Oxidative Dimerization of Pyrrole Derivatives. III. Studies on the 3-Carbonyl Substituted Pyrryl Radicals.[1,2]

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The thermochromic properties of the dimers in solution, obtained by oxidation of 3-carbonyl substituted pyrroles, was determined as being due to the reversible dissociation into pyrryl radicals. The structure and character of the pyrryl radicals are discussed on the basis of substituent effect on thermochromism and ESR studies.

In previous papers,[3),4)] we reported the oxidative dimerization of some pyrroles and the structures of the resulting dimers. This paper describes the radical mechanism for the thermochromic properteis of some dimers and discusses the structures and characters of the pyrryl radicals.

Results and Discussion

Thermochromism in Solution. When a colorless benzene solution of dimer I, bis[3-ethoxycarbonyl-4,5-bis(*p*-methoxyphenyl)-2-methylpyrryl], is heated, a slightly reddish purple color (λ_{max} 555 mμ) and ESR signal are observed at about 60°C, the intensities being enhanced with the rise in temperature. On cooling, the colour disappears reversibly with diminution of the ESR signal intensity. This indicates that the thermochromic property is caused by reversible radical dissociation of the dimer.

It is well-known that the dissociation of such dimers is enhanced by the resonance stabilization of the radicals formed. We examined the properties of other dimers, II–XI, to clarify the substituent effects on the stabilizing ability of the resulting pyrryl radicals. The results are listed in Table 1.

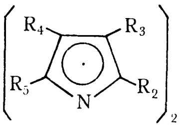
The difference in behavior between dimer I and III makes it clear that a carbonyl substituents in the 3-position is essential for thermochromism. This suggests that the carbonyl groups have a potential radical stabilizing ability presumably due to resonance and the carbonyl function should lie in the same plane as the pyrryls.[5)]

Table 1 also shows that the 3-carbonyl substituted dimers dissociate only when they have a radical stabilizing *p*-anisyl group at 5-position, the 4-substituents being less important. Therefore, it seems that these radicals have a similar steric structure to the original dimers,[3)] in which the phenyl ring at 4-position is bent out of the pyrryl radical plane differing from that at 5-position. The hyperfine splitting of the ESR spectra also supports this view.

The substituent effects are in line with those observed in the dimerization reaction and the rate of interconversion of the dimers,[4)] supporting the intermediacy of identical radical species in these reactions.

ESR Spectra of the Pyrryl Radicals. Figure 1a

TABLE 1. THERMOCHROMIC PROPERTY OF VARIOUS DIMERS IN BENZENE SOLUTION



	R_2	R_3	R_4	R_5	Thermochromism
I	CH_3	$CO_2C_2H_5$	p-$CH_3OC_6H_4$	p-$CH_3OC_6H_4$	+
II	CH_3	$COCH_3$	p-$CH_3OC_6H_4$	p-$CH_3OC_6H_4$	+
III	CH_3	H	p-$CH_3OC_6H_4$	p-$CH_3OC_6H_4$	−
IV	C_2H_5	$CO_2C_2H_5$	p-$CH_3OC_6H_4$	p-$CH_3OC_6H_4$	+
V	CH_3	$CO_2CH_2C_6H_5$	CH_3	p-$CH_3OC_6H_4$	+
VI	CH_3	$CO_2C_2H_5$	C_6H_5	p-$CH_3OC_6H_4$	+
VII	CH_3	$COCH_3$	C_6H_5	p-$CH_3OC_6H_4$	+
VIII	CH_3	$CO_2C_2H_5$	p-$CH_3OC_6H_4$	C_6H_5	−
IX	CH_3	$COCH_3$	p-$CH_3OC_6H_4$	C_6H_5	−
X	CH_3	$CO_2C_2H_5$	C_6H_5	C_6H_5	−
XI	CH_3	$COCH_3$	C_6H_5	C_6H_5	−

+; Thermochromism shown. −; Thermochromism not shown.
Neither irradiation nor grinding of the dimers caused visible change in color.

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1) Part II of this series: Ref. 4.

2) Presented at the 24th Meeting of the Chemical Society of Japan, Tokyo, October 13, 1971.

3) K. Tomita and N. Yoshida, *Tetrahedron Lett.*, **1971**, 1169.

4) K. Tomita and N. Yoshida, This Bulletin, **45**, 3160 (1972).

5) An analogous radical stabilizability of carbonyl groups, including their steric requirement, was reported in the case of pyridinyl radicals. M. Ito and S. Nagakura, This Bulletin, **39**, 369 (1966).

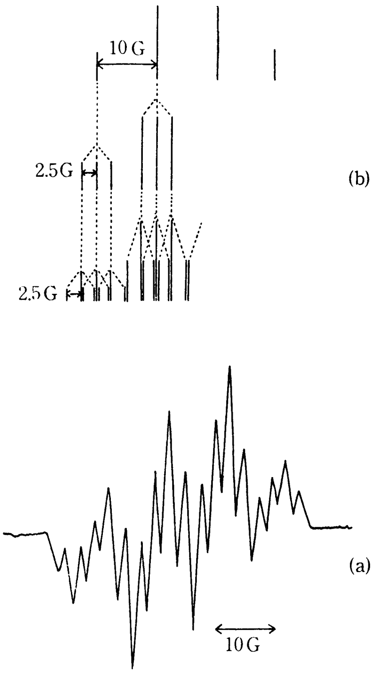


Fig. 1. ESR spectrum from I in degassed toluene at 110°C. (a) Observed spectrum. (b) Stick diagram.

shows the ESR spectra observed for a solution of I in toluene at 110°C. At large amplitude of magnetic modulation, the spectrum showed broad quintet lines (1 : 3 : 3 : 1, a=10G). The ESR spectrum from dimer IV (2-ethyl) exhibited triplet lines (1 : 2 : 1, a=10G) and further subsplittings in each component of the triplet just like those observed in I. It is clear, therefore, that the largest splitting (10G) is caused by the α-protons of the 2-alkyl substituents.

On the other hand, the absence of any interaction of the unpaired electron with protons of the 3-ester group was confirmed by the fact that the radical from dimer II(3-acetyl) gave the same spectrum as that from I. Little participation of the 4-phenyl ring protons was also suggested by the observation of identical spectra from dimer VI(4-phenyl) and I.[6]

The subsplittings should therefore be caused by the nitrogen and the protons(ortho) of the 5-phenyl ring. The isotope labelled dimer XII(^{15}N labelled I) and XIII (I deuterated at an ortho proton of 5-phenyl ring) were prepared and ESR spectra of the corresponding radicals were recorded, as shown in Figs. 2 and 3.

From a comparison of the spectra shown in Figs. 1a, 2 and 3, hyperfine splitting of the pyrryl radical from I could be assigned as follows[7]: a_{H}=10G(2-alkyl protons); a_{H}=2.5G (ortho protons of 5-phenyl ring): $a_{14\mathrm{N}}$=2.5G($a_{15\mathrm{N}}$=3.3G), as illustrated in Fig. 1b.

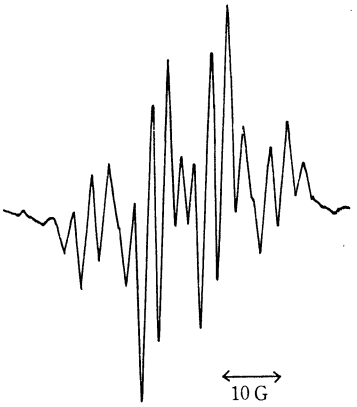


Fig. 2. ESR spectrum from XII in degassed toluene at 110°C.

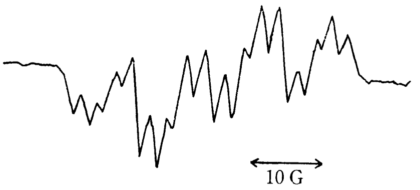
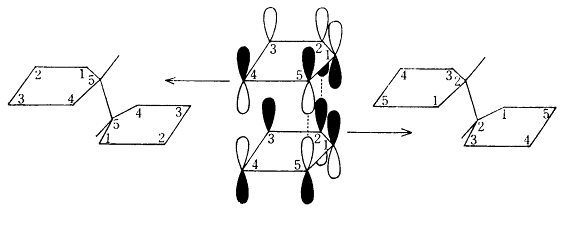


Fig. 3. ESR spectrum from XIII in degassed toluene at 110°C.

The ESR data suggest the occurrence of the large spin densities at 2, 5 and 1(N) positions and consequently a high probability of dimerization of the radicals at these positions, which is consistent with the preferential formation of 2,2′- and 5,5′-dimers.[3],[4] The lack of N,N′ bonding can be attributed to steric hindrance which makes recombination of the radical difficult or weakens the bond of the dimer, if formed at all. It is uncertain why no unsymmetrical dimer, 2,5′, was formed. One possible explanation is that the dimerization proceeds by symmetry-controlled secondary orbital interactions.[8] Thus, the highest overlap of the molecular orbitals could become possible in the assumed transition state leading to the symmetrical dimers, as illustrated in the following scheme.[9]



Experimental

Melting points are uncorrected. The IR spectra were determined by means of Nujol mulls with a Hitachi EPI-S2 spectrophotometer. The NMR spectra were obtained using a Varian A-60 NMR spectrometer, using tetramethylsilane as the internal standard at 32°C. The mass spectra were

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[6] This also shows that the 4-phenyl ring is twisted from the plane of the pyrryl radical and supports the given steric structure.

[7] Partial disagreement in intensities with the theoretical spectrum may be attributed to the difficulty in finding optimum conditions for ESR measurement of these pyrryl radicals.

[8] R. Hoffman and R. B. Woodward, *J. Amer. Chem. Soc.*, **87**, 4388 (1965).

[9] The diagram of the orbital occupied with an odd electron was obtained from HMO calculation. The calculated spin density of the radical is appreciably in accord with that predicted from ESR results.

obtained using a JEOL–JMS–OIS mass spectrometer. The ESR measurements were carried out in *ca.* 10% deaerated solution with a Hitachi MES 4001 type X-band spectrometer, with MES 4701 Thermocontroller, and the splitting constants were measured relative to aqueous solution of Fremy's salt. Visible spectra were obtained using a Cary-14, with Coolnics Circulator CTE-IA.

*Bis[4,5-bis(*p*-methoxyphenyl)-2-methypyrryl] (III).* By a similar procedure as described for the preparation of I, II, IV—XI,[3],[4] III was obtained quantitatively from 4,5-bis(*p*-methoxyphenyl)-2-methylpyrrole as colorless powder, which was recrystallized from acetone to give colorless prisms, mp 142—145°C(decomp.). Found: C, 78.26; H, 6.25; N, 4.78%. Calcd for $C_{38}H_{36}O_4N_2$: C, 78.06; H, 6.21; N, 4.79. Mass spectrum: M^+ 584.

*Bis[3-ethoxycarbonyl-4,5-bis(*p*-methoxyphenyl)-2-methylpyrryl-^{15}N] (XII).* *a)*: After $^{15}NH_3$ gas, generated from $^{15}NH_4Cl$(1.0 g) and 15% aqueous NaOH(10 m*l*), was introduced into acetic acid(50 m*l*), 1.3 g of anisoin and 1.0 g of ethyl acetoacetate were added and the mixture was refluxed for 2 hr. The reaction mixture was poured into ice water and the resulting precipitate was separated by filtration, washed with water and dried *in vacuo* to give 1.65 g of ethyl 4,5-bis(*p*-methoxyphenyl)-2-methylpyrrole-3-carboxylate-^{15}N, mp 131—134°C(benzene-petroleum ether). IR(cm^{-1}): ν_{NH} 3370, $\nu_{C=O}$ 1675. Mass spectrum: M^+ 366.

b): Oxidation of pyrrole-^{15}N afforded dimer XII, quantitatively. mp 138—140°C(decomp.). IR(cm^{-1}): $\nu_{C=O}$ 1725. Mass spectrum: M^+ 730.

*Bis[4,5-bis(*o*-deuterio-*p*-methoxyphenyl)-3-ethoxycarbonyl-2-methyl-pyrryl] (XIII).* *a)*: A mixture of 6.4 g of *o*-bromo-*p*-methoxybenzaldehyde,[10] 2.5 g of 10% palladium on carbon, 4.0 g of sodium acetate and 100 m*l* of methanol was shaken with deuterium under atmospheric pressure at room temperature until uptake ceased (about 20 min). After the mixture was filtered and concentrated below 50°C under reduced pressure, the residue was extracted with ether and the solution was washed with water and dried. After evaporation of ether, the resulting oil was distilled (at 250°C, bath temp.) to give 3.7 g of anisaldehyde-2-*d*. Mass spectrum: M^+ 137. NMR spectrum (ppm in CCl_4): 3.90 (3H, singlet), 6.90—7.87 (3H, multiplet), 9.87(1H, singlet).

b): Anisaldehyde-2-*d* gave anisoin-2,2′-d_2 by the usual benzoin condensation method. Mp 104—107°C. Mass spectrum: M^+ 274.

c): Reaction of 0.25 g of anisoin-2,2'-d_2 and 0.4 g of ethyl acetoacetate in the presence of 1.0 g of ammonium acetate in 20 m*l* of acetic acid afforded 0.20 g of ethyl 4,5-bis(*o*-deuterio-*p*-methoxyphenyl)-2-methylpyrrole-3-carboxylate, mp 131—133°C, by a similar procedure as described for the preparation of pyrrole-^{15}N. NMR spectrum (ppm in $CDCl_3$): 6.70—7.40(6H, multiplet). Mass spectrum: M^+ 367.

d): Oxidation of pyrrole-d_2 gave dimer XIII quantitatively. Mp 136—138°C(decomp.). IR(cm^{-1}): $\nu_{C=O}$ 1725. Mass spectrum: M^+ 732.

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[10] H. H. Hodgson and T. A. Jenkinson, *J. Chem. Soc.*, **1927**, 3041.