

Further application of the present methodology to syntheses of corticosteroids and aglycon of anthracycline antibiotics is in progress in our laboratory.

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**Supplementary Material Available:** Experimental details of reaction of **2** with aldehydes and hydrolysis of **3** or **3'** to **4** and spectral and analytical data for **3a–c**, **3'a–c**, **4a–e**, **6**, **anti-7**, **8**, and **9** (4 pages). Ordering information is given on any current masthead page.

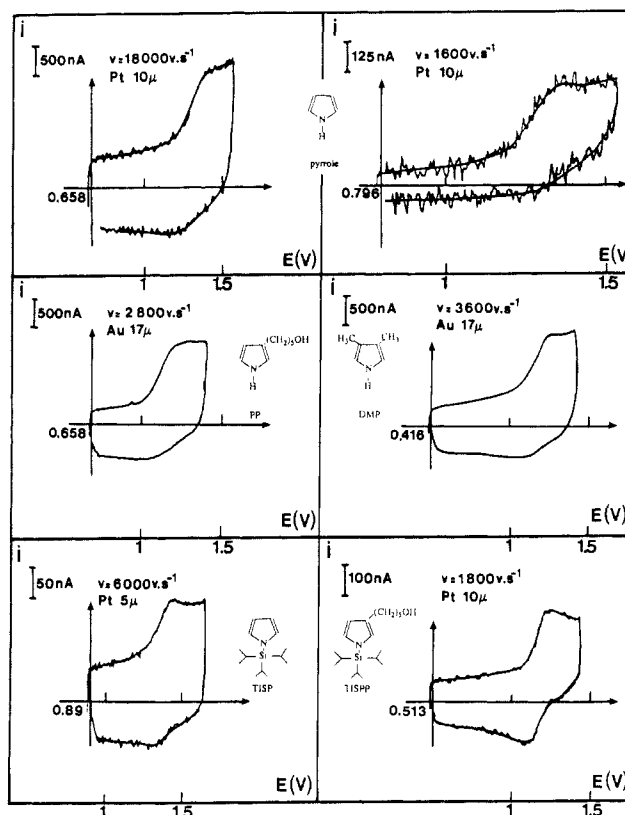
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## Observation of the Cation Radicals of Pyrrole and of Some Substituted Pyrroles in Fast-Scan Cyclic Voltammetry. Standard Potentials and Lifetimes

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Polypyrroles and polysubstituted pyrroles have attracted considerable and increasing attention over the past 10 years in view of their remarkable conducting and electrocatalytic properties.<sup>1</sup> Oxidative electropolymerization of pyrrolic monomers is a convenient and attractive route to polypyrrole electrode coatings and free-standing films. In this connection, rather little is known about the mechanism of the electrochemical reactions involved in the first stages of the electropolymerization process. Although valuable information has been gained about the nucleation processes following the initial generation of dimeric and polymeric species,<sup>2</sup> the mechanism by which these dimers are formed has not been ascertained.<sup>3</sup> Likewise, the standard potentials at which the cation



**Figure 1.** Cyclic voltammetry of pyrrole and substituted pyrroles (4 mM, except for TISP: 10 mM) in acetonitrile + 0.6 M  $\text{Et}_4\text{NClO}_4$  at 20 °C. The compound, the nature and diameter of the ultramicroelectrode, and the scan rate are indicated in each diagram. The instrumentation was the same as previously described.<sup>4k</sup>

**Table I**

compd	std potential	lifetime, $\mu\text{s}$
pyrrole	$1.31 \pm 0.02$	30
PP	$1.11 \pm 0.02$	150
TISP	$1.35 \pm 0.01$	250
DMP	$1.08 \pm 0.01$	300
TISP	$1.17_3 \pm 0.005$	2000

radicals are formed as well as their lifetimes are not known. The reason for this lack of information concerning the reactivity of the electrochemically generated pyrrole cation radical is that the measurement times employed in the experimental studies<sup>2</sup> carried out by potential-step and cyclic voltammetric techniques were too long to allow the observation of the cation radical by means of its rereduction current. Follow-up processes, such as polymer formation from oligomers and polymer growth through nucleation, were the only events that could be observed within the investigated time scales.

In the present preliminary report, we show that it is possible to overcome these difficulties by use of recently developed ultramicroelectrode techniques<sup>4</sup> and thus to observe the pyrrolic cation radicals through their rereduction wave in fast-scan cyclic

(1) (a) The literature on polypyrroles contains over 1000 references. For a general review, see ref 1b, and for a recent review on their electrocatalytic properties, see ref 1c. (b) Street, G. B. *Handbook of Conducting Polymers*; Skotheim, T. A., Ed.; Marcel Dekker: New York, 1986; pp 265–291. (c) Deronzier, A.; Moutet, J. C. *Acc. Chem. Res.* **1989**, *22*, 249.

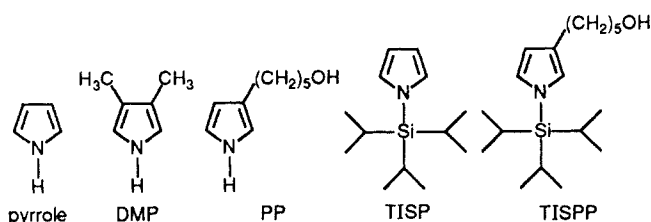
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(3) (a) In the case of pyrrole, the dimerization has been assumed sometimes to result from the radical–radical coupling of two cation radicals<sup>2a</sup> and sometimes to involve the reaction of one cation radical with a pyrrole molecule.<sup>2b–d</sup> The latter mechanism has also been hypothesized in the case of thiophene.<sup>2e–j</sup> (b) While the mechanism of the dimerization of electrochemically generated anion radicals is reasonably understood and has been shown to be of the radical–radical coupling type in most cases (see refs 3c,d and references cited therein), much less is known in the case of cation radicals. The dimerization of the cation radical of 4-methoxybiphenyl, a rather slow reaction, is the only case that has been investigated in some detail.<sup>3e</sup> The reaction was first thought to proceed via radical–radical coupling of two cation radicals<sup>3e</sup> and later shown to involve the coupling of one cation radical with one molecule of the starting 4-methoxybiphenyl, followed by the oxidation of the ensuing dimeric cation radical by another monomeric cation radical.<sup>3f</sup> (c) Savéant, J.-M. *Acta Chem. Scand. B* **1983**, *37*, 365. (d) Savéant, J.-M. *Acta Chem. Scand. B* **1988**, *42*, 721. (e) Aalstad, B.; Ronlan, A.; Parker, V. D. *Acta Chem. Scand. B* **1981**, *35*, 874. (f) Amatore, C.; Savéant, J.-M. *J. Electroanal. Chem.* **1983**, *144*, 59.

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voltammetry. This also allowed by estimation of the corresponding standard potentials and lifetimes.

The following compounds<sup>5</sup> were investigated:



The substituents on the pyrroles were selected in an effort to make them easier to oxidize and to decrease the reactivity of their cation radicals without, however, preventing the feasibility of their anodic electropolymerization.<sup>6</sup> Among these substituted pyrroles, PP is of particular interest since the polymers derived from 3-substituted pyrroles constitute a class of new and promising materials.<sup>7</sup> Their structure is indeed much more regular than that of polypyrrole itself and of poly(*N*-substituted pyrroles). Figure 1 shows their cyclic voltammograms in acetonitrile. In all cases, total or partial reversibility of the cyclic voltammograms could be reached upon raising the scan rate. This is true even for pyrrole itself. It exhibits total irreversibility at 1600 V/s whereas a partial reversibility of about 20% is observed at 18 000 V/s. As expected, reversibility was easier to reach with the four substituted compounds.

The standard potentials and cation radical lifetimes<sup>8</sup> derived from the cyclic voltammograms are listed in Table I.

The variations of these two parameters upon changing the ring-carbon substituents are as expected from electronic inductive effects: given the *N*-substituent, alkyl substitution in the 3-position or in the 3- and 4-positions decreases the standard potential and increases the lifetime. The variations are about the same in the H and Si series. Passing from H to Si with the same substituents on the ring carbons slightly increases the standard potential and significantly increases the lifetime. The latter variation is likely to derive from steric hindrance to dimerization.

It was noticed that, in the cases where only partial reversibility could be reached, a further increase of the scan rate did not bring about significant improvements, whereas much higher scan rates could be used in other instances,<sup>4b</sup> even for the oxidation, also in acetonitrile, of a compound, *N*-methylacridane,<sup>9a</sup> the structure of which is not too far from the presently studied molecules (no polymerization and dimerization occur in that case, however). This is partly due to slow charge-transfer kinetics showing up at these high scan rates. However, surface effects are also likely to interfere, as in the case of the oxidation of aromatic hydrocarbons in *N,N'*-dimethylformamide.<sup>9b</sup>

A new route to the comprehension of the very first stages of the electropolymerization of pyrroles is thus open. Work is

currently in progress to ascertain the dimerization mechanism in the most favorable case, i.e., that of TISPP, where undistorted cyclic voltammograms could be obtained in the whole range of scan rates up to complete reversibility, and to improve the responses obtained in the other cases. Variation of the reaction medium should be helpful in the latter of these purposes.

**Registry No.** PP, 125227-73-8; PP<sup>•+</sup>, 125227-75-0; DMP, 822-51-5; DMP<sup>•+</sup>, 125227-77-2; TISP, 87630-35-1; TISP<sup>•+</sup>, 125227-76-1; TISPP, 125227-74-9; TISPP<sup>•+</sup>, 125227-78-3; pyrrole, 109-97-7; pyrrole cation radical, 34468-30-9; triisopropylsilyl chloride, 13154-24-0; potassium pyrrolide, 16199-06-7.

## Template-Driven Self-Assembly of a Porphyrin-Containing Supramolecular Complex<sup>†</sup>

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Heme-dependent proteins participate in a diverse array of biochemical phenomena including oxygen transport (hemoglobin) and activation (cytochrome P-450 enzymes).<sup>1,2</sup> The proteinoid appendage of these species serves as a steric impediment that precludes  $\mu$ -oxo oligomer formation, as a protective barrier that prevents oxidative decomposition of the porphyrin periphery, as a water-soluble carrier of the heme, and as an entity that maintains the hydrophobic nature of the active site to promote substrate binding and/or retard the oxidation of Fe<sup>2+</sup> to Fe<sup>3+</sup>. With these structural features in mind, we have designed and synthesized a porphyrin encased within a protective barrier that is circumscribed by a hydrophobic groove. The synthetic approach is notable in that it is a template-driven self-assembly of a multicomponent entity. We have recently employed such an approach to construct a rotaxane, and we have found that the self-assembly process, propelled by noncovalent interactions, is extremely facile.<sup>3</sup>

The tetraamino porphyrin **1** (prepared in three steps from *p*-hydroxybenzaldehyde)<sup>4</sup> forms an inclusion complex upon exposure to 10 equiv of heptakis(2,6-di-*O*-methyl)- $\beta$ -cyclodextrin<sup>5,6</sup> ("Me-CD") (**2**) in aqueous solution at pH 6.0. The evidence for complexation is threefold: (1) the Soret band for the tetra-protonated amine porphyrin shifts from 444 to 418 nm in the presence of Me-CD; (2) the chemical shifts for the C-3 and C-5 protons in the <sup>1</sup>H NMR spectrum (300 MHz) for Me-CD move upfield (36.3 and 41.4 Hz, respectively) in the presence of the porphyrin; and (3) the tetraamino porphyrin, which is insoluble in basic (pH 14) water, is rendered freely soluble upon complexation with Me-CD. The inclusion complex was subsequently

(5) (a) *N*-(Triisopropylsilyl)pyrrole (TISP) was prepared by condensation of triisopropylsilyl chloride with potassium pyrrolide. The synthesis of 3,4-dimethylpyrrole (DMP) was carried out according to ref 5b, and the syntheses of 1-(pyrrol-3-yl)pentan-5-ol (PP) and 1-[1-(triisopropylsilyl)pyrrol-3-yl]pentan-5-ol (TISPP) are described elsewhere.<sup>3c</sup> (b) Farnier, M.; Fournari, P. *Bull. Soc. Chim. Fr.* **1975**, 2335. (c) Andrieux, C. P.; Audebert, P.; Merz, A.; Schwarz, R. Submitted for publication.

(6) In all cases, even with TISPP, a polymer film is formed upon setting the potential beyond the oxidation potential of the monomer. Its presence is attested by visual observation and by the typical slow scan voltammetric pattern it exhibits.

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(8) (a) The lifetimes were estimated by adapting a working curve appropriate for the radical-radical coupling mechanism in double potential-step chronoamperometry.<sup>8b</sup> This does not mean that we favor this particular mechanism over other possibilities, particularly the radical-substrate coupling mechanism, but simply that the estimation of the lifetime is not critically dependent on the mechanism used to generate the working curve. (b) Amatore, C.; Hammi, M.; Pinson, J.; Savéant, J.-M. *Electroanal. Chem.* **1985**, 284, 1.

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<sup>†</sup> Dedicated to the memory of Professor Robert V. Stevens and the memory of Professor E. Thomas Kaiser.

\* To whom correspondence should be directed.

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