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THE STRUCTURE OF THE OXIDATION PRODUCT OF PYRROLE, $C_{12}H_{17}N_3O_3$

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Abstract—Chemical and spectroscopic data support the structure 2,5-bis(pyrrolidin-2-on-5-yl)pyrrole, $C_{12}H_{15}N_3O_2{\cdot}H_2O$ (BPP), for the oxidation product of pyrrole, $C_{12}H_{17}N_3O_3$, m.p. 164°, known as trioxo-terpyrrole. This compound is a mixture of two isomers, m.p. 217° and 233° respectively, to which *meso* and *racemic* structures have been assigned. BPP is not considered an intermediate in the formation of pyrrole black.

Angeli observed that pyrrole, oxidized at low temperature with hydrogen peroxide in amounts greater than those required to obtain 2(pyrrolidin-2-on-5-yl)pyrrole (PP)[1,2] yielded, besides an oxypyrrole black, a product $C_{12}H_{17}N_3O_3$, melting at 164°, with formation of gases and blue decomposition products.[1,3] It was called trioxoterpyrrole (TTP)[4] and although its structure was considered relevant for the constitution of pyrrole black, this was not determined.

Pieroni[4] found that TTP behaved as if it contained only one pyrrole group. The structure of TTP has been reexamined because the recent assignation to oxo-bipyrrole of the structure 2(pyrrolidin-2-on-5-yl)pyrrole (compd II, Table 1),[2] led us to believe that this compound is an intermediate in the formation of TTP rather than of pyrrole black, as previously believed. Hence the structure of TTP would confirm or exclude its participitation in the formation of pyrrole blacks.

TTP (m.p. 164°) crystallized from dioxan in two different crystalline forms, m.p. 217° and 233° respectively, the difference being accentuated by crystallization from other solvents; for instance, from water the compound with the higher m.p. (BPPH) exhibits colourless micro-crystalline dendritic aggregates, while that with the lower m.p. (BPPL) is in the form of long colourless needles. The X-ray diffraction patterns of the compounds are also different.[5]

The two compounds (BPPH and BPPL) possess the same formula ($C_{12}H_{17}N_3O_3$) and the same functional groups since the chemical behaviour and the UV, IR and NMR spectra are identical. The mixed m.p. is 164° without appearance of a blue colour,[1,3] obviously due to impurities. Treatment with iodine yields two diiodo derivatives again with different crystalline forms.

Chemical and physico-chemical data support the structure of 2,5-bis(pyrrolidin-2-on-5-yl)pyrrole, $C_{12}H_{15}N_3O_2{\cdot}H_2O$ (compd III, Table 1) for each isomer. As this structure contains two asymmetric carbon atoms, the two crystalline forms (optically inactive) can be attributed to *meso* and *racemic* forms. Angeli's compound (TTP) is thus a mixture.

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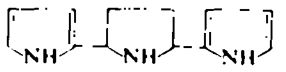
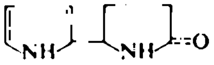
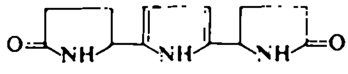
[1] A. Angeli and L. Alessandri, *Gazz. Chim. Ital.* **46**, II, 283 (1916).
[2] L. Chierici and G. P. Gardini, *Tetrahedron* **22**, 53 (1966).
[3] A. Angeli and A. Pieroni, *Gazz. Chim. Ital.* **49**, I, 154 (1919).
[4] A. Pieroni and A. Moggi, *Gazz. Chim. Ital.* **53**, 120 (1923).
[5] M. Nardelli, G. D. Andreetti and A. Manfredotti, *Ric. Sci.* **36**, 276 (1966).

TABLE 1. UV VALUES OF SOME SUBSTITUTED PYRROLES

	Compound	Solvent	mμ(ε)	Ref.
I		EtOH	218(18,100)	2
II		EtOH	215(11,000)	2
III	 · H_2O	EtOH	223(12,600)	

The following facts are in favour of the proposed structure:

(1) Each isomer loses rapidly a molecule of water if heated at 180° *in vacuo*. Angeli's TTP begins to lose water at 164° under normal conditions and thus what is described as decomposition,[1,3] is lose of water. The mol. wts of the anhydrous isomers (cryoscopically determined) are 240 and 246 respectively, but the compounds are extremely hygroscopic and easily reintegrate one water molecule.

(2) The compounds are pyrrole derivatives, confirmed by the positive reaction with a fir sliver and by the formation of α,α'-bis-*p*-bromophenylazopyrrole as already shown for TTP by Pieroni.[4]

(3) The UV data (Table 1) indicate that the pyrrole ring is not conjugated.

(4) Each isomer, after hydrolysis with alkali yields on alkaline oxidation with permanganate α,α'-pyrroledicarboxylic acid. This confirms that the rings bonded to the pyrrole nucleus in the position α,α' are easily hydrolysed.

(5) On treatment with iodine, the corresponding 2,5-bis(pyrrolidin-2-on-5-yl)3,4-diiodopyrroles are formed. The NMR spectra (Table 2) confirm that iodine occupies the positions 3 and 4 of pyrrole nucleus.

(6) The IR spectrum in KBr for each isomer indicates the presence of strongly associated NH-groups (3450–3180 cm^{-1}) and CO-groups (1650 cm^{-1}).

(7) Each isomer is positive to Rydon's[6] chromatic reaction, indicating the presence of a —CO—NH— function.

(8) Finally, the structure was confirmed by NMR analysis.[7] From Table 2, where the chemical shifts in DMSO-d_6 of PP and BPP are listed, it can be seen that the two pyrrole hydrogens are equivalent and coupled to the pyrrole NH-group. The corresponding signal is not present in the diiodo derivatives. The lactam forms of BPP in DMSO were confirmed by the signal attributed to the NH-groups, which does not change in trifluoroacetic acid.

The proposed structure confirms that 2(pyrrolidin-2-on-5-yl)pyrrole is an intermediate in the formation of BPP. This is further substantiated by the preparation of BPP using experimental conditions suggested by Angeli. Paper chromatography

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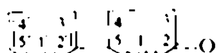
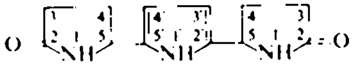
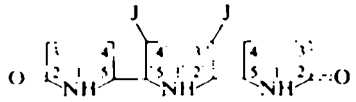
[6] H. N. Rydon and P. W. G. Smith, *Nature, Lond.* **169**, 922 (1952).

[7] R. Mondelli, *Chim. Ind.* **47**, 1212 (1965).

TABLE 2. CHEMICAL SHIFTS IN DMSO-d_6 OF PP,BPP AND DIIODODERIVATIVE

Compound	$H_{5'}$	$H_{4'}$	$H_{3'}$	$H_{1'}$	H_1	H_5	H_3 and H_4
	6·67 Q.	5·94 T.	5·94 T.	10·8	7·85	4·65	1·6–2·5 M. (4H)
	—	5·83 D. $J_{1',4'} = J_{1',3'} =$ 2·5 c/s	5·83 D.	10·6	7·83 S. (2H)	4·63 M. (2H)	1·5–2·6 M. (8H)
	—	—	—	11·6	7·83 S. (2H)	4·75 M. (2H)	2–3 M. (8H)

NMR spectra: Varian A-60 spectrometer; 20-30% DMSO-d_6 solns. Chemical shifts in ppm (δ) with TMS as internal standard. The integrals were measured with a Digital Voltmeter Hewlett-Packard 405 CR.

shows that PP is formed in the reaction after a few minutes (together with other substances of unknown structure which react with diazosulphanilic acid). The formation of BPP can be detected only on the fourth day and after the fifth day the amount of PP decreases while that of BPP increases. With suitable experimental arrangements the process can be followed quantitatively (Experimental).

The structure proposed together with experimental facts indicate that it is very unlikely that both PP and BPP participitate as fundamental intermediates in the oxidative polymerization to pyrrole black.

Research is in progress to show the mechanism of the formation of these two compounds.

TABLE 3. R_f VALUES ON WHATMANN 3MM FILTER PAPER, AT 25°

Solvent	PP*	BPP*
n-BuOH:AcOH:H_2O 4:1:5	0·87	0·71
n-BuOH:AcOH:H_2O 12:3:5	0·86	0·74
iso-AmOH:AcOH:H_2O 12:3:5	0·81	0·60
EtOH:H_2O 9:1	0·78	0·66
Dioxan:H_2O 25:1	0·86	0·38
EtOH:conc. ammonia:H_2O 20:1:4	0·87	0·74

* Red-violet colouration of spots after developing with diazosulphanilic acid and then 1N NaOH.

EXPERIMENTAL

2,5-Bis(pyrrolidin-2-on-5-yl)pyrrole (BPP; *trioxo-terpyrrole*). A soln of pyrrole (10 ml) in AcOH (130 ml) was cooled in an ice bath and added, with stirring, with 35% H_2O_2 (17 ml);[1] the low temp was maintained for 9 hr and then the reaction was left at room temp for 20 days and finally the soln was concentrated by evaporation, adding repeatedly small amounts of water until the AcOH was eliminated. The pyrrole black was filtered off and washed with water. The soln concentrated under vacuum gave a product (1·7 g) which recrystallized from EtOH, m.p. 164° with dec. (Found: C, 57·49; H, 7·00; N, 16·91. Calc. for $C_{12}H_{17}N_3O_3$: C, 57·35; H, 6·82; N, 16·72%.) Finely ground and heated under vacuum (0·5 mm, 150°) the substance lost 7·10% H_2O (calc. for $1H_2O$: 7·17%). The compd lost about 15% water by heating at the m.p.

Low melting isomer (BPPL). A hot sat soln of BPP in dioxan (charcoal) crystallized on slow cooling yielding pale yellow crystals, m.p. 180–200°, with blackening. Repeated crystallizations from dioxan and finally from water, yielded long colourless needles, m.p. 217° with dec. (Found: C, 57·43; H, 6·74; N, 16·88. $C_{12}H_{15}N_3O_2 \cdot H_2O$ requires: C, 57·35; H, 6·82; N, 16·72%.) The compound, finely ground, lost 7·13% water (calc. for $1H_2O$:7·17%) by heating under vacuum (0·5 mm, 180°). (Found: C, 61·49; H, 6·53; N, 18·00. $C_{12}H_{15}N_3O_2$ requires: C, 61·78; H, 6·48; N, 18·02%.) Mol. wt., (cryoscopic) in AcOH, 240 (calc.: 233·27). Optically inactive in AcOH soln (10%).

High melting isomer (BPPH). The dioxan filtrate, after separation of BPPL and concentration to ½vol (steam bath) yielded heavy micro-crystals, light yellow, m.p. 220–230°. Repeated crystallizations from dioxan and finally from water yielded dendritic colourless crystals, m.p. 233° with dec. (Found: C, 57·48; H, 6·83; N, 16·92. $C_{12}H_{15}N_3O_2 \cdot H_2O$ requires: C, 57·35; H, 6·82; N, 16·72%.) The finely ground compound lost 7·15% water (calc. for $1H_2O$: 7·17%) by heating under vacuum (0·5 mm, 180°). (Found: C, 61·50; H, 6·55; N, 17·87. $C_{12}H_{15}N_3O_2$ requires: C, 61·78; H, 6·48; N, 18·02%.) Mol. wt. (cryoscopic) in AcOH, 246 (calc.: 233·27.) Optically inactive in AcOH soln (10%).

Iodination. To a cold water soln (80 ml) of each isomer (100 mg), 2N K_2CO_3 (2 ml) was added and then dropwise and under stirring a I_2 soln (KI g 3, I_2 g 0·4, H_2O 10 ml) until the soln was permanently coloured. Immediately the I_2 excess was destroyed with a few drops of $Na_2S_2O_3$aq and the ppt, slightly pink, was dissolved in excess EtOH. The diiodo derivatives were separated by concentrating the EtOH soln decolourized with charcoal, yielding light crystals for the low melting isomer and colourless flakes for the high melting one, both decomposing without melting. (Diiodo-derivative from BPPL, Found: C, 29·84; H, 2·71; N, 8·43; I, 52·54; from BPPH, Found: C, 30·03; H, 2·93; N, 8·50; I, 52·07; $C_{12}H_{13}I_2N_3O_2$ requires: C, 29·71; H, 2·70; N, 8·66; I, 52·33%.)

Oxidation. A suspension of each isomer (200 mg) in 10% KOH (6 ml) was refluxed until evolution of ammonia ceased (about 2 hr). After cooling, the alkaline soln was added dropwise to a cooled sat soln of $KMnO_4$ until the colour was stable for 5 min. The excess of permanganate was destroyed with a few drops of $NaHSO_3$aq, the MnO_2 was filtered off and the filtrate acidified with conc. HCl and repeatedly extracted with ether. The residue, dissolved in EtOH (1 ml), was chromatographically analysed (bidimensionally: 3MM filter paper, first run: n-buthanol–AcOH–water, 12:3:5; second run: EtOH–conc. ammonia–water, 20:1:4). The chromatogram, developed with diazosulphanilic acid,[8] showed the presence of 2,5-pyrroledicarboxylic acid.[9] About 20% yield, gas chromatographically determined.[10]

Chromatographic analysis. A soln of pyrrole (10 ml) in AcOH (130 ml), cooled in ice was added with H_2O_2 (35%, 17 ml). After 5 min a sample (1 ml) was taken and the oxidizing agent destroyed with Pt black. The chromatographic analysis was made on the centrifuged soln (0·01 ml: Whatmann 3MM filter paper, n-buthanol–AcOH–water, 12:3:5; average length: 25 cm). The chromatogram was developed with diazosulphanilic acid and then with 1N NaOH. By operating in the same way on various samples of the remaining reaction mixture, it was observed that the intensity of the spot due to PP increased until the fourth day. Then, BPP appeared, which increased until the end of the reaction, while the amount of PP decreased. Red-violet colour, after developing, for both compounds; R_f see Table 3.

Quantitative determination. In accordance with the procedure outlined, using the same ratio to 40 g of pyrrole, after 100 hr half the soln was neutralized with conc. NH_4OH (ice cooling), the pyrrole black was filtered off and the soln extracted with chf. The pigment was repeatedly washed with water and dried at 120° (3·5 g). PP (2 g, m.p. 136°) was obtained from the $CHCl_3$ following Angeli's[1] procedure.

After 20 days, from the residual soln, BPP (4·3 g) was purified by crystallization as described for 2,5-bis(pyrrolidin-2-on-5-yl)pyrrole. Pyrrole black was also obtained (4 g). From the filtrate of BPP and from the washings of pyrrole black, by extraction with chf, PP (0·31 g) was obtained.

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[8] R. Nicolaus and G. Oriente, *Gazz. Chim. Ital.* **84**, 230 (1954).

[9] L. Chierici and G. C. Artusi, *Ann. Chim. Roma* **53**, 1633 (1963).

[10] L. Chierici and G. Scapini, *Ric. Sci., Rend.* **34**, (II-A), 164 (1964).