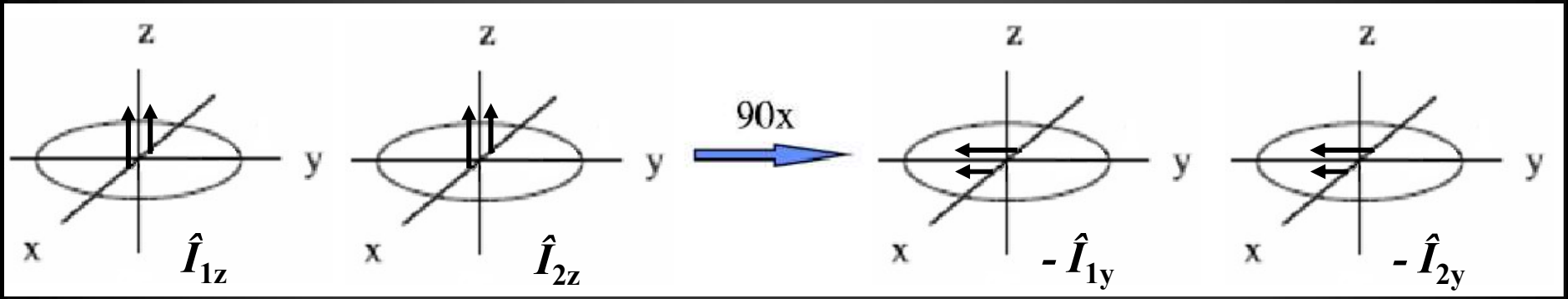
COSY

Product operator formalism:

$\pi/2 - t_1 - \pi/2 - t_2$ (acquisition)

1st stage: 1st 90°x

$$\hat{I}_{1z} + \hat{I}_{2z} \xrightarrow{\pi/2\ x} -\hat{I}_{1y} - \hat{I}_{2y}$$



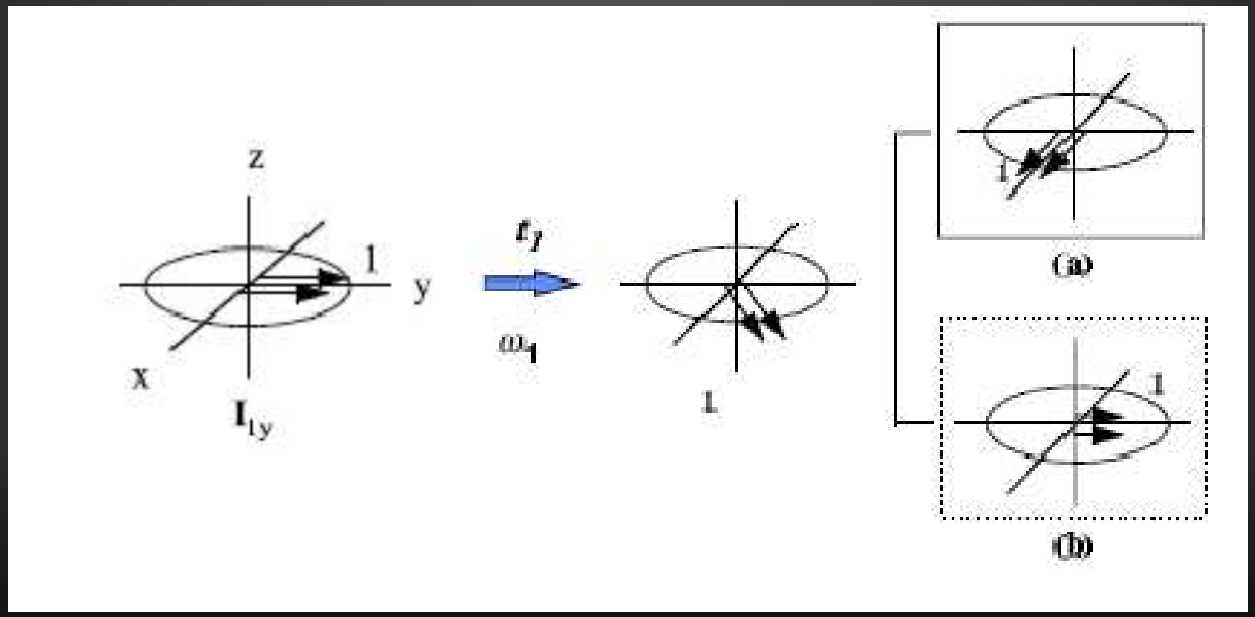
COSY

Product operator formalism:

2nd stage: chemical shift **(Ω) and** ***(J) evolution at t_1***

$$-\hat{I}_{1y} - \hat{I}_{2y} \xrightarrow{\Omega_1 t_1 \hat{I}_{1z} + \Omega_2 t_1 \hat{I}_{2z}}$$

$$-\hat{I}_{1y}\cos(\Omega_1 t_1) + \hat{I}_{1x}\sin(\Omega_1 t_1)$$



COSY

Product operator formalism:

2nd stage: chemical shift **(Ω) and** ***(J) evolution at t_1***

$$-\hat{I}_{1y} - \hat{I}_{2y} \xrightarrow{\Omega_1 t_1 \hat{I}_{1z} + \Omega_2 t_1 \hat{I}_{2z}}$$

$$-\hat{I}_{1y}\cos(\Omega_1 t_1) + \hat{I}_{1x}\sin(\Omega_1 t_1) - \hat{I}_{2y}\cos(\Omega_2 t_1) + \hat{I}_{2x}\sin(\Omega_2 t_1)$$

COSY

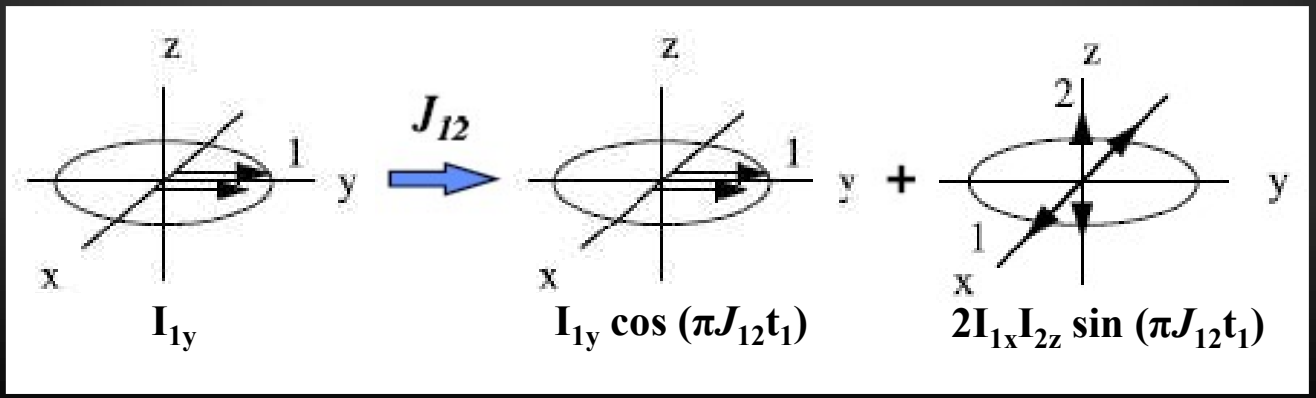
Product operator formalism:

2nd stage: chemical shift (Ω) and (J) evolution at t_1

$$- \hat{I}_{1y} \cos(\Omega_1 t_1) + \hat{I}_{1x} \sin(\Omega_1 t_1) - \hat{I}_{2y} \cos(\Omega_2 t_1) + \hat{I}_{2x} \sin(\Omega_2 t_1)$$

$$\pi J_{12} t_1 2(\hat{I}_{1z}\hat{I}_{2z}) \rightarrow$$

$$- \hat{I}_{1y} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1x} \hat{I}_{2z} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$



COSY

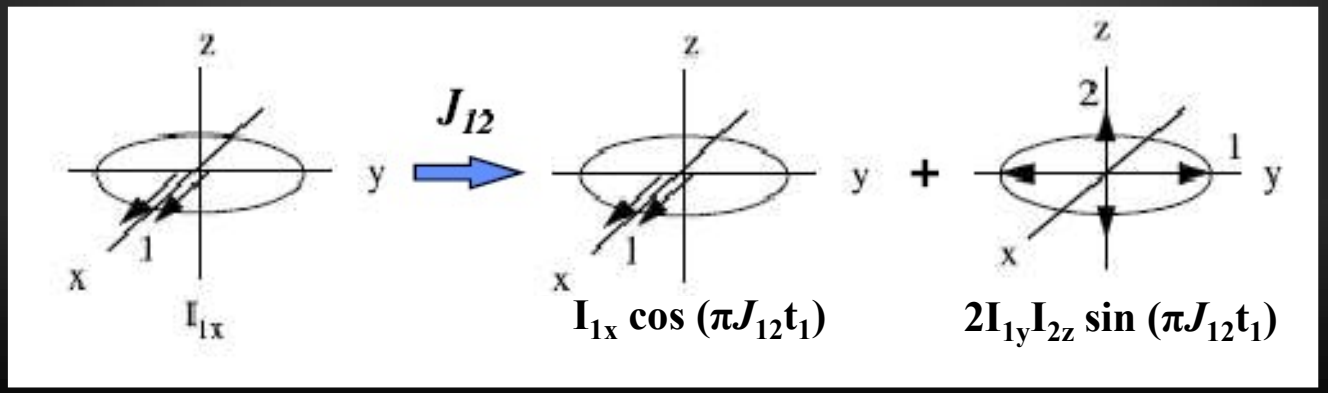
Product operator formalism:

2nd stage: chemical shift (Ω) and (J) evolution at t_1

$$- \hat{I}_{1y} \cos(\Omega_1 t_1) + \hat{I}_{1x} \sin(\Omega_1 t_1) - \hat{I}_{2y} \cos(\Omega_2 t_1) + \hat{I}_{2x} \sin(\Omega_2 t_1)$$

$$\xrightarrow{\pi J_{12} t_1 2(\hat{I}_{1z}\hat{I}_{2z})}$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$



COSY

Product operator formalism:

2nd stage: chemical shift (Ω) and (J) evolution in t_1

$$- \hat{I}_{1y} \cos(\Omega_1 t_1) + \hat{I}_{1x} \sin(\Omega_1 t_1) - \hat{I}_{2y} \cos(\Omega_2 t_1) + \hat{I}_{2x} \sin(\Omega_2 t_1)$$

$$\xrightarrow{\pi J_{12} t_1 2(\hat{I}_{1z}\hat{I}_{2z})}$$

$$\begin{aligned}
&- \hat{I}_{1y} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2\, \hat{I}_{1x}\, \hat{I}_{2z} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1) \\
&+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2\, \hat{I}_{1y}\, \hat{I}_{2z} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \\
&- \hat{I}_{2y} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2\, \hat{I}_{1z}\, \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1) \\
&+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2\, \hat{I}_{1z}\, \hat{I}_{2y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)
\end{aligned}$$

COSY

Product operator formalism:

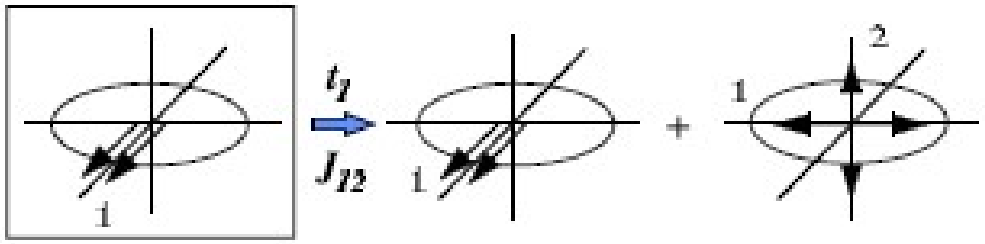
$$- \hat{I}_{1y} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1x} \hat{I}_{2z} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- \hat{I}_{2y} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

In-phase single-quantum antiphase single-quantum



$\hat{I}_{1x} \sin(\Omega_1 t_1)$ In-phase $\hat{I}_{1x}$ $\cos(\pi J_{12} t_1)$ Antiphase $\hat{I}_{1y} \hat{I}_{2z}$ $\sin(\pi J_{12} t_1)$

COSY

Product operator formalism:

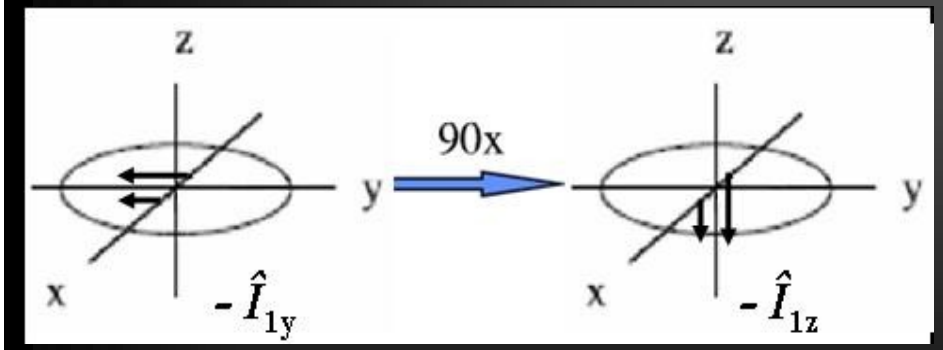
$$-\hat{I}_{1y}\cos(\Omega_1 t_1)\cos(\pi J_{12} t_1) + 2\,\hat{I}_{1x}\hat{I}_{2z}\cos(\Omega_1 t_1)\sin(\pi J_{12} t_1)$$

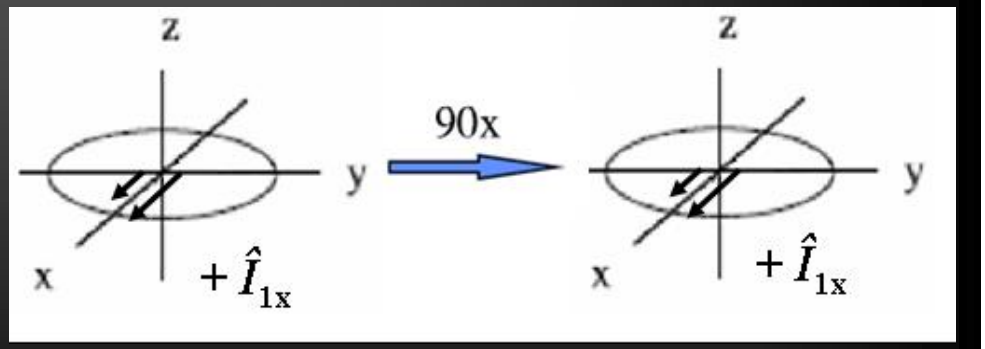
$$+\hat{I}_{1x}\sin(\Omega_1 t_1)\cos(\pi J_{12} t_1) + 2\,\hat{I}_{1y}\hat{I}_{2z}\sin(\Omega_1 t_1)\sin(\pi J_{12} t_1)$$

$$-\hat{I}_{2y}\cos(\Omega_2 t_1)\cos(\pi J_{12} t_1) + 2\,\hat{I}_{1z}\hat{I}_{2x}\cos(\Omega_2 t_1)\sin(\pi J_{12} t_1)$$

$$+\hat{I}_{2x}\sin(\Omega_2 t_1)\cos(\pi J_{12} t_1) + 2\,\hat{I}_{1z}\hat{I}_{2y}\sin(\Omega_2 t_1)\sin(\pi J_{12} t_1)$$

3rd stage: 2nd 90°x $\pi/2_x$





$$-\hat{I}_{1z}\cos(\Omega_1 t_1)\cos(\pi J_{12} t_1)$$

$$+\hat{I}_{1x}\sin(\Omega_1 t_1)\cos(\pi J_{12} t_1)$$

COSY

Product operator formalism:

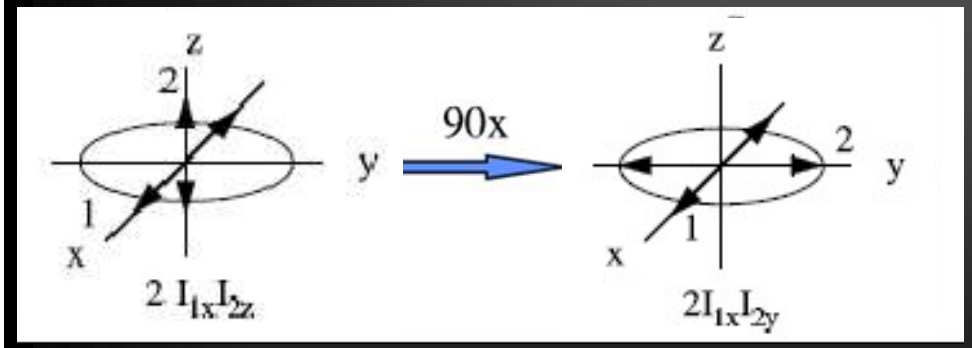
$$- \hat{I}_{1y} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1x} \hat{I}_{2z} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

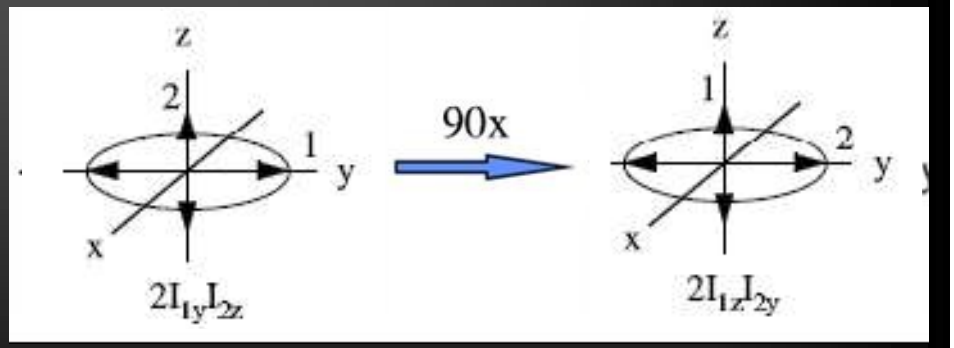
$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- \hat{I}_{2y} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

3rd stage: 2nd 90°x $\pi/2_x$





$$- 2 \hat{I}_{1x} \hat{I}_{2y} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- 2 \hat{I}_{1z} \hat{I}_{2y} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

COSY

Product operator formalism:

$$- \hat{I}_{1y} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1x} \hat{I}_{2z} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- \hat{I}_{2y} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

3rd stage: 2nd 90°x $\xrightarrow{\pi/2\ _x}$

$$- \hat{I}_{1z} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1x} \hat{I}_{2y} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- \hat{I}_{2z} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

COSY

Product operator formalism:

$$- \hat{I}_{1y} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1x} \hat{I}_{2z} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- \hat{I}_{2y} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) + 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

3rd stage: 2nd 90°x $\xrightarrow{\pi/2\ x}$ **M_z** **MQ**

$$- \hat{I}_{1z} \cos(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1x} \hat{I}_{2y} \cos(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$- \hat{I}_{2z} \cos(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2x} \cos(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

4th stage* (acquisition): *chemical shift* (Ω) and (*J*) *evolution at t_2

$\Omega_1 t_2 \hat{I}_{1z} + \Omega_2 t_2 \hat{I}_{2z}$ →

$\pi J_{12} t_2 2(\hat{I}_{1z} \hat{I}_{2z})$ →

COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

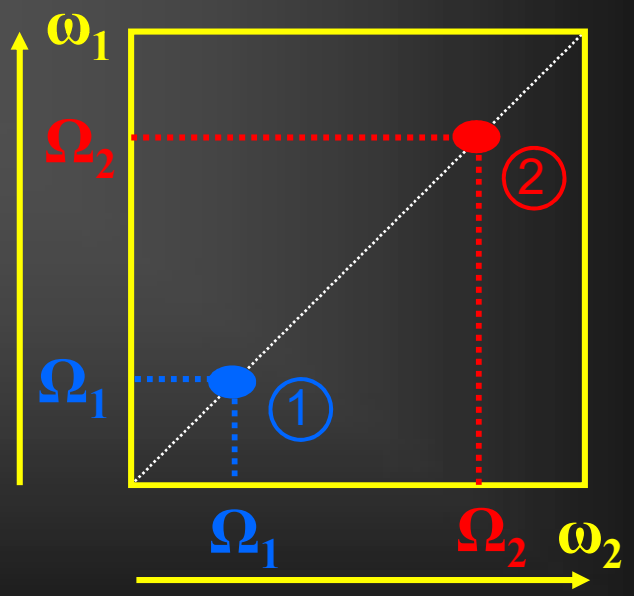
$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

Conclusions:

① $\Omega_{1\,at}\, t_1$ & $\Omega_{1\,at}\, t_2$

② $\Omega_{2\,at}\, t_1$ & $\Omega_{2\,at}\, t_2$

Diagonal peaks



COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

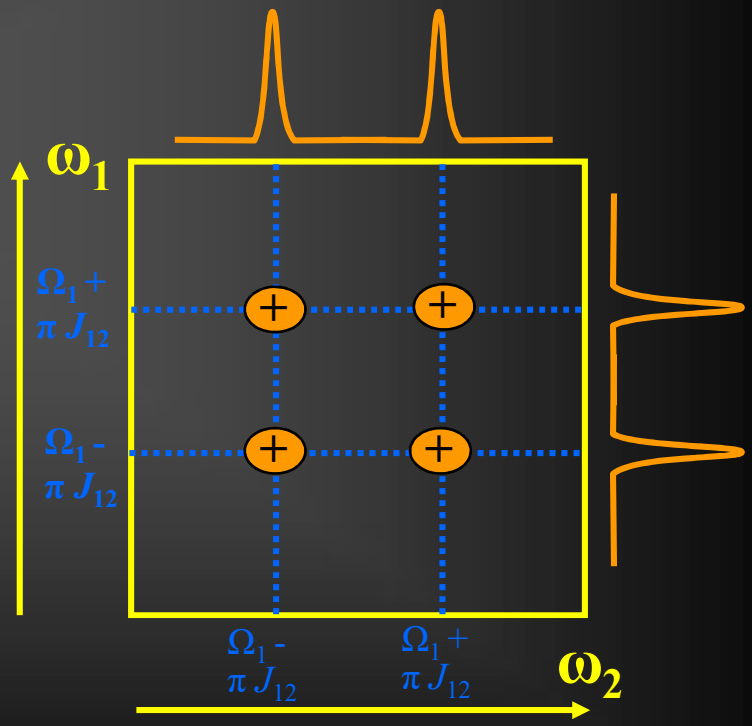
Conclusions:

① $\Omega_{1\,em}\, t_1$ e $\Omega_{1\,em}\, t_2$

Diagonal peak

$$+ \hat{I}_{12x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1)$$

Multiplet "In-phase"



COSY

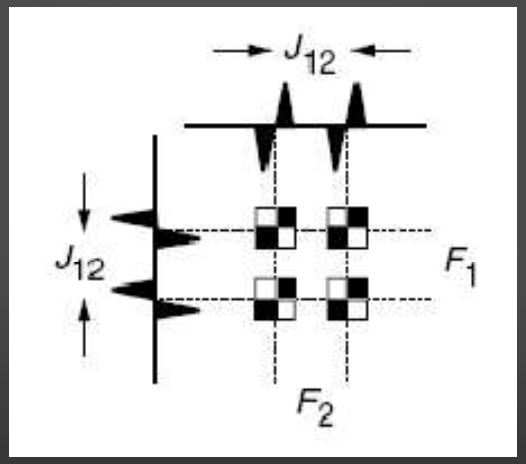
Product operator formalism:

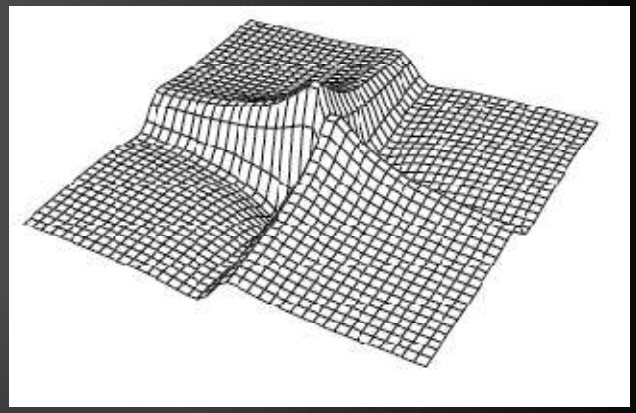
$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

Conclusions:

Doubly dispersive



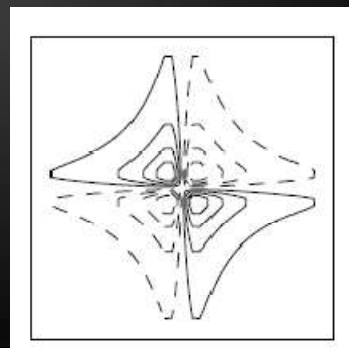


① $\Omega_{1\,at}\, t_1$ & $\Omega_{1\,at}\, t_2$

Diagonal peaks

$$+ \hat{I}_{12x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1)$$

$$\tfrac{1}{2} [\sin(\Omega_1 t_1 + \pi J_{12} t_1) + \sin(\Omega_1 t_1 - \pi J_{12} t_1)]$$



COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \; - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

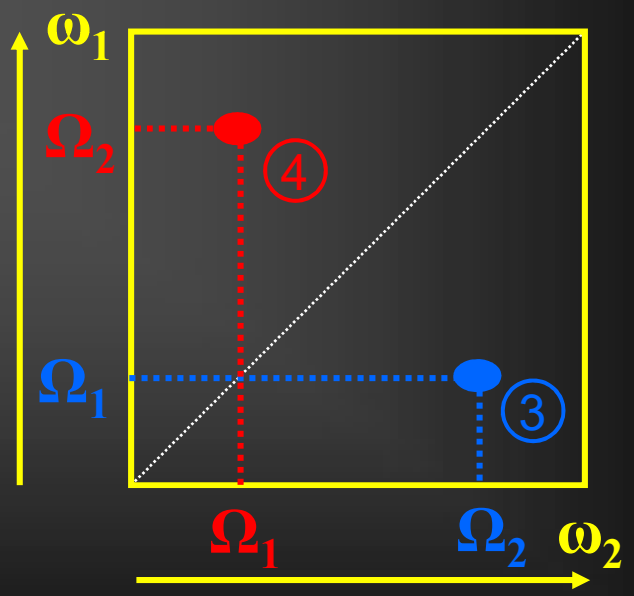
$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \; - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

Conclusions:

③ $\Omega_{1\,at}\, t_1$ & $\Omega_{2\,at}\, t_2$

④ $\Omega_{2\,at}\, t_1$ & $\Omega_{1\,at}\, t_2$

Cross-peaks



COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \boxed{- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)}$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

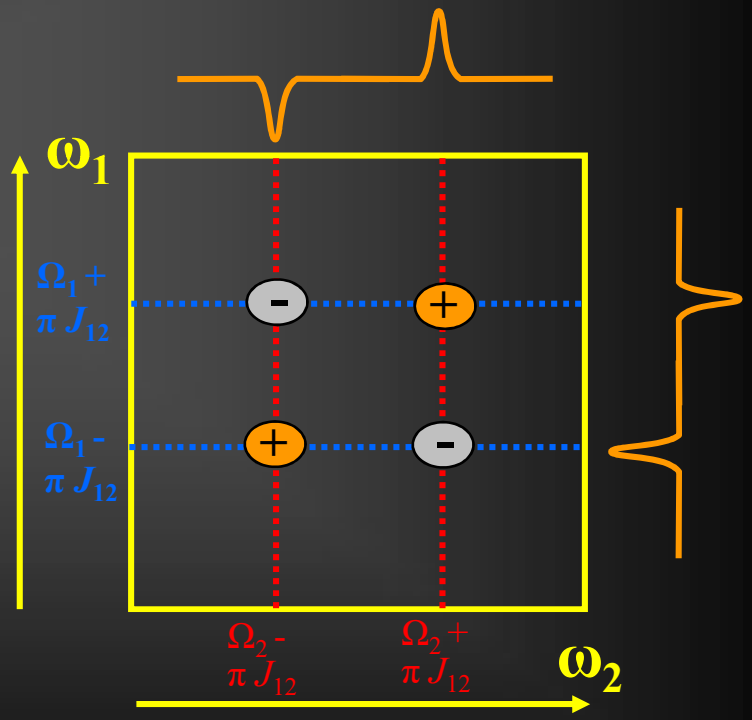
Conclusions:

③ $\Omega_{1\ at}\ t_1$ & $\Omega_{2\ at}\ t_2$

Cross-peak

$$- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

Multiplet “Antiphase”



COSY

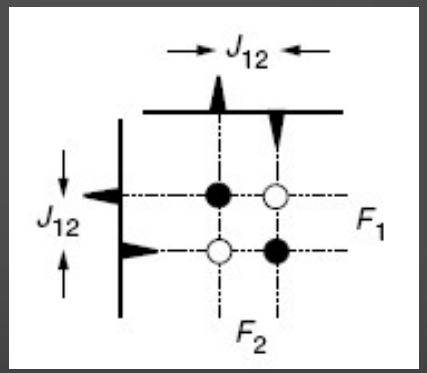
Product operator formalism:

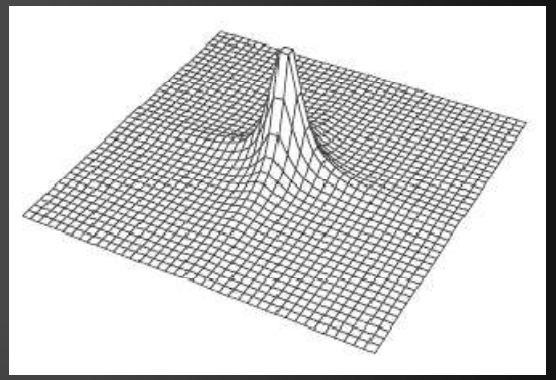
$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \boxed{- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)}$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

Conclusions:

Doubly Absorptive



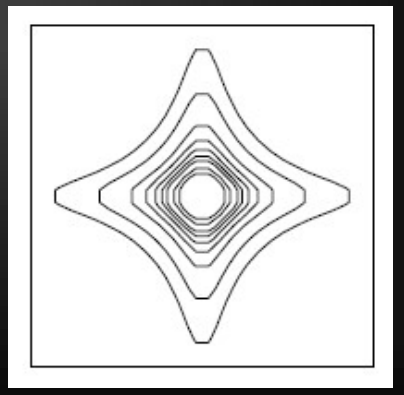


③ $\Omega_{1\,at}\, t_1$ & $\Omega_{2\,at}\, t_2$

Cross-peak

$$- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$\tfrac{1}{2} [-\cos(\Omega_1 t_1 + \pi J_{12} t_1) + \cos(\Omega_1 t_1 - \pi J_{12} t_1)]$$



COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) - 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1)$$

4th stage* (acquisition): *chemical shift* (Ω) and (*J*) *evolution at t_2

$$\xrightarrow{\Omega_1 t_2 \hat{I}_{1z} + \Omega_2 t_2 \hat{I}_{2z}}$$

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_1 t_2) + \hat{I}_{1y} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_1 t_2)$$

$$- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_2 t_2) + 2 \hat{I}_{1z} \hat{I}_{2x} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_2 t_2)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_2 t_2) + \hat{I}_{2y} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_2 t_2)$$

$$- 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_1 t_2) + 2 \hat{I}_{1x} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_1 t_2)$$

$$\xrightarrow{\pi J_{12} t_2 2(\hat{I}_{1z} \hat{I}_{2z})}$$

COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_1 t_2) \cos(\pi J_{12} t_2) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

$$+ \hat{I}_{1y} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_1 t_2) \cos(\pi J_{12} t_2) - 2 \hat{I}_{1x} \hat{I}_{2z} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_2 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{2x} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1z} \hat{I}_{2x} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_2 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_2 t_2) \cos(\pi J_{12} t_2) + 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$+ \hat{I}_{2y} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_2 t_2) \cos(\pi J_{12} t_2) - 2 \hat{I}_{1z} \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_1 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{1x} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1x} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_1 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{1y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

COSY

Product operator formalism:

$$+ \hat{I}_{1x} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_1 t_2) \cos(\pi J_{12} t_2) + 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

$$+ \hat{I}_{1y} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_1 t_2) \cos(\pi J_{12} t_2) - 2 \hat{I}_{1x} \hat{I}_{2z} \sin(\Omega_1 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_2 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{2x} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1z} \hat{I}_{2x} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_2 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{2y} \sin(\Omega_1 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$+ \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_2 t_2) \cos(\pi J_{12} t_2) + 2 \hat{I}_{1z} \hat{I}_{2y} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \cos(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$+ \hat{I}_{2y} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_2 t_2) \cos(\pi J_{12} t_2) - 2 \hat{I}_{1z} \hat{I}_{2x} \sin(\Omega_2 t_1) \cos(\pi J_{12} t_1) \sin(\Omega_2 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1y} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_1 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{1x} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \cos(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$

$$- 2 \hat{I}_{1x} \hat{I}_{2z} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_1 t_2) \cos(\pi J_{12} t_2) + \hat{I}_{1y} \sin(\Omega_2 t_1) \sin(\pi J_{12} t_1) \sin(\Omega_1 t_2) \sin(\pi J_{12} t_2)$$