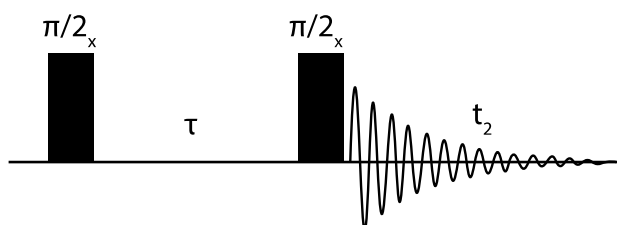


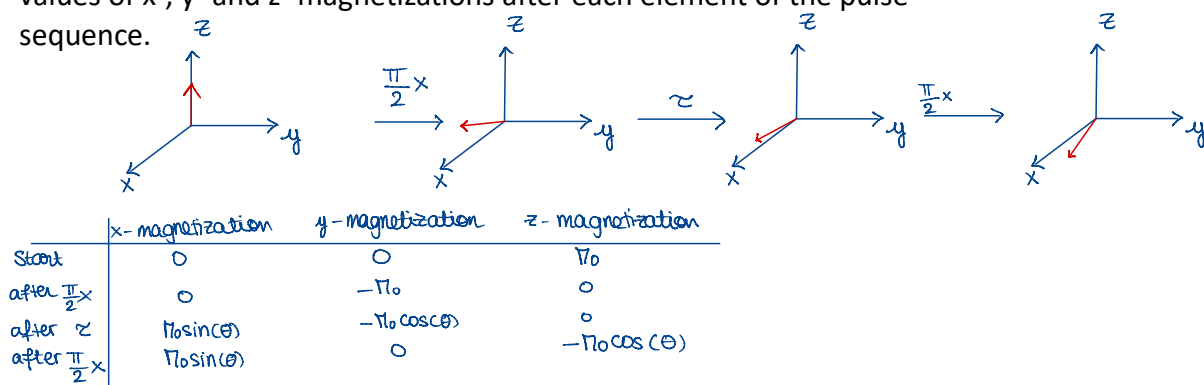
## Jigsaw 5C

### Vector Model: Effect of pulses

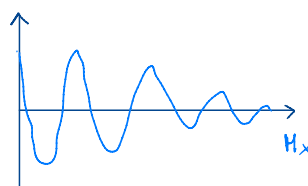
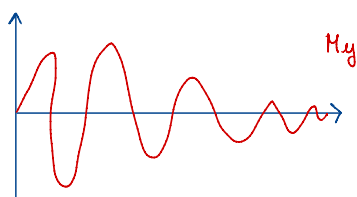
1. A pulse sequence is shown below.



- a. Use vector diagrams to predict the outcome of the sequence when applied to equilibrium magnetization. In your answer, set up a table describing the values of x-, y- and z- magnetizations after each element of the pulse sequence.



- b. For a fixed delay  $\tau$ , sketch a graph of the x- and y-magnetization as a function of the offset  $\Omega$  between the transmitter frequency and Larmor frequency  $\Omega = (\omega\tau - \omega_0)$  during  $t_2$ .



if  $\Omega = 0$  or  $\Omega = k\pi$   
 $\Rightarrow$  magnetization = 0  
 if  $\Omega < 0$ , function is inverted

- c. At what values of  $\Omega\tau$  do any nulls occur?

for  $M_y$ :  $\theta = k\pi$   
 for  $M_x$ :  $\theta = \frac{\pi}{2} + k\pi$

2. In a simple pulse-acquire experiment, to determine a pulse length, an operator observed a positive signal for pulse lengths of 5 and 10  $\mu\text{s}$ . As the pulse was lengthened further the intensity decreased, went through a null at 20.5  $\mu\text{s}$  and then became negative.

a. Explain what is happening in this experiment.

The pulse flips the net magnetization by an angle  $\theta = \gamma B_1 \tau$  where  $\tau$  is the pulse length.

- for short pulses (5 and 10  $\mu\text{s}$ ),  $\theta$  is small and  $\sin\theta > 0$ : positive signal
- as  $\tau$  increases,  $\theta$  approaches  $\pi$  and  $\sin\theta \rightarrow 0$ : null at  $\pi$  flip.
- for  $\tau$  larger than  $\pi$ ,  $\pi < \theta < 2\pi$ ,  $\sin\theta$  becomes negative: the signal inverts sign.

b. Use the data to determine the RF field strength in Hz and in  $\text{rad}\cdot\text{s}^{-1}$ .

null at  $\tau_\pi = 20.5 \mu\text{s}$ , thus  $\theta = \pi$  at that pulse length.

$$f_1 = \frac{\theta}{2\pi\tau} = \frac{\pi}{2\pi\tau} = \frac{1}{2\tau} = \frac{1}{2 \times 20.5 \times 10^{-6}} = 2.439 \times 10^4 \text{ Hz} = 24.39 \text{ kHz}$$

$$\text{thus, one has: } \omega_1 = 2\pi f_1 = \frac{\pi}{\tau} = \frac{\pi}{20.5 \times 10^{-6}} = 1.5325 \times 10^5 \text{ rad}\cdot\text{s}^{-1}$$

c. Find the length of a  $90^\circ$  pulse.

$$\text{at } \frac{\pi}{2}: \quad \tau_{90} = \frac{\pi/2}{\omega_1} = \frac{1}{2} \tau_\pi = \frac{20.5}{2} = 10.25 \mu\text{s}$$

d. At what pulse length will the next null be observed?

null occurs at  $\theta = n\pi$

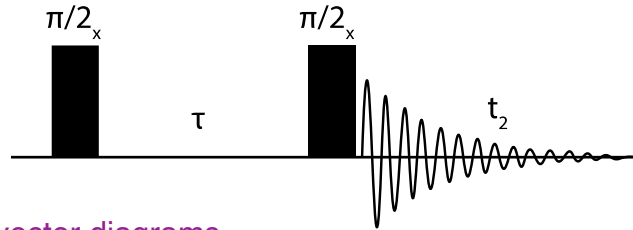
the next null after  $\theta = \pi$  will occur at  $\theta = 2\pi$

$$\text{thus: } \tau_{2\pi} = 2\tau_\pi = 2 \times 20.5 = 41 \mu\text{s}$$

# Jigsaw 5C

## Vector Model: Effect of pulses

1. A pulse sequence is shown below.



missing vector diagrams...

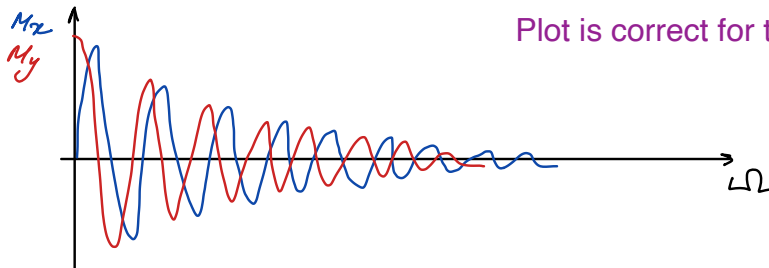
a. Use vector diagrams to predict the outcome of the sequence when applied to equilibrium magnetization. In your answer, set up a table describing the values of x-, y- and z- magnetizations after each element of the pulse sequence.  $\Omega$  - offset

careful with effects of pulses and signs; x pulse puts z magnetization onto the -y axis

An x pulse has no effect on the x-magnetization; a pulse will rotate the magnetization about the axis along which the pulse is directed. After the second 90deg x pulse,  $M_x = M_0 \cdot \sin(\Omega \tau)$   
 $M_y = 0$ ;  $M_z = -M_0 \cdot \cos(\Omega \tau)$  (negative, since it was negative in the third row of the table)

	$M_x$	$M_y$	$M_z$
initial	0	0	$M_0$
$\pi/2_x$	0	$-M_0$	0
$\tau$	$M_0 \sin(\Omega \tau)$	$M_0 \cos(\Omega \tau)$	0
$\pi/2_x$	<del>0</del>	<del><math>M_0 \cos(\Omega \tau)</math></del>	<del><math>M_0 \sin(\Omega \tau)</math></del>
$t_2$	$M_0 \cos(\Omega \tau) \cdot \sin(\Omega t_2)$	$M_0 \cos(\Omega \tau) \cdot \cos(\Omega t_2)$	$-M_0 \sin(\Omega \tau) \cdot \cos(\Omega t_2)$

b. For a fixed delay  $\tau$ , sketch a graph of the x- and y-magnetization as a function of the offset  $\Omega$  between the transmitter frequency and Larmor frequency  $\Omega = (\omega \tau - \omega_0)$  during  $t_2$ .



Plot is correct for the values from the table

c. At what values of  $\Omega \tau$  do any nulls occur?

$$\cos(\Omega \tau) = 0 \Rightarrow \Omega \tau = \left(n + \frac{1}{2}\right) \pi, n = 0, 1, 2, \dots$$

Missing answer for sin function

2. In a simple pulse-acquire experiment, to determine a pulse length, an operator observed a positive signal for pulse lengths of 5 and 10  $\mu\text{s}$ . As the pulse was lengthened further the intensity decreased, went through a null at 20.5  $\mu\text{s}$  and then became negative.

- a. Explain what is happening in this experiment.  $\theta = \gamma B_1 t$

at  $\theta = \pi$  magnetisation flipped to  $-z$

$\Rightarrow$  for  $\theta > \pi$ , magnetisation changes sign

Need a bit more detail...

- b. Use the data to determine the RF field strength in Hz and in  $\text{rad}\cdot\text{s}^{-1}$ .

$$\pi = \gamma B_1 t_{\text{null}} = \omega_1 t_{\text{null}}$$

$$\Rightarrow \omega_1 = \frac{\pi}{t_{\text{null}}} = \frac{\pi}{20,5 \cdot 10^{-6}} = 1,53 \cdot 10^5 \text{ rad/s}$$

$$\nu_1 = \frac{\omega_1}{2\pi} = 2,44 \cdot 10^4 \text{ Hz}$$

- c. Find the length of a  $90^\circ$  pulse.

$$t_{90} = \frac{t_{\text{null}}}{2} = 10,25 \mu\text{s}$$

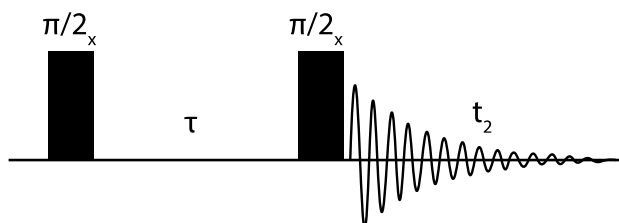
- d. At what pulse length will the next null be observed?

$$t_{2, \text{null}} = 2 \cdot t_{\text{null}} = 41 \mu\text{s}$$

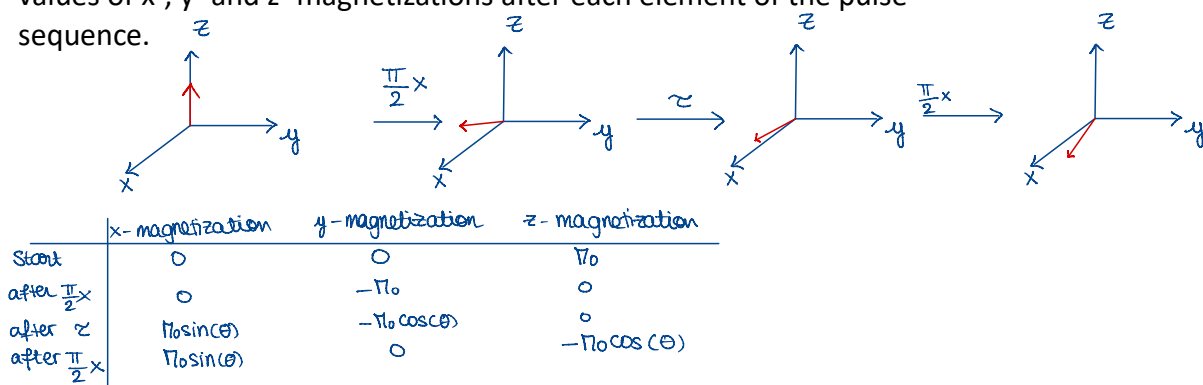
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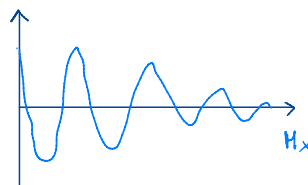
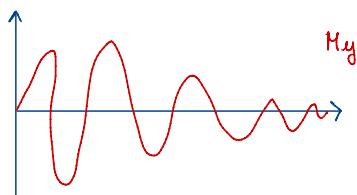
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