

¹³C NMR Signal Enhancement by using Parahydrogen Induced Polarization (PHIP) and Appropriate Pulse Sequences

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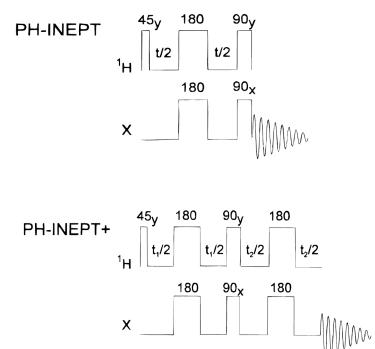
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Introduction

Parahydrogen induced polarization (PHIP) has turned out to be a versatile technique to obtain hyperpolarized molecules exhibiting strong NMR signals via a chemical approach. PHIP makes use of breaking the high initial symmetry of parahydrogen during homogeneously catalyzed hydrogenations of unsaturated substrates and, therefore, of the creation of nonequivalent protons in the products. Consequently, the population of the energy levels of their spin states deviates from the Boltzmann distribution characteristic for systems in thermal equilibrium. This leads to absorption and emission signals in the NMR spectra if recorded *in situ* and a theoretical signal increase of up to 10^5 , which is in practice limited by relaxation processes in the product. Transfer of polarization to hetero-nuclei can be implemented randomly in weak magnetic fields or selectively via special pulse sequences. Optimization of polarization transfer to e.g. ¹³C is crucial for applications like metabolic imaging where the highest possible ¹³C polarization is required to obtain high SNR images [1].

Method

The symmetry properties of molecular hydrogen give rise to two spin isomers, the magnetic orthohydrogen ($I = 1$) and the nonmagnetic parahydrogen ($I = 0$). Normal H₂ consists of 75% of ortho- and 25% parahydrogen. As the latter is thermodynamically favored, it can be enriched up to 98%. If the hydrogenation is conducted at low magnetic field, followed by transfer into the NMR magnet and subsequent spectra acquisition, the experiment is referred to as Adiabatic Longitudinal Transport After Dissociation Engenders Nuclear Alignment (ALTADENA), leading to signals either in net absorption or emission. If the hydrogenation and NMR measurement are carried out in high field, it is termed Parahydrogen And Synthesis Allow Dramatically Enhanced Nuclear Alignment (PASADENA), leading to characteristic antiphase signals exhibiting both absorption and emission of the NMR resonances resulting from the respective protons. To achieve a polarization transfer to ¹³C we applied the PH-INEPT and the PH-INEPT+ sequence shown in scheme 1 to a PASADENA experiment under pressure at elevated temperature [2, 3].



Scheme 1 Pulse sequences
PH-INEPT and PH-INEPT+ [1]

Result

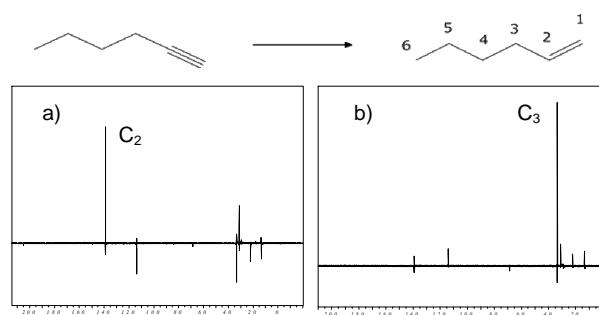


Fig. 1 ¹³C PH-INEPT+ NMR spectra of 1-hexyne in acetone-d₆ at ~50°C with a delay of a) 10 ms and b) 15 ms

Two pulse sequences were compared with regard to their efficiency of polarization transfer to ¹³C, namely the PH-INEPT and the PH-INEPT+ sequence. Regarding our model compound 1-hexyne the PH-INEPT+ sequence showed higher signal enhancements displayed in fig. 1. The obtained ¹³C PH-INEPT+ NMR spectra of 1-hexyne in acetone-d₆ at ~50°C performed with delays of a) 10 ms and b) 15 ms shows signal enhancements for all carbons of the hydrogenation product 1-hexene. The highest polarization transfer for a delay time of 10 ms was observed for carbon 2 with a signal increase of 3500, whereas a delay of 15 ms transferred most of the polarization to carbon 3 with a signal increase of nearly 4000.

Conclusion

Spontaneous polarization transfer from ¹H to ¹³C in the parahydrogenation product 1-hexene under ALTADENA conditions only showed signal enhancements less than 100. By applying appropriate pulse sequences to a "PASADENA under pressure" experiment we achieved polarization transfers to ¹³C yielding a signal enhancement of up to 4000.

References

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