MAGNETIC RESONANCE IN CHEMISTRY, VOL. 24, 1077–1079 (1986)

Synthesis and EPR and ENDOR Investigations of Coppinger's Radical with Perdeuteriated *tert*-Butyl Groups

J. von Gersdorff, B. Kirste and H. Kurreck*
Institut für Organische Chemie der Freien Universität Berlin, Takustr. 3, 1000 Berlin 33, FRG

The synthesis of Coppinger's radical (galvinoxyl) with perdeuteriated *tert*-butyl groups is described. Its EPR spectrum exhibits markedly decreased line widths (0.015 mT) compared with the unlabelled radical (0.039 mT). The correspondingly higher resolution allows a complete analysis of the ^{13}C hyperfine coupling constants. A comparison of the EPR and ENDOR spectra of unlabelled and of two selectively deuteriated Coppinger's radicals is given.

KEY WORDS EPR ENDOR Galvinoxyl Coppinger's radical Deuteriation

INTRODUCTION

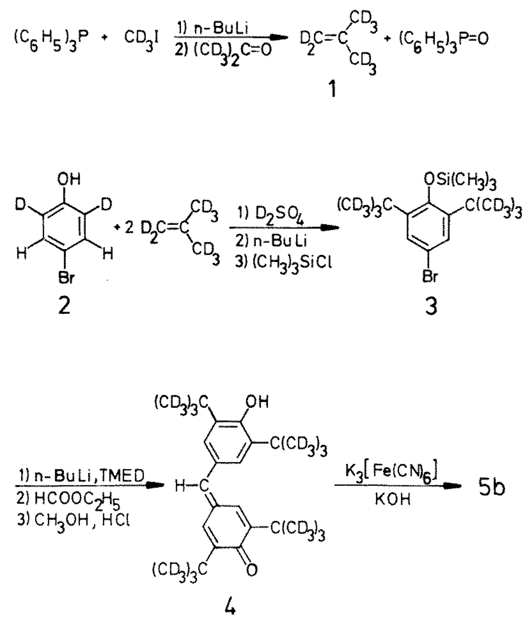
The galvinoxyl radicals and particularly their parent compound, which is also known as Coppinger's radical (**5a**),[1] belong to the most stable organic radicals. They are thermally stable and fairly insensitive towards atmospheric oxygen. Since a multitude of mono-, bi- and oligo-radicals can easily be prepared via an organometallic pathway,[2] galvinoxyls have proved to be excellent model compounds for EPR and ENDOR (electron nuclear double resonance[3]) spectroscopic investigations.[4,5] The stability of galvinoxyls is due to the delocalization of the unpaired electron over two phenoxy moieties and to steric shielding of the oxygen atoms by the bulky *tert*-butyl groups. Whereas the presence of the *tert*-butyl groups is clearly advantageous because of their stabilizing effect, on the other hand they exhibit a disadvantage in spectroscopic investigations. Although the hyperfine coupling of the *tert*-butyl protons is small (coupling constant 0.12 MHz) and hence usually not resolved in EPR spectra (see, however, Ref. 6), the interaction with 36 equivalent protons gives rise to a significant line broadening (see Fig. 1A). The considerable line width (*ca* 0.04 mT) limits the spectral resolution, and decreases the accuracy of line width studies which are employed, for example, in investigations of dynamic effects.[5]

Complete deuteriation of the *tert*-butyl groups should remove these disadvantages since the line width should be decreased by about a factor of three because of the smaller gyromagnetic ratio of deuterons relative to protons ($\gamma_H/\gamma_D \approx 6.5$, but nuclear spin $I_D = 1$). However, the introduction of (perdeuteriated) *tert*-butyl groups is a critical step in the synthesis of galvinoxyls.[7–9] In this paper we report on the synthesis of Coppinger's radical with perdeuteriated *tert*-butyl groups and its characterization by EPR and ENDOR spectroscopy.

EXPERIMENTAL

Compounds

The key step in the synthesis of galvinol **4**, i.e. the introduction of perdeuteriated *tert*-butyl groups, consists in the Friedel–Crafts alkylation of 4-bromo-[2,6-^{2}H$_2$]phenol (**2**) with [^{2}H$_8$]isobutene (**1**) (see Scheme 1). Use of the selectively deuteriated



Scheme 1

---

* Author to whom correspondence should be addressed.

0749–1581/86/121077–03$05.00

Received 9 July 1986
Accepted 17 July 1986

compound **2**, which was obtained from 4-bromophenol by H/D exchange with $NaOD/D_2O$,[10] is necessary to ensure a high degree of deuteriation. [$^2H_8$]isobutene (**1**) was prepared by a Wittig reaction from [$^2H_3$]methyl iodide and [$^2H_6$]acetone. The synthesis of galvinol **4** was achieved by organometallic reaction of the trimethylsilyl protected compound **3** with ethyl formate. The degree of deuteriation of galvinol **4** ($C_{29}H_6D_{36}O_2$, m/z 458) was determined by mass spectrometry [(93.8 ± 0.3)%, measured at low voltage (18 eV)]; the observed isotopic distribution in the range of the molecular ion corresponds to statistical expectation (m/z 451–460, maximum of 24% at m/z 456).

1: To a suspension of triphenyl[$^2H_3$]methylphosphonium iodide (115 g, 0.283 mol), prepared from triphenylphosphine (90.5 g, 0.345 mol) and [$^2H_3$]methyl iodide (50 g, 0.345 mol), in tetrahydrofuran (500 ml), was added dropwise with stirring a solution of *n*-butyllithium (23% in *n*-hexane; 113 ml, 0.28 mol) under nitrogen at room temperature. After dissolution of the orange–red ylide, [$^2H_6$]acetone (18.1 g, 0.283 mol) was added dropwise, resulting in the precipitation of the phosphonium betaine. The betaine was decomposed by cautious heating to the boiling point of the solvent; gaseous **1** which was developing above 40 °C was passed through a condenser (−5 °C) and condensed in a pressure bottle. Yield: 12 g (66%).

3: 12 g of **1** (0.188 mol) were passed through a vigorously stirred solution of **2** (16 g, 0.09 mol) and concentrated D_2SO_4 (3 ml) in cyclohexane (250 ml) for 8 h at 65 °C; unreacted **1** was collected and passed again through the solution. The reaction mixture was washed with 15% NaOH to extract monoalkylated phenol and then with water. The organic layer was filtered through silica gel and the solvent was then removed under vacuum. The crude product (3.3 g, yellowish oil) was dissolved in tetrahydrofuran (20 ml) and treated with *n*-butyllithium (4 ml, 23% in *n*-hexane) at 0 °C and then with chlorotrimethylsilane (1–2 ml) until a hydrolysed sample proved to be acidic. The reaction mixture was concentrated, washed with water and the solvent was then removed under vacuum. Recrystallization from methanol gave 1 g of **3** (3%); m.p. 145–146 °C. Degree of deuteriation: 94.0 ± 0.3% (MS).

4: 0.5 g of **3** (1.3 mmol) was treated with *n*-butyllithium (0.6 ml, 23% in *n*-hexane, 1.5 mmol) and *N,N,N′,N′*-tetramethylethylenediamine (0.2 ml) with cooling in an ice–salt mixture. Ethyl formate (50 mg, 0.67 mmol) was added after 45 s. Removal of the protective trimethylsilyl groups was achieved in methanol with a drop of concentrated HCl. Purification by preparative thick-layer chromatography (silica gel–toluene) gave 82.3 mg (30%) of yellow crystals; m.p. 157 °C after recrystallization from glacial acetic acid. Degree of deuteriation: 93.8 ± 0.3% (MS).

5b: Galvinoxyl radical was generated by oxidation of a solution of **4** in toluene with an aqueous alkaline solution of potassium hexacyanoferrate(III). The organic layer was separated, transferred to the sample tube and carefully deoxygenated prior to EPR/ENDOR measurements by flushing with purified nitrogen.

Instrumentation

EPR and ENDOR spectra were recorded on a Bruker ER 220D EPR spectrometer equipped with a Bruker cavity (ER 200ENB) and laboratory-built NMR facilities described elsewhere.[3] The spectrometer was interfaced to a minicomputer (HP 1000/A600), used for controlling the scan oscillator and the RF power (which was kept constant over the frequency range) in addition to data acquisition and handling and storage of the spectra.

RESULTS AND DISCUSSION

The EPR and ENDOR spectra of unlabelled Coppinger's radical (**5a**), of the radical with perdeuteriated *tert*-butyl groups (**5b**) and of a radical that is deuteriated at the ring positions (**5c**)[9] are compared in Fig. 1. The EPR spectrum of **5b** reveals a striking decrease of the line width (from 0.039 to 0.015 mT) and a concomitant improvement in resolution relative to **5a**. It consists of a well resolved

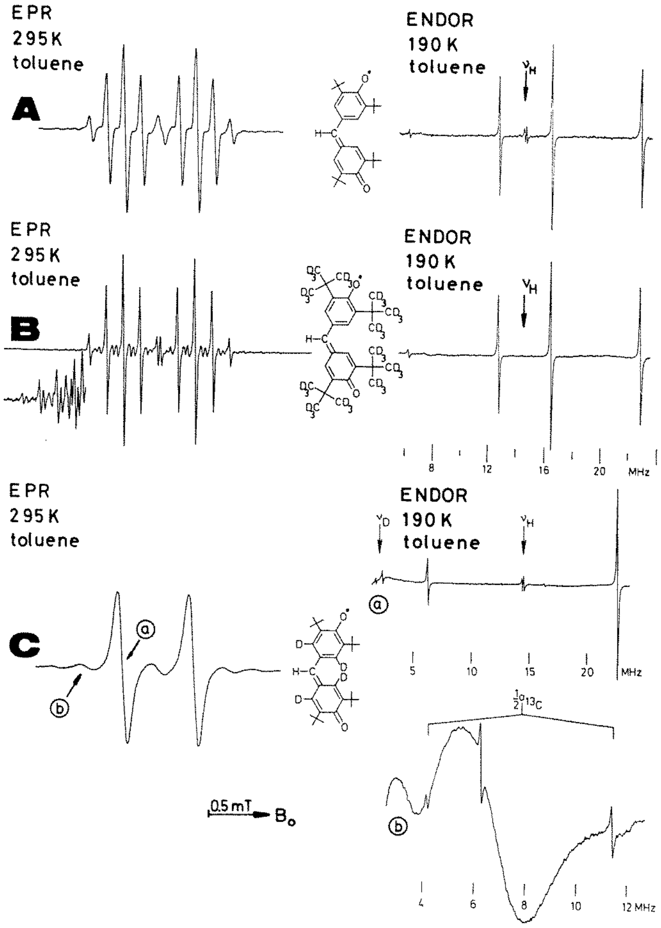


Figure 1. EPR (left) and ENDOR spectra (right) of (A) unlabelled Coppinger's radical (**5a**) and of the selectively deuteriated radicals **5b** (B) and **5c** (C). ENDOR spectrum (b), bottom right, exhibits a pair of ^{13}C ENDOR signals that were recorded in natural isotopic abundance (carbonyl C atoms).[9]

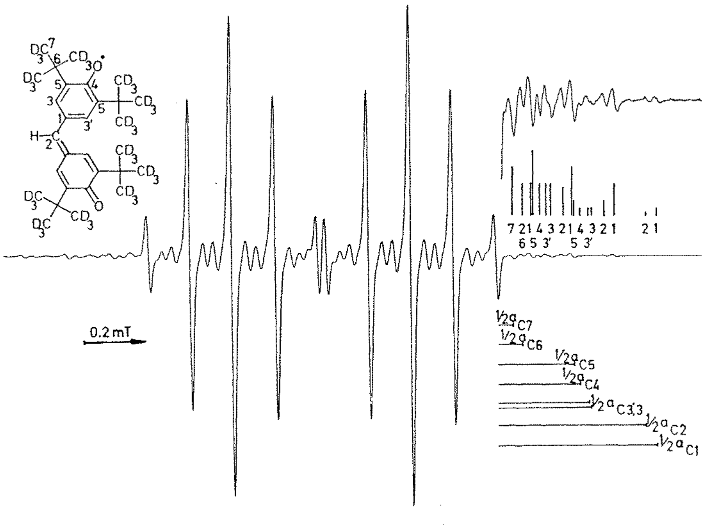


Figure 2. EPR spectrum of the selectively deuteriated radical **5b** in toluene at 295 K and analysis of ^{13}C coupling constants (satellite lines in the wings recorded with ten-fold gain). The assignment of the ^{13}C hyperfine coupling constants to molecular positions is given (position 1, 30.02; 2, 28.17; 3, 17.85; 3', 17.16; 4, 15.86; 5, 14.36; 6, 4.85; and 7, 3.01 MHz).

doublet of quintets due to hyperfine couplings with the methine proton and four ring protons. Furthermore, satellite lines from radicals with natural ^{13}C contents are easily recognized. As expected, signals from *tert*-butyl protons cannot be seen in the ^{1}H ENDOR spectrum of **5b**. The largest hyperfine coupling constant, which belongs to the methine proton, is influenced by isotope effects: 16.58 MHz in **5a**, 16.55 MHz in **5b** and 16.51 MHz in **5c**[9] (toluene, 190 K). The origin of the isotope effects is probably a slight change in the equilibrium geometry (twist angles of the phenoxy groups; the likely mechanism for **5c** because of the smaller effective Van der Waals radius of ^{2}H relative to ^{1}H), or a decreased amplitude of the torsional oscillations of the phenoxy groups (mass effect, the likely mechanism for **5b**).

An analysis of the ^{13}C hyperfine couplings from the positions of the satellite lines is given in Fig. 2. The particularly intense satellite signals in the central part of the EPR spectrum may be assigned to radicals with ^{13}C nuclei in the *tert*-butyl groups. The ^{13}C coupling constants of all carbon atoms can be determined from the positions of the lines in the wings [the *meta* positions (3,3') are non-equivalent[9]]. On the other hand, the determination of the complete set of ^{13}C coupling constants from the EPR spectrum of unlabelled Coppinger's radical (**5a**) is not possible because of the insufficient spectral resolution. Meanwhile, however, these data have been obtained in a ^{13}C ENDOR study of radical **5c** (with ^{13}C in natural abundance) and assigned to molecular positions.[9] Within experimental error, the ENDOR data agree with the present EPR data. As an example, the natural abundance ^{13}C ENDOR line pair of the carbonyl C atoms (position 4, see Fig. 2) of **5c** is reproduced in Fig. 1 (bottom right). It should be noted that radical **5b** proved to be less suitable for ^{13}C ENDOR studies because of baseline problems and because the proper field setting is much more critical than in the case of **5c**.

CONCLUSIONS

It has been demonstrated that the EPR line width of Coppinger's radical can be reduced substantially (by about a factor of 3) when the *tert*-butyl groups are replaced with perdeuteriated *tert*-butyl groups. The drastically improved resolution allows the determination of the complete set of ^{13}C coupling constants from the respective satellite lines observable in the EPR spectrum. Owing to the decreased line widths, the selectively deuteriated Coppinger's radical should be a useful spin probe for studies of molecular mobility. Moreover, application of the synthetic pathway described here to the synthesis of substituted galvinoxyls with perdeuteriated *tert*-butyl groups is straightforward. The achievable improvement in spectral resolution should be helpful, for example, in investigations of oligoradicals or in studies of internal dynamics.

Acknowledgements

H.K. gratefully acknowledges financial support by the Fonds der Chemischen Industrie and the Deutsche Forschungsgemeinschaft (Normalverfahren).

REFERENCES

1. G. M. Coppinger, *J. Am. Chem. Soc.* **79,** 501 (1957).
2. W. Gierke, W. Harrer, H. Kurreck and J. Reusch, *Tetrahedron Lett.* 3681 (1973); W. Harrer, H. Kurreck, J. Reusch and W. Gierke, *Tetrahedron* **31,** 625 (1975).
3. H. Kurreck, B. Kirste and W. Lubitz, *Angew. Chem.* **96,** 171 (1984); *Angew. Chem., Int. Ed. Engl.* **23,** 173 (1984).
4. B. Kirste, W. Harrer and H. Kurreck, *Angew. Chem.* **93,** 912 (1981); *Angew. Chem., Int. Ed. Engl.* **20,** 873 (1981); K. Schubert, B. Kirste and H. Kurreck, *Angew. Chem.* **95,** 149 (1983); *Angew. Chem., Int. Ed. Engl.* **22,** 150 (1983); *Angew. Chem., Suppl.* 128 (1983).
5. K. Hinrichs, B. Kirste, H. Kurreck and J. Reusch, *Tetrahedron* **33,** 151 (1977). B. Kirste, H. Kurreck, W. Harrer and J. Reusch, *J. Am. Chem. Soc.* **101,** 1775 (1979); B. Kirste, W. Harrer, H. Kurreck, K. Schubert, H. Bauer and W. Gierke, *J. Am. Chem. Soc.* **103,** 6280 (1981).
6. K. H. Hausser, H. Brunner and J. C. Jochims, *Mol. Phys.* **10,** 253 (1966).
7. G. H. Stillson and D. W. Sawyer, *US Pat.* 2 459 597 (1949); *Chem. Abstr.* **43,** 3459e (1949).
8. H. Hart and F. A. Cassis, *J. Am. Chem. Soc.* **73,** 3179 (1951).
9. B. Kirste, H. Kurreck and M. Sordo, *Chem. Ber.* **118,** 1782 (1985).
10. D. H. Williams and S. W. Cooks, *J. Am. Chem. Soc.* **90,** 2150 (1968).