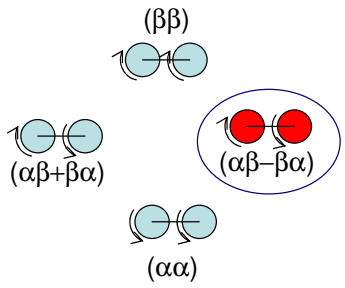
Preparation of a

Hyperpolarized Imaging Probe using para-H_2

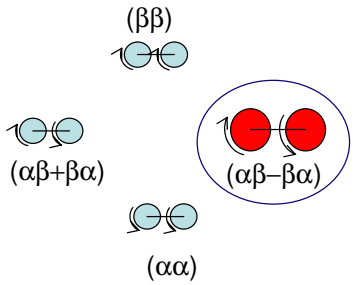
Hyperpolarization ≡ non equilibrium condition

Normal-H_2



RT Equilibrium condition
25% paraH_2
75% orthoH_2

Para -H_2

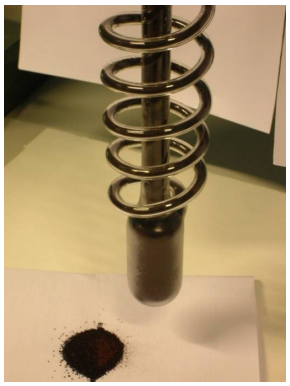


RT non-equilibrium condition
51% paraH_2
49% orthoH_2

Liquid N_2 (77K)
Equilibrium condition
48% para-H_2
52% ortho-H_2

para-H_2

Normal-H_2



Charcoal + Fe_2O_3

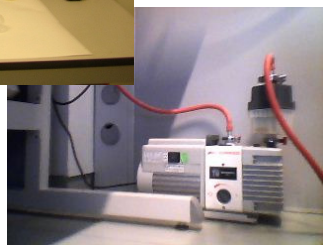
ortho ↔ para

manometer

Vacuum line

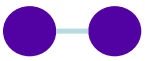
Hydrogen generator

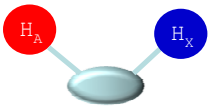
Vacuum pump



The symmetry of the H_2 molecule must be broken

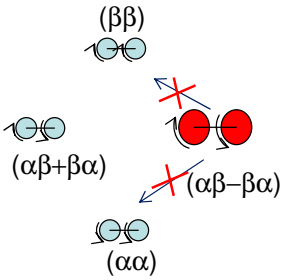
to exploit hyperpolarization effect



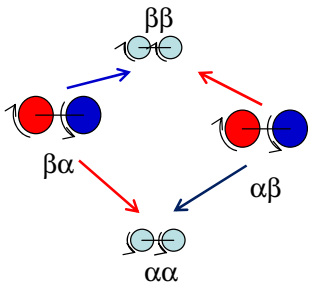


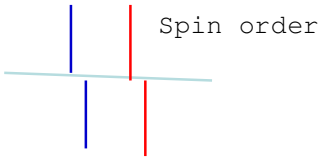
$|\nu_A - \nu_X| >> J_{AX}$

(PASADENA experiment)



Para-H_2 NMR silent





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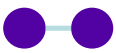
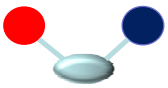
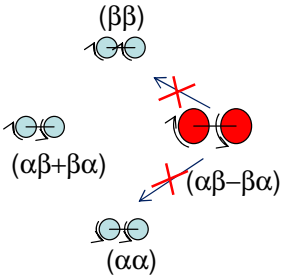


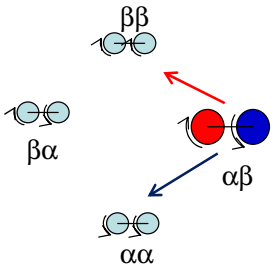


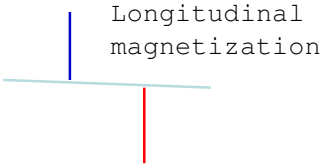
$|\nu_A - \nu_B| \approx J_{AB}$

(Altadena experiment)

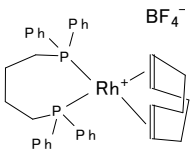


Para-H_2 is NMR silent

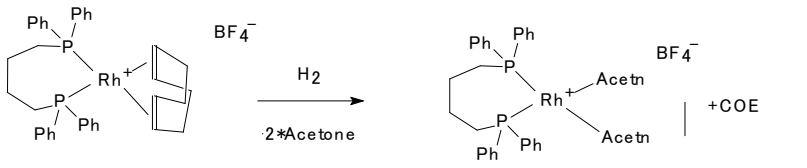




materials



Catalyst activation

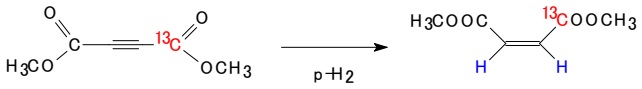


The solution is deoxigenated

NMR tube is freezeD in liq N_2, H_2 (1 bar) is added

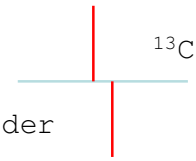
NMR tube is defreezed (H_2 4 bar) and shaken

Parahydrogenation reaction



^{13}C hyperpolarization

Parahydrogenation at earth magnetic field (50 μT)



^{13}C–NMR

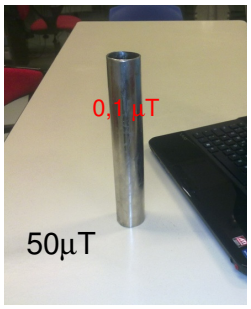
Spin order

Parahydrogenation at (almost) zero field

^{13}C–NMR

Longitudinal magnetization

μ-metal cylinder



50μT

ν_H-ν_C ≈ 1500 Hz >> J_{HC}

Weak ^{1}H–^{13}C coupling → Pasadena-like

→ Spin order

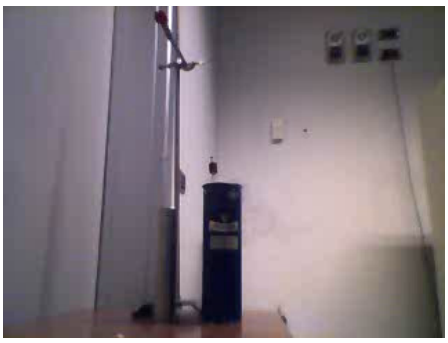
0,1 μT

ν_H-ν_C ≈ 3Hz ≈ J_{HC}

Strong ^{1}H–^{13}C coupling → Altadena-like

→ Longitudinal magnetization

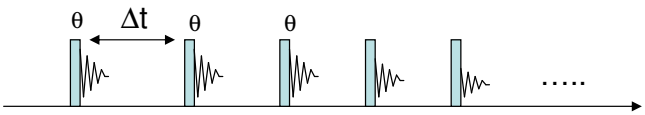
50μT —fast→ 0,1 μT —slow→ 50μT



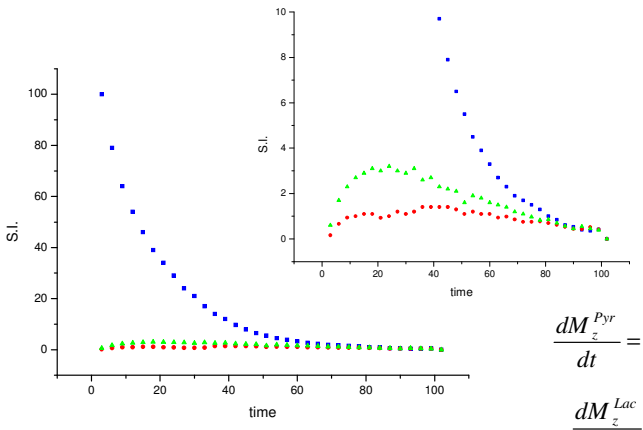
⇒ ^{13}C NMR

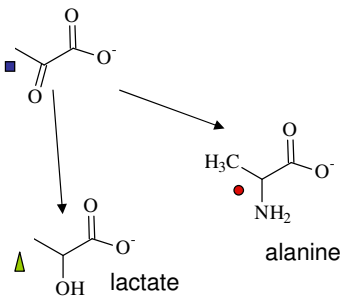
⇒ ^{13}C MRI (1 scan!)

We can follow the fate of hyperpolarized molecules in real time



… if we had HP pyruvate

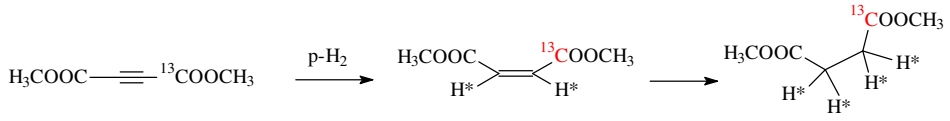


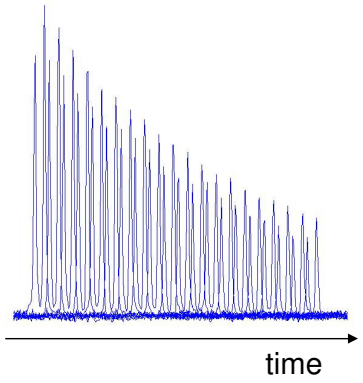


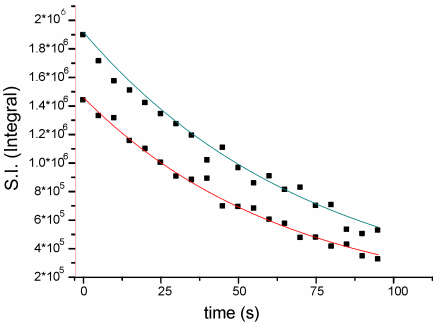
$$\frac{dM_z^{Pyr}}{dt} = -k_{Pyr-Lac} M_z^{Pyr}(t) - \frac{1}{T_1^{Pyr}} M_z^{Pyr}(t)$$

$$\frac{dM_z^{Lac}}{dt} = +k_{Pyr-Lac} M_z^{Pyr} - \frac{1}{T_1^{Lac}} M_z^{Lac}(t)$$

… or merely follow HP decay
(and obtain T_1 in much less time than using IR)







T_1 (MAME)=88s (blue line)

$$M = M_0 \exp(-n\Delta t / T_1)(\cos\theta)^n \sin\theta + A_0$$

M_0=magnetization at time zero, n=repetition number, Δt=5s