CHEMISTRY LETTERS, pp. 2033 - 2036, 1984. 

# PHYSICOCHEMICAL PROPERTIES OF 3,6-DI-t-BUTYL-1,4-DIHYDROPYRROLO[3,2-b]-PYRROLE AND ITS N-METHOXYCARBONYL DERIVATIVES

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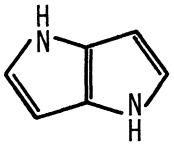
3,6-Di-t-butyl-1,4-dihydropyrrolo[3,2-b]pyrroles and its N-methoxycarbonyl derivatives were synthesized and their IR, NMR, and UV spectra as well as the oxidation potentials were measured. On the basis of these data, aromaticity and basicity of this novel 10π-aromatic system 1,4-dihydropyrrolo[3,2-b]pyrrole were discussed.

1,4-Dihydropyrrolo[3,2-b]pyrrole (1) composed of two fused pyrrole moieties is a hither-to-unknown compound, and it is one of the fundamental heterocycles possessing 10π-electrons and isoelectronic to indole. The 1,4-dimethyl[1] and 4-methyl-2-methoxycarbonyl derivatives[2] have been reported, but their physical and chemical properties were unexplored except for some spectral data. Therefore, these heterocyclic systems including 2 [3] and 3 [4] should be investigated in more details as new class of nitrogen-containing aromatic compounds.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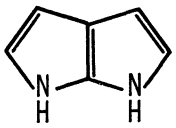
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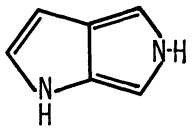
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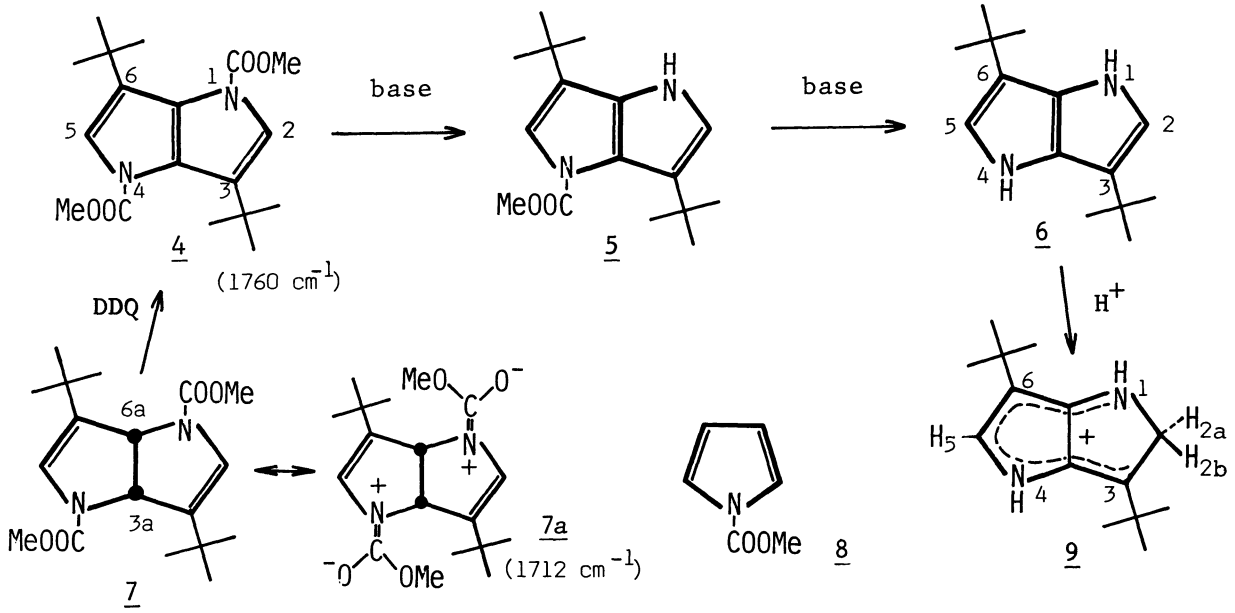
In previous papers,[5,6] we reported a simple synthetic method of dimethoxycarbonyl derivative (4) of 3,6-di-t-butyl-1,4-dihydropyrrolo[3,2-b]pyrrole starting with p-di-t-butylbenzene by a nitrene addition reaction. When di-ester 4 is treated with 1.8 mol/dm³ KOH-MeOH at 50 °C for 4 h, mono-ester 5 (mp 168-169 °C) is obtained in 92% yield. On refluxing in 98% hydrazine hydrate or in 1.8 mol/dm³ KOH-MeOH, both 4 and 5 give the target compound, 3,6-di-t-butyl-1,4-dihydropyrrolo[3,2-b]pyrrole (6, mp 203-205 °C (decomp)) in more than 90% yield. We wish to deduce aromaticity of this system by comparing the spectral properties with pyrrole, N-methoxycarbonylpyrrole (8), and tetrahydropyrrolo[3,2-b]pyrrole 7.[5]

It is well-known that pyrrole is an electron-rich heterocyclic compound possessing 6π-electrons and has dipole moment of 1.8 D with direction from the N-atom to the nucleus center. Therefore, in the IR spectrum of N-methoxycarbonyl derivative 8 the carbonyl absorption appears in high frequency region (1758 $cm^{-1}$) owing to its poor polarization. Contrary to this, the methoxycarbonyl group of tetrahydro-derivative 7 can polarize as shown in a canonical structure 7a and the carbonyl absorption exists in lower frequency region (1712 $cm^{-1}$). Di-ester 4 exhibits




the carbonyl absorption at 1760 $cm^{-1}$ indicating a significant shift (48 $cm^{-1}$) to higher frequency region compared with 7. The polarizability of carbonyl group in compound 4 is in the almost same order as N-methoxycarbonylpyrrole (8). These phenomena show that the lone pair electrons of nitrogen atoms are employed for the 10π-aromatization. Therefore, this dihydropyrrolo[3,2-b]pyrrole system is considered to be new entry of 10π-electron compound with aromatic character.[7)]

Table 1. $^1$H-NMR Spectral Data (δ ppm)[a)] of Compounds 4, 5, 6, 7, 8, and Pyrrole

| Compound | α-H | β-H | N-H | t-But | COOMe |
|---|---|---|---|---|---|
| 4 | 7.04 (s) | ---- | --- | 1.41 | 3.93 |
| 5 | 6.95 (d)<br>6.56(d,d) | ---- | 7.5 | 1.34<br>1.45 | 3.92 |
| 6 | 6.49 (d) | ---- | 7.2 | 1.36 | ---- |
| 7 | 6.30 (s) | ---- | --- | 1.12 | 3.75 |
| Pyrrole | 6.68 | 6.22 | 8.0 | ---- | ---- |
| 8 | 7.20 | 6.20 | --- | ---- | 3.94 |

a) NMR spectra were measured using 5-8 mg of samples in 0.4 ml of $CDCl_3$.

Table 2. Half Oxidation Potentials (vs. SCE) and Ionization Potentials of Compounds 4, 5, 6, and Pyrrole

| Compound | 4 | 5 | 6 | Pyrrole |
|---|---|---|---|---|
| $E_{1/2}^{ox}$ (V)[a)] | 1.15 | 0.82 | 0.44 | 1.25[b)] |
| IP (eV)[c)] | 9.8 | ---[d)] | 8.0 | 8.21[e)] |

a) measured by cyclic voltammetry using Pt-electrode in 0.1 mol/dm³ $(NEt_4)ClO_4/CH_3CN$ (scanning rate: 100 mV/s). b) Ref. 8. c) from Ionization Efficient Curve. d) not determined. e) Ref. 9.

As shown in Table 1, α-protons adjacent to N-COOMe group show the signals at 7.04 and 6.95 ppm, respectively, in 1,4-dihydropyrrolo[3,2-b]pyrroles 4 and 5, whereas α-proton of tetrahydro-derivative 7 appears at 6.30 ppm. From this high field shift of α-proton, it is concluded that a diatropic ring current ascribed to aromaticity exists in compounds 4 and 5. By decarboxylation, the chemical shift of α-proton moves to 6.56 ppm in 5 and 6.49 ppm in 6. The chemical shift of 6.49 ppm is higher than that of the corresponding α-proton (6.68 ppm) of pyrrole. The similar discrepancy is also observed in the α-protons of N-methoxycarbonyl derivatives, 4 and 8. In addition, it is noticeable that the nitogen proton of 6 appears in higher field compared with pyrrole. These data suggest the more electron-excess character of the dihydropyrrolopyrroles in comparison with the pyrroles.

In Table 2 are listed half oxidation potentials and ionization potentials of 4, 5, 6, and pyrrole. It should be noted that the values of 1,4-dihydropyrrolo[3,2-b]pyrrole 6 are lower than those of pyrrole. This shows an anomalous electron-excess character of this system. In addition, in these related compounds a linear relationship exists between the half oxidation potentials and the HOMO levels which are calculated by HMO method using parameters of Gleiter's.[10] Accordingly, the electron-rich 10π-aromatic character is considered to be an inherent property of 1,4-dihydropyrrolo[3,2-b]pyrrole.

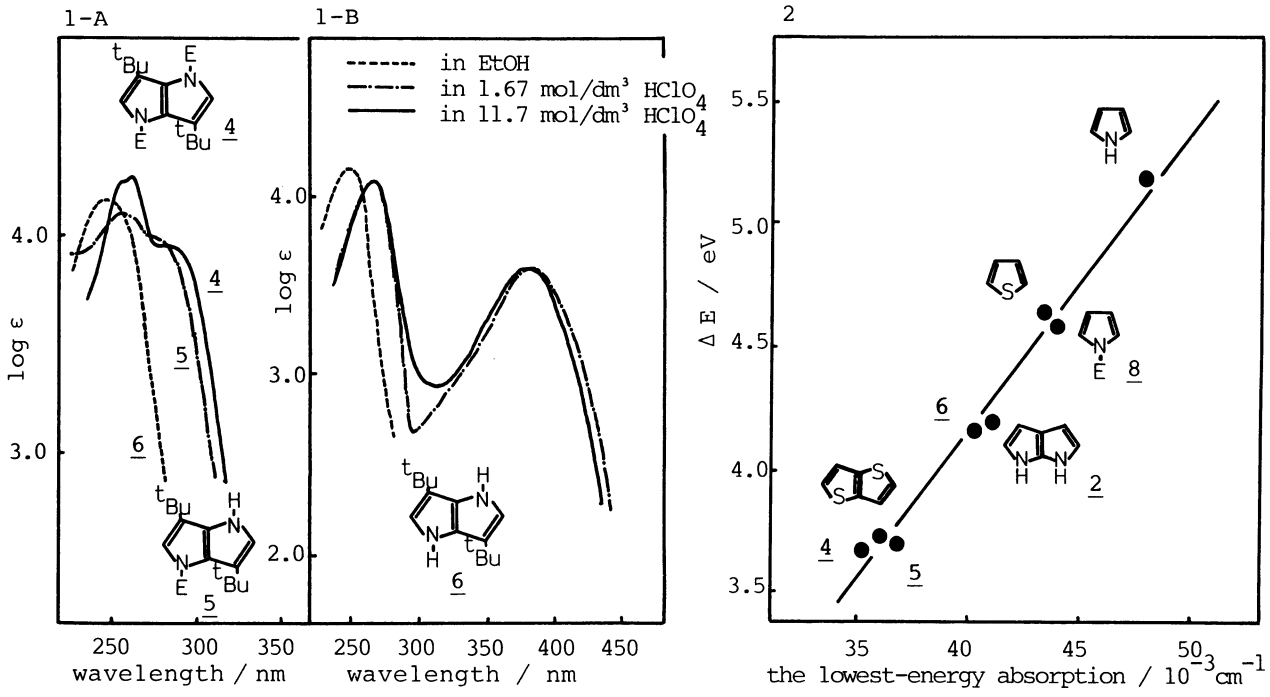



Fig. **1-A.** UV spectra of compounds 4, 5, and 6 in cyclohexane.
**1-B.** UV spectra of 6 in 1.67 and 11.7 mol/dm³ $HClO_4$.

Fig. **2.** Relationship between lowest absorption and calculated excitation energy for 2, 4, 5, 6, 8, pyrrole, thiophene and thieno[3,2-b]thiophene.

Electronic spectra of compounds 4, 5, and 6 are shown in Fig. **1-A.** When methoxycarbonyl groups are introduced on 1,4-dihydropyrrolo[3,2-b]pyrrole 6, a bathochromic shift is observed. This can be explained by MO consideration, i.e., the introduction of electron-withdrawing substituent should lower the LUMO level

compared with the HOMO level.[10] As shown in Fig. 2, there is observed a considerably good linear relationship between the lowest absorption and the calculated excitation energies ($\Delta E = E_{LUMO} - E_{HOMO}$) in a series of the compounds 2, 4, 5, 6, 8, pyrrole, thiophene, and thieno[3,2-b]thiophene.

When 6 is dissolved in concd HCl, mono-hydrochloride, mp 255-260 °C (decomp), is obtained in good yield. $^1$H-NMR spectrum of 6 in $CF_3COOH$ shows the structure of α-protonated species 9;[11] δ 1.37(t-Bu), 1.49(t-Bu), 4.92($H_2$ and $H_{2'}$, m), 7.95($H_5$, m), 8.43(NH, m), 8.88(N'H, m), $J_{H_2-H_5}$ = 1.5 Hz, $J_{NH-H_5}$ = 1.0 Hz, $J_{N'H-H_5}$ = 3.0 Hz. Electronic spectra of 6 in EtOH and in 1.67 and 11.7 mol/dm$^3$ aqueous perchloric acid solution are shown in Fig. 1-B.

Acid dissociation constant (pKa) of 9 is also measured by UV spectral determination procedure using an absorption at 380 nm in Perrin buffer solution,[12] and pKa value of 3.6 is determined. Upon comparison of this value with the basicity of pyrrole (-3.8) and indole (-3.6), 1,4-dihydropyrrolo[3,2-b]pyrrole 6 is considered to be much more basic than these compounds. More electron-excess and more basic character is one of significant feature of pyrrolo[3,2-b]pyrrole 6.[13]

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7) In mono-ester 5, the absorption observed at 1698 cm$^{-1}$ shows the intramolecular polarization or the intermolecular hydrogen-bond formation between carbonyl and NH group.
8) The value of 1.20 V is also reported by Diaz using Pt-electrode under similar condition. A.F. Diaz, A. Martines, K.K. Kanazawa, and M. Salmon, J. Electroanal. Chem. Interfacial Electrochem., 130, 181 (1981).
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11) HMO calculation of dihydropyrrolo[3,2-b]pyrrole also gives the frontier electron density of 0.517 at α-position, which is higher than that (fr(E)=0.172) of β-position.
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13) The treatment of 6 with NaH in tetrahydrofuran gave the dianion which was converted to N,N'-dimethyl derivative, mp 202-203 °C, in 65% yield.

(Received August 22, 1984)