



## Host–Guest Complexes of some Stable Free Radicals

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**Abstract.** Hydrophobic host–guest complexes of some water soluble stable free radicals – potassium nitrosodisulfonate (Fremy's salt), 2-*p*-phenylsulphonic acid-2-phenyl-1-picrylhydrazyl ( $\text{KSO}_3\text{-DPPH}^\cdot$ ) and 2,2-*p*-phenylsulphonic acid-1-picrylhydrazyl ( $(\text{KSO}_3)_2\text{DPPH}^\cdot$ ), both of them as potassium salts, with 18-C-6, B18-C-6 and DB18-C-6 crown ethers, were obtained and characterised by elemental analysis, IR, ESR and UV-Vis.

**Key words:** stable free radicals; Fremy's salt; DPPH; crown ethers; complexes, ESR spectroscopy

### 1. Introduction

Fremy's salt (potassium nitrosodisulfonate) is a stable nitroxide free radical, of violet colour ( $\lambda_{\text{max}} = 545 \text{ nm}$ ) in aqueous solution, but dimeric in the solid state, and of yellow colour [1]; owing to this behaviour it was compared with nitrogen dioxide ( $2\text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4$ ) [2]. The mild oxidising character of Fremy's salt makes it useful in selective oxidation of some (bio)organic compounds, such as amino acids, proteins and vitamins; in addition, Fremy's salt is mainly used as an ESR standard and in some radical processes [3–5].

Stable free radicals of the hydrazyl type are well known, an important characteristic being their high hydrophobicity [6]. The best known radical of this type is 2,2-diphenyl-1-picrylhydrazyl (DPPH). The potassium salts of the sulphonated derivatives of DPPH (2-*p*-phenylsulphonic acid)-2-phenyl-1-picrylhydrazyl,  $\text{KO}_3\text{S-DPPH}^\cdot$  and 2,2-*p*-phenylsulphonic acid-1-picrylhydrazyl,  $(\text{KO}_3\text{S})_2\text{DPPH}^\cdot$  are water soluble and insoluble in organic non-polar media (benzene, methylene chloride) [7].

Fremy's salt, like  $\text{KO}_3\text{S-DPPH}^\cdot$  and  $(\text{KO}_3\text{S})_2\text{DPPH}^\cdot$  (Figure 1), is soluble only in water. For some processes involving these stable free radicals it is necessary to make them soluble in organic media, in which the reaction partner is soluble. To achieve this aim, it is necessary to work in an omogen phase (which ensures a fast rate of reaction). To achieve this purpose two main ways are used: by means of a common solvent (usually hard to find) or, better, by means of interphasic carriers (often with increased advantages) [8].

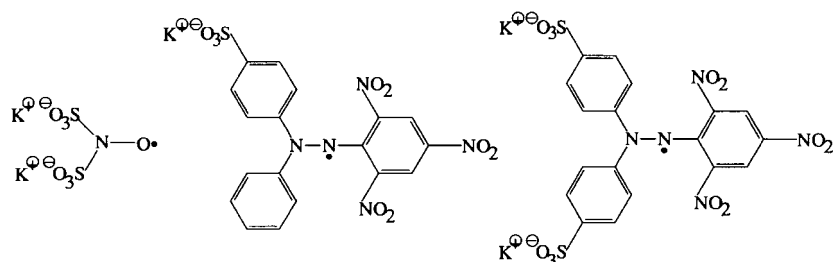


Figure 1. Molecular structure of Fremy's salt,  $\text{KO}_3\text{S-DPPH}^\cdot$  and  $(\text{KO}_3\text{S})_2\text{DPPH}^\cdot$ .

Crown ethers, complexating agents of cations, form hydrophobic host-guest complexes with different inorganic salts [8, 9]. Formation of these complexes takes place by replacement of the inner solvation sphere of the cation ( $\text{M}^+$ ) with crown ether (CE), the corresponding anion stabilising the macrocation  $(\text{CE} \cdot \cdot \text{M})^+$  formed in an electrical neutral hydrophobic complex  $(\text{CE} \cdot \cdot \text{M})^+ \text{A}^-$ . Interphasic transfer from aqueous solution or the solid state of some salts into an organic phase by means of the CE also results in the activation of the anion. The process is known as interphasic transfer catalysis and has many applications [10–12].

The aim of this paper is to obtain and characterise the supramolecular complexes of some stable free radicals with CEs. These complexes can be involved in many biological or chemical processes of the radical type.

## 2. Experimental

*Apparatus.* UV-Vis: Specord Carl Zeiss Jena; IR: Carl Zeiss UR-10; ESR: JES 3B (JEOL. Co.), CHN analyser: Carlo Erba 1106. The ESR spectra were recorded at room temperature on a JES-3B (JEOL) spectrometer with 100 kHz field modulation using X-band frequency. The parameters of the ESR spectra were measured in comparison with those of Fremy's salt ( $a_N = 13.0$  Gauss).

*Materials.* Sulphonated derivatives of DPPH $^\cdot$  were obtained by the method described in the literature [7, 13]. Fremy's salt and crown ethers were Aldrich products. Solvents used were purchased from Chimopar and used without purification.

### 2.1. THE FORMATION OF HOST-GUEST COMPLEXES OF FREMY'S SALT, $\text{KO}_3\text{S-DPPH}^\cdot$ AND $(\text{KO}_3\text{S})_2\text{DPPH}^\cdot$ WITH DIFFERENT CES IN THE LIQUID PHASE

*Host-guest complexes of Fremy's salt* can be obtained in dimethylformamide (DMF) or dimethylsulphoxide (DMSO); for this, solid Fremy's salt was stirred with a solution of CE in these solvents. Solid Fremy's salt dissolved (insoluble in the absence of CE) and the solution colour become violet.

*Host-guest complexes of  $KO_3S$ -DPPH and  $(KO_3S)_2DPPH$*  can be obtained in almost any organic solvent, by stirring the solid salt with CE in the chosen solvent.

## 2.2. THE FORMATION OF SOLID HOST-GUEST COMPLEXES OF FREMY'S SALT, $KO_3S$ -DPPH AND $(KO_3S)_2DPPH$ WITH 18-C-6, B18-C-6 AND DB18-C-6

*The formation of solid host-guest complexes of Fremy's salt.* 200 mg 18-C-6 were added to 100 mg Fremy's salt suspended in 5 mL DMF and the reaction mixture was stirred for 1/2 h. The violet solution obtained was filtered off and 50 mL petroleum ether (30–60 °C) were added to the filtrate; under powerful stirring isopropyl alcohol was added dropwise until the immiscible layers of DMF and petroleum ether become homogeneous; at the same time, the solid host-guest complex precipitated as violet crystals. The reaction mixture was cooled for 1/2 h, filtered off and the solid washed several times with petroleum ether. Yield 200 mg host-guest complex. For the complexes of B18-C-6 or DB18-C-6 the same procedure was applied, using a mixture of isopropyl alcohol: acetone 8:2 v:v instead of isopropyl alcohol. IR (KBr,  $cm^{-1}$ ): 2(18-C-6...K)<sup>+</sup>(O<sub>3</sub>S)<sub>2</sub>NO<sup>2-</sup>: 835, 965, 1100, 1345, 2880, 3445; 2(B18-C-6...K)<sup>+</sup>(O<sub>3</sub>S)<sub>2</sub>NO<sup>2-</sup>: 580, 1040, 1100, 1310, 2900, 3400; 2(DB18-C-6...K)<sup>+</sup>(O<sub>3</sub>S)<sub>2</sub>NO<sup>2-</sup>: 580, 1015, 1140, 1245, 2900, 3440.

*The formation of solid host-guest complexes of  $KO_3S$ -DPPH and  $(KO_3S)_2DPPH$ .* 100 mg 18-C-6 was added to 100 mg  $KO_3S$ -DPPH<sub>2</sub> suspended in 50 mL methylene chloride and the mixture was stirred for 1/2 h, filtered off and the solution obtained was concentrated to 10 mL; under stirring 100 mL petroleum ether (30–60 °C) was added; the host-guest complex precipitated and was redissolved in methylene chloride, stirred with solid PbO<sub>2</sub> or KMnO<sub>4</sub> for 2 h, and the violet solution was filtered off, concentrated and the solid host-guest complex (18-C-6...K)<sup>+</sup>-O<sub>3</sub>S-DPPH<sup>-</sup> precipitated with petroleum ether. Similarly the complexes between B18-C-6 or DB18-C-6 were obtained. The same procedure was applied in the case of the  $(KO_3S)_2DPPH$  free radical. IR (KBr,  $cm^{-1}$ ): (18-C-6...K)<sup>+</sup>-O<sub>3</sub>S-DPPH<sup>-</sup>: 1110, 1240, 1345, 1540, 1590, 3440; ((18-C-6...K)<sup>+</sup>)<sub>2</sub>(-O<sub>3</sub>S)<sub>2</sub>DPPH<sup>-</sup>: 1110, 1225, 1530, 1590, 2910, 3440.

Table I. The complexing ratio between potassium cation and CE (K<sup>+</sup> : CE) determined by elemental analysis

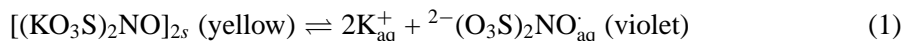
Free radical	CE	K <sup>+</sup> : CE : A:	Formula	H%*	C%*	H%**	C%**	K <sup>+</sup> : CE
$(KO_3S)_2NO^{\cdot}$	18-C-6	2 : 2 : 1	C <sub>24</sub> H <sub>48</sub> NO <sub>19</sub> S <sub>2</sub> K <sub>2</sub>	6.07	36.17	6.20	36.17	1 : 1
	B18-C-6	2 : 2 : 1	C <sub>32</sub> H <sub>48</sub> NO <sub>19</sub> S <sub>2</sub> K <sub>2</sub>	5.42	43.04	5.55	43.00	1 : 1
	DB18-C-6	2 : 2 : 1	C <sub>40</sub> H <sub>48</sub> NO <sub>19</sub> S <sub>2</sub> K <sub>2</sub>	4.89	48.57	4.82	48.37	1 : 1
$KO_3S$ -DPPH <sup>·</sup>	18-C-6	1 : 1 : 1	C <sub>30</sub> H <sub>35</sub> N <sub>5</sub> O <sub>15</sub> SK	4.54	46.39	4.40	46.19	1 : 1
	B18-C-6	1 : 1 : 1	C <sub>34</sub> H <sub>35</sub> N <sub>5</sub> O <sub>15</sub> SK	4.28	49.41	4.09	49.61	1 : 1
	DB18-C-6	1 : 1 : 1	C <sub>38</sub> H <sub>35</sub> N <sub>5</sub> O <sub>15</sub> SK	4.04	52.29	3.90	52.49	1 : 1
$(KO_3S)_2DPPH^{\cdot}$	18-C-6	2 : 2 : 1	C <sub>42</sub> H <sub>58</sub> N <sub>5</sub> O <sub>24</sub> S <sub>2</sub> K <sub>2</sub>	5.04	43.52	5.11	43.72	1 : 1
	B18-C-6	2 : 2 : 1	C <sub>50</sub> H <sub>58</sub> N <sub>5</sub> O <sub>24</sub> S <sub>2</sub> K <sub>2</sub>	4.66	47.84	4.83	47.93	1 : 1
	DB18-C-6	2 : 2 : 1	C <sub>58</sub> H <sub>58</sub> N <sub>5</sub> O <sub>24</sub> S <sub>2</sub> K <sub>2</sub>	4.33	51.55	4.05	51.91	1 : 1

\* Calculated. \*\* Experimental.

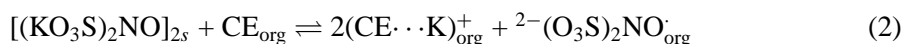
### 3. Results and Discussion

#### 3.1. THE FORMATION OF HOST–GUEST COMPLEXES BETWEEN FREMY’S SALT AND CE

By dissolving Fremy’s salt in water the peroxide bond present in the solid dimer is broken [1].



The attempt to transfer Fremy’s salt from aqueous solution or from the solid state into an organic phase (benzene, chloroform) with 15-C-5, 18-C-6, B15-C-5, B18-C-6, DB18-C-6, DCH18-C-6 or D18-C-6 (C = crown, B = benzo, DB = dibenzo, DCH = dicyclohexyl, D = decyl) was not successful; unsatisfactory results were obtained with solid Fremy’s salt and CE dissolved in alcohol (only a low concentration of the supramolecular complex can be obtained). Host–guest complexes (violet colour) may be obtained using CE in polar organic solvents like DMF or DMSO and solid Fremy’s salt (which is insoluble in them; in the absence of CE no reaction occurs, Fremy’s salt remains as a yellow solid).



The host–guest complexes formed in the liquid phase were spectrophotometrically identified at  $\lambda_{\text{max}} = 545 \text{ nm}$  [14]; these show the same physico-chemical characteristics (ESR and UV-Vis spectra, oxidative properties) as an aqueous solution of Fremy’s salt. The complexes with 18-C-6, B18-C-6 and DB18-C-6 were obtained in the solid state in violet crystalline form, implying that the anion is not a dimer.

To obtain the solid complexes between 18-C-6, B18-C-6 and DB18-C-6 and Fremy’s salt, petroleum ether was added to the violet solution obtained in DMF from solid Fremy’s salt and CE, and, with powerful stirring, isopropanol until the two liquid phases (DMF is insoluble in petroleum ether) become homogeneous; at the same time, the solid host–guest complex precipitates as violet crystals. The complex with 18-C-6 is soluble in  $\text{CH}_2\text{Cl}_2$  and  $\text{CHCl}_3$ , giving a violet solution with  $\lambda_{\text{max}} = 545 \text{ nm}$  and the ESR spectrum consisting of a triplet arising from the  $\text{N}-\text{O} \cdot$  moiety, (Figure 2) is very similar ( $a_{\text{N}} = 13.0 \text{ G}$ ) to that of Fremy’s salt in water.

For the solid complexes the complexation ratios were determined by elemental analysis or by a spectrophotometrical method [15], measuring the absorbance of a solution of known concentration. In all the cases the values obtained were 1 : 1 ( $\text{K}^+ : \text{CE}$ ).

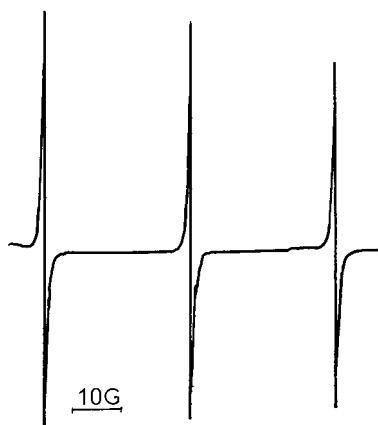


Figure 2. ESR spectrum of Fremy's salt complex with 18-C-6 in methylene chloride.

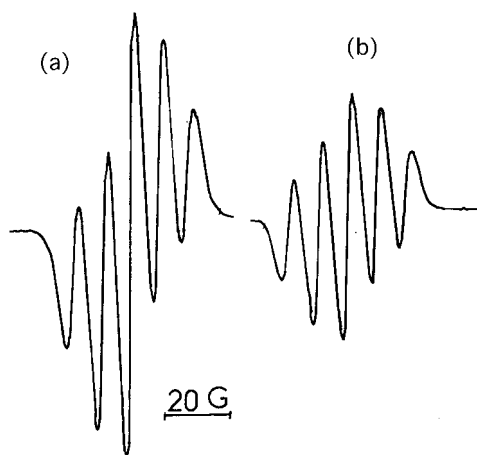
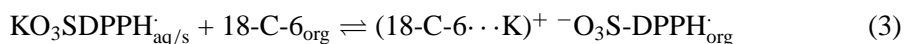
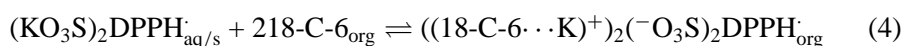


Figure 3. The ESR spectra of the host-guest complexes of the (a)  $\text{KO}_3\text{S-DPPH}\cdot$  and (b)  $(\text{KO}_3\text{S})_2\text{DPPH}\cdot$  free radicals with 18-C-6.

### 3.2. THE FORMATION OF THE HOST-GUEST COMPLEXES OF $\text{KO}_3\text{S-DPPH}\cdot$ AND $(\text{KO}_3\text{S})_2\text{DPPH}\cdot$ WITH CE

The hydrazines  $\text{KO}_3\text{SDPPH}_2$  and  $(\text{KO}_3\text{S})_2\text{DPPH}_2$ , like the corresponding stable free radicals  $\text{KO}_3\text{S-DPPH}\cdot$  and  $(\text{KO}_3\text{S})_2\text{DPPH}\cdot$  are water soluble [7]. All these compounds can be transferred from an aqueous phase or the solid state into an organic phase by CE. The host-guest complexes thus formed were identified in methylene chloride by ESR ( $a_{\text{N}} = 9.0$  G, Figure 3) and UV-Vis ( $\lambda_{\text{max}} = 535$  nm; in water  $\lambda_{\text{max}} = 524$  and 518 nm, respectively [13]). The ESR spectra (Figure 3) consist of a quintuplet ( $a_{\text{N}} = 9.06$ ) arising from the  $\text{N}-\dot{\text{N}}$  moiety.





These complexes can be easily obtained in the solid state by adding petroleum ether to their solution in methylene chloride. For the solid complexes the complexation ratios were determined by elemental analysis and by a spectrophotometrical method [15]. The values obtained were 1 : 1  $\text{K}^+$  : CE. Similarly, the parent hydrazines  $\text{KO}_3\text{SDPPH}_2$  and  $(\text{KO}_3\text{S})_2\text{DPPH}_2$  can be first transferred to the organic phase as host–guest complexes and then oxidised to the host–guest complexes of the stable free radicals. In this way it is easier to obtain the solid complexes (the oxidation yield increases from 40 to 90%).

#### 4. Conclusions

The host–guest complexes of some stable free radicals with CE were obtained and characterised. The complexation ratio between the cation and CE was 1 : 1. The process described is useful for the transfer of some kind of water soluble radicals into an organic phase.

#### References

1. H. Zimmer, D.C. Lankin, and S.W. Horgan: *Chem. Rev.* **71**, 229 (1971).
2. A. Hantzsch and W. Semple: *Chem. Ber.* **28**, 2744 (1895).
3. L. Zhanghi, H.Y. Zhengxu, Z.Y. Kaichao, and L. Youcheng: *J. Phys. Org. Chem.* **5**, 33 (1992).
4. G.R. Angel, P. Deya, and J. Sao: *J. Org. Chem.* **55**, 4285 (1986).
5. J.B. Cloughley, J. Maxwell, and M. Hooper: *J. Pharm. Pharmacol.* **25**, 174 (1973).
6. G. Ionita, T. Constantinescu, and P. Ionita: *J. Planar Chromatogr. Modern TLC* **11**, 142 (1998).
7. G.V. Putirszkaja and T. Siladi: *Acta Chim. (Budapest)*, **72**, 329 (1972).
8. E. Weber, J.L. Toner, I. Goldberg, F. Vögtle, D.A. Laider, J.F. Stoddart, R.A. Bartsch, and C.L. Liotta: in S. Patai and Z. Rappoport (eds.), *Crown Ethers and Analogs*, Wiley (1989).
9. C.J. Pedersen: *J. Am. Chem. Soc.* **89**, 7017 (1967).
10. M. Makosza: *Pure Appl. Chem.* **43**, 439 (1975).
11. M. Makosza and B. Serafin: *Rocz. Chem.* **39**, 1223 (1965).
12. F. Montanari, D. Landini, and F. Rolla: in *Host–Guest Complex Chemistry II*, Verlag-Berlin, (1982), p. 147.
13. P. Ionita, M.T. Caproiu, and A.T. Balaban, unpublished results.
14. J.H. Murib and D.M. Ritter: *J. Am. Chem. Soc.* **74**, 3394 (1952).
15. C. Luca, P. Ionita, M.T. Caproiu, and T. Constantinescu: *Rev. Roum. Chim.* **43**, 25 (1998).