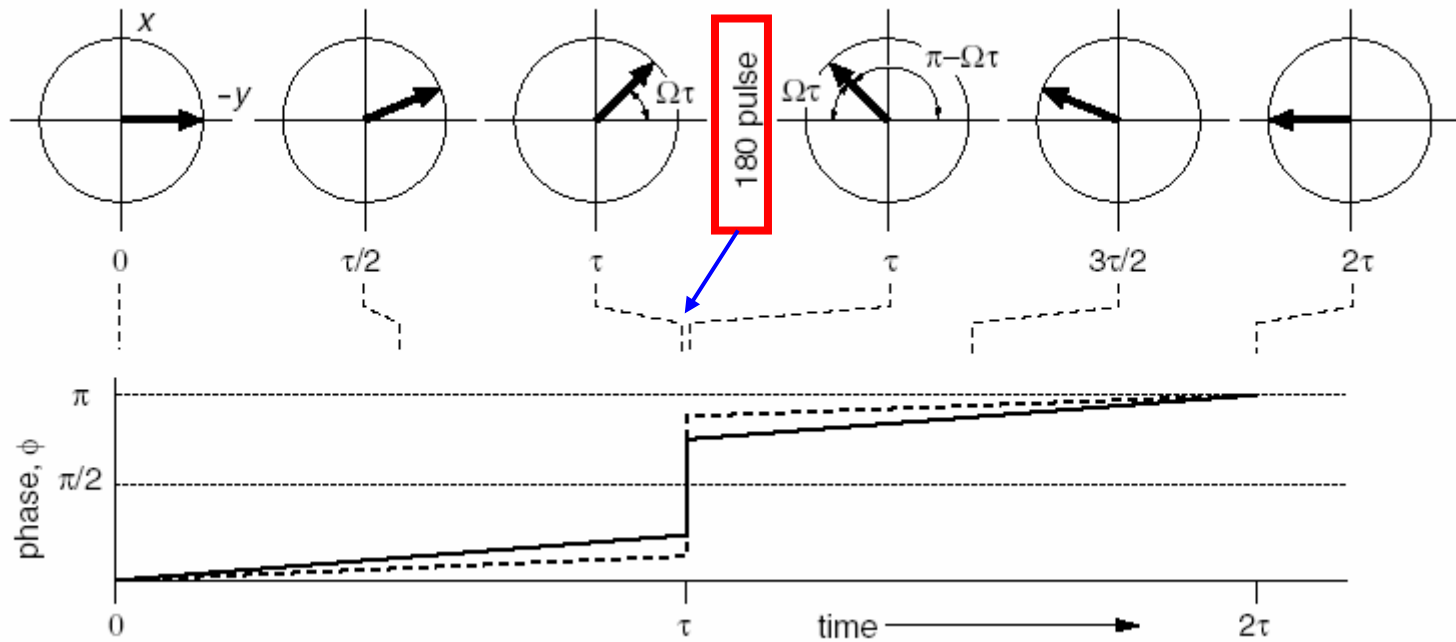
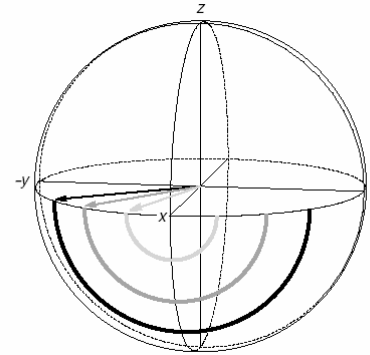
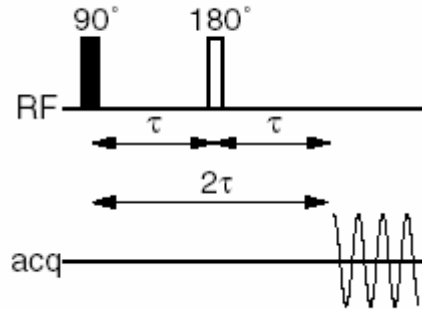
$$(\omega_1/2\pi) = \frac{1}{2t_{180}} \text{ Hz}$$

$$\omega_1 = \frac{\pi}{t_{180}} = \frac{\pi}{15.5 \times 10^{-6}} = 2.03 \times 10^5 \text{ rad s}^{-1}$$

$$(\omega_1/2\pi) = \frac{1}{2t_{180}} = \frac{1}{2 \times 15.5 \times 10^{-6}} = 32.3 \text{ kHz}$$

Vektorový model NMR

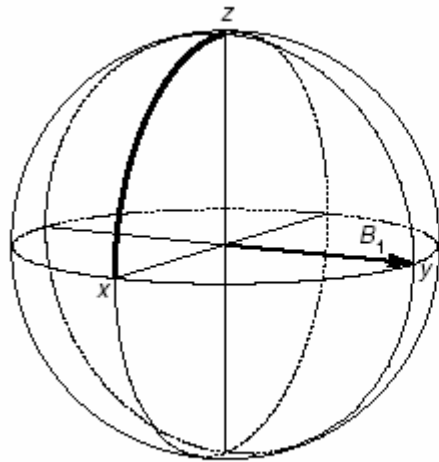
Spinové echo



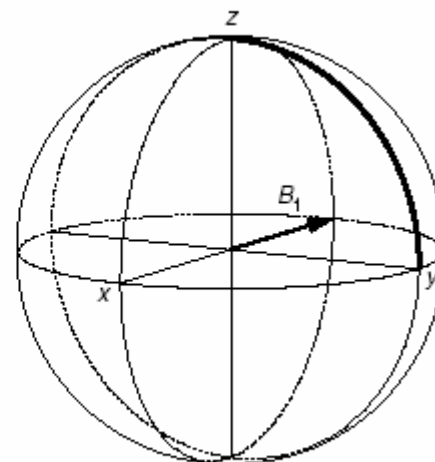
Vektorový model NMR

Fáze rf pulzů

(a)

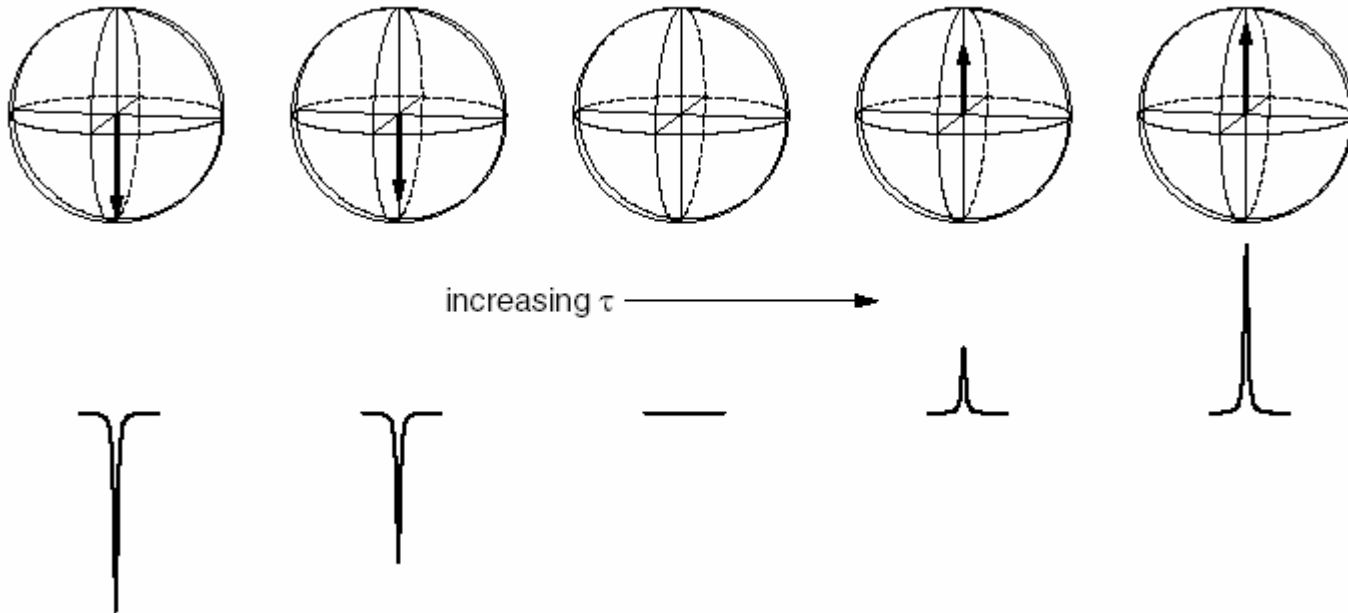
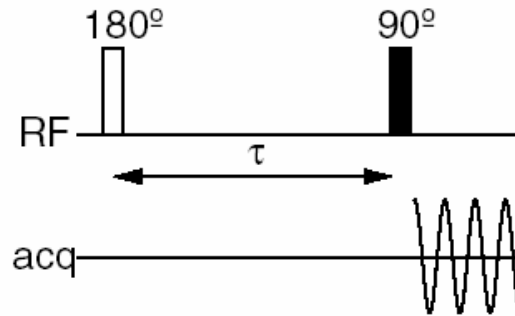


(b)



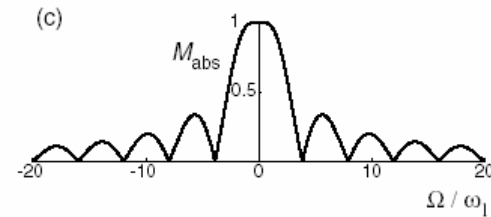
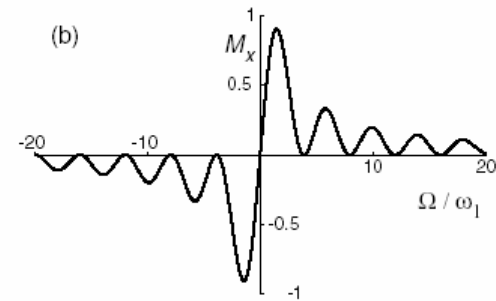
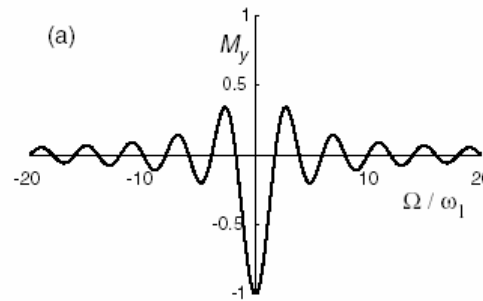
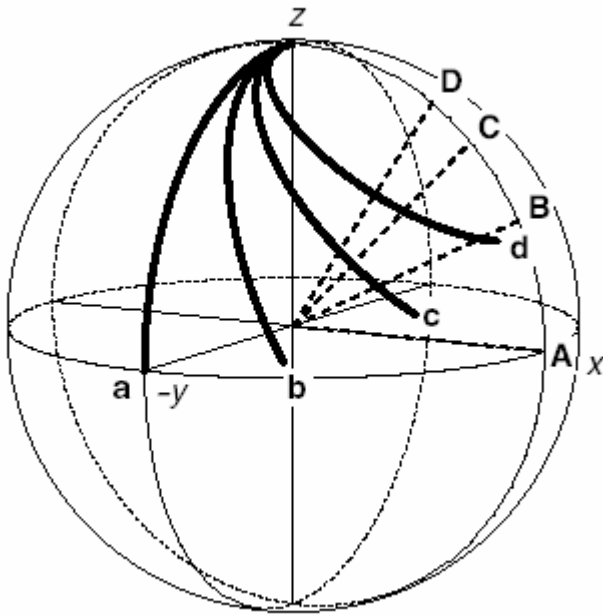
Vektorový model NMR

Relaxace



Vektorový model NMR

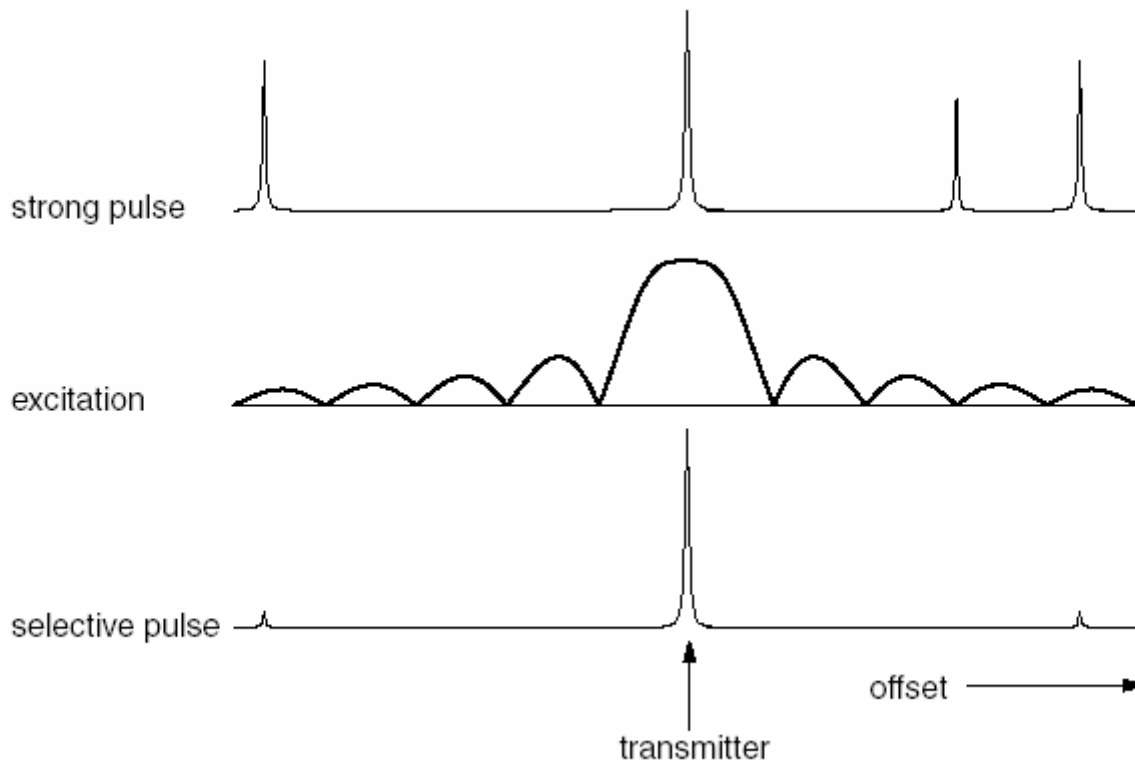
Off-rezonanční vlivy a slabé pulzy



$$M_{\text{abs}} = \sqrt{M_x^2 + M_y^2}$$

Vektorový model NMR

Selektivní excitace a slabé pulzy



Vektorový model NMR

Selektivní inverze a slabé pulzy

