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^{7}Li,^{31}P Shift correlation. Application to the structural assignment of benzyllithium complexes of *N*-methyl-*N*-benzylphosphinamide†

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A correlation experiment between ^{7}Li and ^{31}P nuclei through scalar coupling is described for the first time. The utility of the method is demonstrated by identifying the species formed in the benzylic lithiation of *N*-benzyl-*N*-methyldiphenylphosphinamide in Et$_2$O solution.

Understanding the chemical behaviour of organolithium compounds is generally complicated by the presence of different species in the reaction medium.[1] In a first approach, the aggregation state of these species must be determined. For lithium organophosphorus complexes this information may be readily obtained *via* the ^nJ-couplings (n = 1, 2) between the phosphorus and the lithium nuclei.[2] For example, the observation of $^2J_{PLi}$ provides insight into the structure of lithiated reagents involved in Wittig-type olefination reactions.[2d,3] This simple strategy proved to be also very effective for the elucidation of the ion pair structure of organolithium compounds through HMPA titration studies.[4] The observation of P,Li coupling constants of both lithium isotopes is well documented.[5] However, only ^{31}P,^{6}Li shift correlations are known.[6] The ^{6}Li nucleus gives rise to sharper signals and longer relaxation times than the ^{7}Li isotope due to its smaller quadrupolar moment. The major drawback of ^{6}Li NMR correlation experiments is that, as a consequence of the relatively low receptivity of the metal nucleus derived from its low natural abundance (7.4%), they require the use of uniformly ^{6}Li-enriched samples ($>$95% isotopic abundance) to attain reasonable measuring times. In contrast, the ^{7}Li nucleus is highly abundant (92.6%) and has a large magnetogyric constant (ratio $\gamma(^7\text{Li})/\gamma(^6\text{Li}) = 2.64$). These characteristics allow ^{7}Li NMR spectra to be measured readily with the additional benefits of larger dispersion of signals and coupling constants than those of the ^{6}Li isotope. Two main limitations may be envisaged in designing ^{31}P,^{7}Li correlation experiments: the signal width of the ^{7}Li signals and the small difference between the frequencies of resonance of both heteronuclei. ^{7}Li is a nucleus of moderate quadrupolar moment that usually exhibits short longitudinal (T_1) and transversal (T_2) relaxation times. These features imply that transverse magnetization arising from broad signals may be completely lost during the delays included in a pulse sequence due to relaxation *via* T_2, so that no correlation will be finally observed. This effect will be exacerbated at the low temperatures conventionally used in the NMR study of organolithium compounds to slow down chemical exchange processes, thus preventing the detection of any correlation above the noise level.

Herein we describe the first application of the 2D HMQC pulse sequence for the spin pair ^{31}P,^{7}Li. The scope of the method is illustrated through variable concentration and temperature NMR studies of **Li$^+$1$^-$** in Et$_2$O-d_{10} prepared by treating *N*-benzyl-*N*-methyldiphenylphosphinamide **1** (Ph$_2$P(O)N(Me)CH$_2$Ph) with LiBu^t (ratio 1 : 1.4).‡ In order to slow down chemical exchange processes all NMR experiments were performed at temperatures below −90 °C. The resolution enhanced ^{31}P{^{1}H} NMR spectrum of **Li$^+$1$^-$** for a 0.1 M sample is given in Fig. 1a. It shows the presence of 3 signals **I** : **II** : **III** in a ratio of 4 : 12 : 84. Signal **I** at δ 37.21 ppm exhibits a broad shape, whereas signals **II** and **III** split into apparent broad doublets. Similar unusual line shapes arising from the coupling of one phosphorus to one ^{7}Li nucleus (I = 3/2) are precedented.[4b–e] The confirmation that the split observed does indeed proceed from the scalar coupling to ^{7}Li was obtained through the acquisition of the ^{31}P{^{7}Li,^{1}H} NMR spectrum.† Under simultaneous ^{1}H and ^{7}Li decoupling all phosphorus signals appear as sharp singlets (Fig. 1b). The variations of the line shape in solution of a I = 1/2 nucleus coupled to a quadrupolar nucleus have been explained in terms of relaxation effects and the magnitude of the scalar coupling.[7]

The ^{7}Li NMR spectrum was not affected by line shape distortions. Under appropriate resolution enhancement three multiplets labeled **A** to **C** (Fig. 1c) are observed: δ 0.48 (d, $^2J_{PLi}$ = 2.6 Hz), 0.42 (d, $^2J_{PLi}$ = 8.3 Hz), −0.81 (t, $^2J_{PLi}$ = 6.1 Hz) ppm. The multiplicity of the lithium signals indicates that the lithium nucleus **C** is coupled to two phosphorus nuclei, whereas the lithiums **A**, **B** are coupled only to one ^{31}P. Intensity criteria would allow only the identification of the pair **III**-**B**. The complete assignment of the ^{31}P and ^{7}Li NMR spectra was carried out through the 2D shift correlation between the two heteronuclei. For that purpose, we selected the 2D HMQC pulse scheme modified to accomplish ^{1}H decoupling during all of the experiment (Fig. 2). The elimination of the refocusing period preceding the acquisition of the FID is a

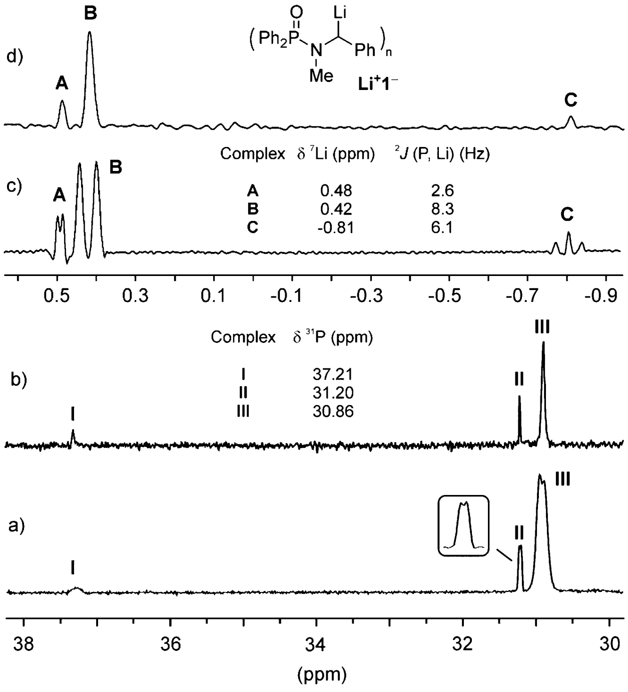

Fig. 1 NMR spectra of a 0.1 M sample of **Li$^+$1$^-$** at −105 °C in Et$_2$O-d_{10}. (a) ^{31}P{^{1}H} (202.46 MHz), including an expansion of **II**; (b) ^{31}P{^{7}Li,^{1}H} (202.46 MHz); (c) ^{7}Li{^{1}H}; and (d) ^{7}Li{^{31}P,^{1}H} NMR (194.37 MHz). Gaussian multiplication of the FID (parameters: LB = −6, GB = 0.14 for ^{31}P, and LB = −8, GB = 0.24 for ^{7}Li) prior to the Fourier transformation was applied.

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† Electronic Supplementary Information (ESI) available: General NMR data, ^{1}H, ^{31}P HMQC NMR rows for the three major signals **I**, **II**, **III** at −105 °C in Et$_2$O-d_{10}, monomer–dimer equilibrium evaluation of **Li$^+$1$^-$**, ^{13}C{^{1}H,^{31}P} NMR spectrum and expansion of the lithiated carbon region at −105 °C. See http://www.rsc.org/suppdata/cc/b4/b400994K/

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precaution necessary to minimize losses of magnetization along the pulse sequence.

Two detection modes are possible. The higher receptivity of ^{31}P *vs.* ^{7}Li makes it advantageous to use ^{31}P observation ($R^{C}(^{31}P)/R^{C}(^{7}Li) \approx 2.5$. However, ^{7}Li detection will require shorter overall measuring times due to its rapid relaxation with respect to ^{31}P. Fig. 2 shows the first example of $^{7}Li,^{31}P\{^{1}H\}$ HMQC spectra.§ All possible correlations could be observed, thus establishing the connectivity between the ^{31}P signals **I** and **II** with the triplet **C** and the doublet **A**, respectively.

Standard ^{13}C, DEPT, $^{1}H,^{13}C$ gHMQC, and $^{1}H,^{31}P$ gHMQC NMR spectra showed that all species in solution are benzylic anions. The metallated carbon of complexes **II-A** and **III-B** appears at δ 62.96 and 61.83 ppm, respectively.†[8] What is more important, in the $^{13}C\{^{31}P,^{1}H\}$ NMR spectrum the signal at δ 62.96 resolves into a 1 : 1 : 1 : 1 quartet of $^{1}J(^{13}C,^{7}Li)$ 11.2 Hz. This coupling indicates that **II-A** is a monomer. ^{31}P NMR measurements in the concentration range 0.2–0.0025 M revealed that the variations of the integrals of the ^{31}P signals **II** and **III** fit very well for a monomer–dimer equilibrium (K = 0.0058, rms = 0.9997). These data, combined with the $^{31}P,^{7}Li$ couplings observed, allow the assignment of complexes **II-A** and **III-B** to the structures shown in Fig. 3. Most probably, the lithium cations bind to solvent molecules to achieve tetracoordination.[1] These features of **III-B** are in agreement with the crystal structure of the dimer $[PhCHNMe_2Li{\cdot}Et_2O]_2$.[9] It implies that in ether solution $\mathbf{Li^{+}1^{-}}$ exists predominantly as a dimer where the monomeric units are connected through C–Li bridges. Dimers of **II-A** with oxygen atoms bridging the lithium atoms seem to be energetically disfavoured. Such a type of dimer exhibiting a $(OLi)_2$ core may be reasonably assigned to the minor species **I-C** (Fig. 3) based on the triplet observed for the ^{7}Li signal. An analogous situation has been found in dimeric $\{[Ph(2\text{-}Pyr)NLi]{\cdot}[(Me_2N)_3PO]\}_2$.[10] The solid state structure consists of a mixture of two isomers showing $(NLi)_2$ and $(OLi)_2$ rings. Structures similar to **II-A** and **I-C** have been proposed as possible species resulting from the lithiation of a *N*-benzylphosphoric triamide in THF.[11] Significantly, neither $^{13}C,^{7}Li$ nor $^{31}P,^{7}Li$ couplings could be resolved at −108 °C. To our knowledge, this is the first time that the solution structure of a benzyllithium bearing a phosphinamide group at the carbanionic center has been spectroscopically characterised.

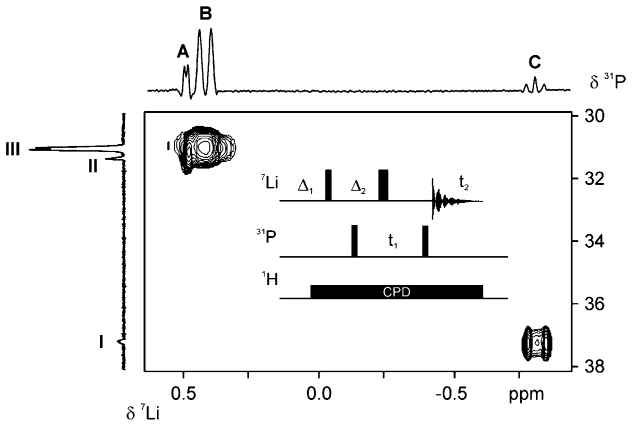

Fig. 2 $^{7}Li,^{31}P\{^{1}H\}$ HMQC spectrum (194.37 MHz) of $\mathbf{Li^{+}1^{-}}$ at −105 °C in $Et_2O\text{-}d_{10}$. The inset shows the pulse sequence used (thin and thick bars represent 90° and 180° pulses, respectively).

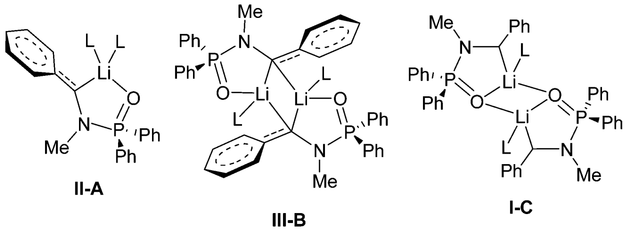

Fig. 3 Benzylic anions **II-A, III-B** and **I-C** constructed through C_2–Li_2 and O_2–Li_2 cores bridges, respectively (L = Et_2O).

In summary, 2D $^{7}Li,^{31}P$ heteronuclear shift correlation through scalar coupling has been succesfully applied to the identification of the complexes formed upon benzylic lithiation of *N*-benzyl-*N*-methyldiphenylphosphinamide in Et_2O solution. The new method is an important tool for elucidating the solution structure of lithium organophosphorus compounds that avoids the use of labeled substances.

Notes and references

‡ *Sample preparation*: 41 μL of a 1.7 M $LiBu^{t}$ solution in pentane were placed in a Schlenk and evaporated under vacuum at −30 °C. Then 0.3 mL of dry $Et_2O\text{-}d_{10}$ were added and this solution was transferred *via* cannula to a NMR tube containing a solution of *N*-benzyl-*N*-methyldiphenylphosphinamide **1** (16.1 mg) dissolved in 0.2 mL of dry $Et_2O\text{-}d_{10}$ at −90 °C. The sample was transferred to the magnet at the same temperature.

§ *Selected* $^{7}Li,^{31}P\{^{1}H\}$ *HMQC parameters*: spectral width, 5200 Hz for ^{31}P and 1360 Hz for ^{7}Li; 38 increments recorded; final matrix after zero filling, 2048 × 128; evolution delay of $^{n}J_{PLi}$, 16 ms; 256 scans per increment in F1; qsine multiplication of $\pi/2$ in F2 and Gaussian multiplication of LB = −6, GB = 0.3 in F1 prior to transformation (magnitude mode). Repetition delay of 0.2 s. Time = 2 h 40 min.

1 W. Bauer and P. v. R. Schleyer, *Adv. Carbanion Chem.*, 1992, **1**, 89.
2 (*a*) J. Colquhoun, H. C. E. McFarlane and W. McFarlane, *J. Chem. Soc., Chem. Commun*, 1982, 220; (*b*) R. E. Mulvey, K. Wade, D. R. Armstrong, G. T. Walker, R. Snaith, W. Clegg and D. Reed, *Polyhedron*, 1987, **6**, 987; (*c*) D. Barr, M. J. Doyle, R. E. Mulvey, P. R. Raithby, D. Berd, R. Snaith and D. S. Wright, *J. Chem. Soc., Chem. Commun*, 1989, 318; (*d*) S. E. Denmark, P. C. Miller and S. R. Wilson, *J. Am. Chem. Soc.*, 1991, **113**, 1468; (*e*) F. E. Romesberg, J. H. Gilchrist, A. T. Harrison, D. J. Fuller and D. B. Collum, *J. Am. Chem. Soc.*, 1991, **113**, 5751; (*f*) F. López-Ortiz, E. Peláez-Arango, B. Tejerina, E. Pérez-Carreño and S. García-Granda, *J. Am. Chem. Soc.*, 1995, **117**, 9972.
3 (*a*) S. E. Denmark, K. A Swiss and S. R. Wilson, *J. Am. Chem. Soc.*, 1993, **115**, 3826; (*b*) S. E. Denmark, K. A Swiss and S. R. Wilson, *Angew. Chem., Int. Ed. Engl.*, 1996, **35**, 2515; (*c*) I. Fernández, J. M. Álvarez-Gutiérrez, N. Kocher, D. Leusser, D. Stalke, J. González and F. López-Ortiz, *J. Am. Chem. Soc.*, 2002, **124**, 15184.
4 (*a*) L. M. Jackman and X. Chen, *J. Am. Chem. Soc.*, 1992, **114**, 403; (*b*) H. J. Reich, J. P. Borst, R. R. Dykstra and D. P. Green, *J. Am. Chem. Soc.*, 1993, **115**, 8728; (*c*) H. J. Reich, J. P. Borst and R. R. Dykstra, *Tetrahedron*, 1994, **50**, 5869; (*d*) H. J. Reich, J. E. Holladay, J. D. Mason and W. H. Sikorski, *J. Am. Chem. Soc.*, 1995, **117**, 12137; (*e*) H. J. Reich, J. E. Holladay, T. G. Walker and J. L. Thompson, *J. Am. Chem. Soc.*, 1999, **121**, 9769; (*f*) H. J. Reich, W. S. Goldenberg, A. W. Sanders, K. L. Janttzi and C. C. Tzschucke, *J. Am. Chem. Soc.*, 2003, **125**, 3509.
5 H. Günther, in *Advanced Applications of NMR to Organometallic Chemistry*, ed. M. Gielen, R. Willem and B. Wrackmeyer, John Wiley, New York, 1996, ch. 9, pp. 247–290.
6 (*a*) F. E. Romesberg, M. P. Bernstein, J. H. Gilchrist, A. T. Harrison, D. J. Fuller and D. B. Collum, *J. Am. Chem. Soc.*, 1993, **115**, 3475; (*b*) F. López-Ortiz and R. J. Carbajo, *Curr. Org. Chem.*, 1998, **2**, 97.
7 (*a*) J. Bacon, R. J. Gillespie and J. W. Quail, *Can. J. Chem.*, 1963, **41**, 3063; (*b*) N. Murali and B. D. Nageswara-Rao, *J. Magn. Reson. A*, 1996, **118**, 202; (*c*) P. Kofod, *J. Magn. Reson. A*, 1996, **119**, 219; (*d*) G. Fraenkel, S. Subramanian and A. Chow, *J. Am. Chem. Soc.*, 1995, **117**, 6300.
8 The ^{13}C signals of complex **I-C** were either overlapped or below the detection threshold. Full assignment of **II-A** and **III-B** will be published elsewhere.
9 G. Boche, M. Marsch, J. Harbach, K. Harms, B. Ledig, F. Schubert, J. C. W. Lohrenz and H. Ahlbrecht, *Chem. Ber.*, 1993, **126**, 1887.
10 D. Barr, W. Clegg, R. E. Mulvey and R. Snaith, *J. Chem. Soc., Chem. Commun.*, 1984, 700.
11 J. F. K. Müller, M. Zehnder, F. Barbosa and B. Spingler, *Helv. Chim. Acta*, 1999, **82**, 1486.