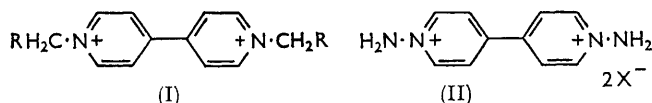


Bipyridylium Quaternary Salts and Related Compounds. Part II.† The Preparation of the 1,1'-Diamino-4,4'-bipyridylium Dication and its Behaviour in Alkaline Solution‡

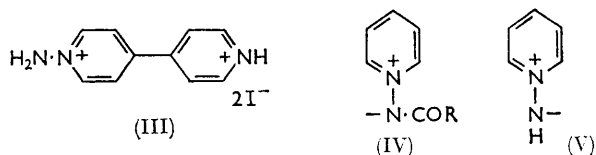
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The preparation of the 1,1'-diamino-4,4'-bipyridylium dication is described. In alkaline solution, this gives a product believed to be a nitrogen betaine derived by loss of a proton.

THE size of the substituents on the quaternary nitrogen atoms of a 4,4'-bipyridylium salt has a marked influence on its herbicidal effect.¹ Thus paraquat ion (1,1'-dimethyl-4,4'-bipyridylium ion) (I; R = H) is considerably more active as a herbicide than the 1,1'-diethyl cation (I; R = Me) and activity falls rapidly as the

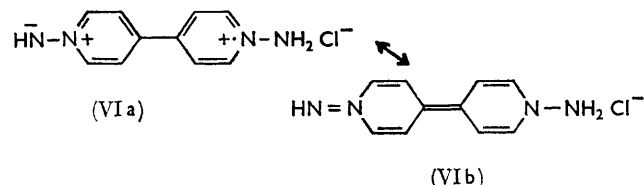


homologous series is further ascended. Particular interest, therefore, attached to the preparation and properties of the 1,1'-diamino-compound (II) in which the *N*-substituent is comparable in size with that in paraquat. Reaction of the potassium salt of hydroxylamine-*O*-sulphonic acid² with 4,4'-bipyridyl in aqueous solution afforded the desired compound (II), which was isolated as the di-iodide. The monoamino-compound (III) could also be isolated from the reaction. The u.v. spectrum of the diquaternary dichloride (II; X = Cl) resembled that of paraquat dichloride [λ_{max} 257 m μ (ϵ 21,000)]; however, the main absorption band occurs at 295 m μ , possibly because of the greater bathochromic effect of an amino-group than a methyl group.



Dilute aqueous solutions of the dichloride (II; X = Cl) became deep yellow on treatment with a trace of alkali; the colour was dispelled immediately by acidification. The u.v. spectrum of the alkaline solution differed markedly from that of the neutral solution. In addition to an intense band at 417 m μ , peaks of lesser intensity were present at 250 and 296 m μ . In view of the ease with which nitrogen betaines of type (IV) are obtained by alkaline treatment of the corresponding *N*-acylamino-pyridinium salts,³ and the postulated⁴ existence of the betaine (V) in 1,3-dipolar addition reactions, it seemed possible that the change in the u.v. spectrum of a

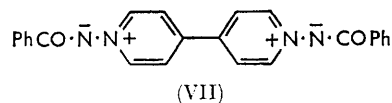
solution of (II; X = Cl) on basification was due to the loss of a proton from one of the amino-groups of (II; X = Cl) to form the nitrogen betaine (VI).



It is interesting that the preparation of the nitrogen betaine trimethylamine imine, Me₃N⁺-NH⁻ has recently been reported.⁵ In the present case, stabilisation of the nitrogen betaine would be afforded by contributions from other canonical forms such as (VIb). Contributions from this quinonoid structure would account for the production of the coloured species on basification of a solution of (II).

When a concentrated aqueous solution of the amino-compound (II) was treated with one equivalent of alkali, a red crystalline solid separated. This was unstable when wet, but after washing with water and drying in a vacuum desiccator, it could be kept in a stoppered tube for some days. The structure has not been established but on the basis of elemental analysis it is probably the betaine (VI); solubility difficulties prevented a molecular weight determination, so a dimeric structure analogous to that of the compound obtained by alkaline treatment of 1-amino-quinolinium salts⁴ cannot be excluded.

In dilute alkaline solution the diamino-compound (II) reacted readily with benzoyl chloride to give the dibenzoyl derivative (VII).



Attempts to obtain *N*-alkylated derivatives of the diamino-cation (II) by reaction of *N*-methylhydroxylamine-*O*-sulphonic acid or *N*-hydroxypiperidine-*O*-sulphonic acid with 4,4'-bipyridyl were unsuccessful, no quaternary salt being obtained. 2,2'-Bipyridyl

† Part I, J. E. Downes, *J. Chem. Soc. (C)*, 1967, 1491.

‡ British Patent Application No. 17785/64.

¹ R. F. Homer, G. C. Mees, and T. E. Tomlinson, *J. Sci. Food Agric.*, 1960, **11**, 309.

² Cf. R. Gösl and A. Meuwesen, *Chem. Ber.*, 1959, **92**, 2521.

³ T. Okamoto, M. Hirobe, C. Mizushima, and A. Osawa, *J. Pharm. Soc. Japan*, 1963, **83**, 309.

⁴ R. Huisgen, R. Grashey, and R. Krischke, *Tetrahedron Letters*, 1962, 387.

⁵ R. Appel, H. Heinen, and R. Schöllhorn, *Chem. Ber.*, 1966, **99**, 3118.

was also recovered after treatment with hydroxylamine-*O*-sulphonic acid under conditions in which 4,4'-bipyridyl was converted into the diamino-quaternary salt (II).

In contrast with the paraquat ion (I; R = H) the 1,1'-diamino-4,4'-bipyridylium dication (II) did not give a stable free radical on reduction. Treatment of an aqueous solution of (II) with zinc dust produced a dark grey colour which disappeared very rapidly. The polarographic reduction curve of the diamino-compound was more complex than that obtained from paraquat ion and has not yet been fully interpreted. The diamino-compound (II) was less active than paraquat (I; R = H) as a herbicide, and this may be partly correlated with the relative instability of the radical derived from the diamino-compound (II), since the unusual stability of the radical derived from paraquat (I; R = H) is an important factor underlying the current theory⁶ of its herbicidal action.

EXPERIMENTAL

Nuclear magnetic resonance spectra were obtained using a Varian 60 Mc./sec. spectrometer. U.v. spectra were measured with an Unicam SP 800 spectrometer.

1,1'-Diamino-4,4'-bipyridylium Dichloride.—Hydroxylamine-*O*-sulphonic acid (113 g.) in water (200 ml.) was cooled to -5° and neutralised with potassium hydroxide (5M; 200 ml.). The solution was added to a suspension of 4,4'-bipyridyl dihydrate (96 g.) in water (300 ml.) at 30° . The suspension was stirred on a steam-bath until the solid dissolved, and then for a further 2 hr. The cooled solution was treated with a saturated solution of potassium carbonate (69 g.). The yellow solution was diluted with methanol until no further solid separated, and the potassium sulphate filtered off. The filtrate was made acid with concentrated hydriodic acid and cooled to 0° . The solid which separated was washed with acetone and recrystallised from water, affording the *bipyridylium salt* (75 g.) as yellow plates, m. p. 210° (Found: C, 27.3; H, 2.9; N, 12.8. $C_{10}H_{12}I_2N_4$ requires C, 27.15; H, 2.7; N, 12.7%). In another experiment, cooling the filtrate from the foregoing product to -10° gave a second solid, m. p. 175° (decomp.) (from water), which was identified as 1-amino-4,4'-bipyridylium di-iodide (Found: C, 27.0; H, 2.9; N, 9.0. $C_{10}H_{11}I_2N_3 \cdot H_2O$ requires C, 27.0; H, 2.9; N, 9.4%).

For conversion into the dichloride, the bipyridylium salt (80 g.) in water (500 ml.) was stirred and heated under reflux for 30 min. with silver chloride freshly prepared from silver nitrate (160 g.). The hot suspension was mixed with charcoal and filtered. The filtrate was evaporated and the residue recrystallised from aqueous alcohol to give the colourless *dichloride* (35 g.), m. p. 288° (decomp.). The analytical figures corresponded best to a partial hydrate of the dichloride; although they differ only slightly from those for the anhydrous compound the assumption of partial hydration seems justified since the dichloride is slightly hygroscopic (Found: C, 45.4; H, 4.7; N, 21.5. $C_{10}H_{12}Cl_2N_4 \cdot \frac{1}{4}H_2O$ requires C, 45.5; H, 4.7; N, 21.2%);

λ_{\max} (water) 295 m μ (ϵ 22,700). An aqueous solution brought to pH 10 had λ_{\max} 250, 296, and 416 m μ . The n.m.r. spectrum (in dimethyl sulphoxide) consisted of doublets at τ 0.91 and 1.04, and 1.33 and 1.47 (A_2B_2 pattern of protons of bipyridyl rings) and a singlet at 1.19 (NH_2).

When 2,2'-bipyridyl was subjected to treatment with hydroxylamine-*O*-sulphonic acid under the conditions described above for 4,4'-bipyridyl, the bipyridyl was recovered from the reaction, no quaternary salt being formed.

Product from Alkaline Treatment of (II; X = Cl).—1,1'-Diamino-4,4'-bipyridylium dichloride (5 g.) in water (10 ml.) was treated with sodium hydroxide (2M; 10 ml.). A brick-red crystalline precipitate separated almost immediately. This was washed thoroughly with water and acetone, and dried in a desiccator over phosphoric oxide. The yield of dry *product*, m. p. 280° (decomp.), was 3.2 g. (Found: C, 49.9; H, 6.0; Cl^- , 14.2; N, 22.9. $C_{10}H_{11}ClN_4 \cdot H_2O$ requires C, 49.9; H, 5.5; Cl^- , 14.8; N, 23.3%). Attempts to dissolve this material in deuterium oxide or dimethyl sulphoxide gave deeply coloured, turbid solutions from which no n.m.r. spectrum could be obtained. In view of this result, no attempt was made to carry out a molecular weight determination.

Dianhydro-1,1'-dibenzamido-4,4'-bipyridylium Dihydroxide (VII).—1,1'-Diamino-4,4'-bipyridylium dichloride (2.6 g.) was shaken with benzoyl chloride (2.3 ml.) and sodium carbonate (0.5M; 20 ml.). A yellow solid separated immediately; this was washed with water and acetone and then recrystallised from aqueous acetic acid, affording the *product* as yellow leaflets (1.4 g.), m. p. 295° (decomp.). Considerable difficulty was experienced in obtaining a satisfactory elementary analysis for this compound. The values quoted are the best from a number of experiments (Found: C, 72.5; H, 4.3; N, 14.2. $C_{24}H_{18}N_4O_2$ requires C, 73.1; H, 4.6; N, 14.2%). The n.m.r. spectrum of a solution in trifluoroacetic acid consisted of doublets centred at τ 1.0 and 1.6 (A_2B_2 pattern of protons of bipyridyl rings) and a peak at 2.7 (C_6H_5).

Attempted Reaction of N-Methylhydroxylamine-*O*-sulphonic Acid with 4,4'-Bipyridyl.—N-Methylhydroxylamine-*O*-sulphonic acid (12.7 g., prepared by the method of Smith *et al.*⁷) in water (30 ml.) was neutralised with potassium hydroxide (5M; 20 ml.) below 0° . The solution was added to 4,4'-bipyridyl dihydrate (9.6 g.) in water (30 ml.) and the mixture heated on a steam-bath for 2 hr. Working up gave only salts of 4,4'-bipyridyl.

Attempted Reaction of N-Hydroxypiperidine-*O*-sulphonic Acid with 4,4'-Bipyridyl.—N-Hydroxypiperidine-*O*-sulphonic acid (18.1 g., prepared by method of Smith *et al.*⁷) was suspended in water (65 ml.) and neutralised below 0° with potassium hydroxide (5M; 20 ml.). The solution was added to 4,4'-bipyridyl dihydrate (9.6 g.) in water (30 ml.) and the solution heated at 80 – 85° for $1\frac{1}{2}$ hr. Working up gave only 4,4'-bipyridyl.

[7/648 Received, May 24th, 1967]

⁶ A. Calderbank, *Biochem. J.*, 1966, **101**, 2P.

⁷ P. A. S. Smith, H. R. Alul, and R. L. Baumgarten, *J. Amer. Chem. Soc.*, 1964, **86**, 1139.