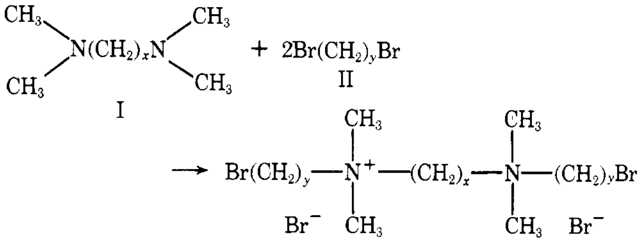
Communications to the Editor

A Study on Ionene Polymers. Synthesis of Linear Oligomers of α,ω-Diamine Type from *N,N,N′,N′*-Tetramethyl-α,ω-diaminoalkanes and α,ω-Dihaloethers[1]

In previous studies[2,3] the synthesis of cyclic and linear oligomers as well as ionene polymers[4] from *N,N,N′,N′*-tetramethyl-α,ω-diaminoalkanes (I) and α,ω-dibromoalkanes (II) have been well established. However, the linear oligomers have so far been limited to the ones of α,ω-dibromide type (III) formed by 1:2 addition of I and II.[3] Thus, motivated by our interest in the biological activities of the linear oligomers and ionene polymers[5] and in the application of those ammonium salts in synthetic chemistry, we have made attempts to synthesize linear oligomers of the α,ω-diamine type based on the principle described in our previous paper,[6] namely, by reducing the reactivity of either the diamine or the dihalide or both. In this communication we wish to report the first synthesis of such linear oligomers of well-defined structures (IVa–e) by 2:1 addition of I (x = 2 and 3) and α,ω-dihalides having one or more ether linkages.



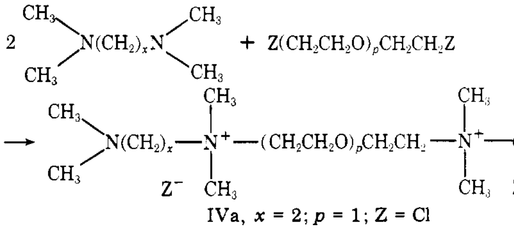
$$(CH_3)_2N(CH_2)_xN(CH_3)_2 + 2Br(CH_2)_yBr \longrightarrow Br(CH_2)_y-\overset{CH_3}{\underset{Br^-\ CH_3}{N^+}}-(CH_2)_x-\overset{CH_3}{\underset{CH_3\ Br^-}{N}}-(CH_2)_yBr$$

IIIa, $x = 4; y = 2$
b, $x = 6; y = 1$
c, $x = 6; y = 2$

The results of the model reactions[7,8] for the reactions of I with II (or the x-y reactions[2,3] for short) indicate that the second step of quaternization of I or II, particularly of the latter, can occur only with difficulty when x or y is smaller than three. The successful synthesis of III explicitly reflects the circumstances. The linear oligomers of the α,ω-diamine type could not be synthesized by 2:1 addition of I and II because of bond scission[2] in the initial 1:1 addition product, when $x = 1$, or because of the too high reactivity[6–8] for linear oligomerization of the terminal dimethylamino groups in the 2 – y reactions ($x = 2, y > 3$). Furthermore, the polymers obtained by the 2 – y reactions had relatively low intrinsic viscosities.[3] Based on these facts we considered that linear oligomers of the α,ω-diamine type would be most easily prepared from tetramethyldiaminoethane and an α,ω-dihalide. In order to avoid polymerization reaction in this system, according to the above principle, we initially chose as the α,ω-dihalide α,ω-dichloro ethers having one or more oxygens not too far from the terminal carbons.[9] The following describes some of our trials.

The reaction of tetramethyldiaminomethane with bis(2-chloroethyl) ether in acetonitrile at 25–50 °C afforded in low yields (2–36%) a cyclic monoammonium salt, i.e., *N,N*-dimethylmorpholinium chloride, according to the mechanism proposed previously,[2] while the reaction of tetramethyldiaminoethane with bis(chloromethyl) ether yielded at an unusually fast rate[10] a seven-membered cyclic diammonium salt, i.e., *N,N,N′,N′*-tetramethylhexahydro-1,3,6-oxadiazepine.[11] These results are simply analogous to those[2,3] of the corresponding reactions of I with II.

In contrast to the above results, the reaction of tetramethyldiaminoethane with bis(2-chloroethyl) ether in acetonitrile at 25 °C gave in a low yield (21–28%) a linear oligomer of α,ω-diamine type, i.e., 3-oxapentamethylenebis((2-*N,N*-dimethylaminoethyl)dimethylammonium) dichloride (IVa), as a white crystalline precipitate,[12] irrespective of the molar ratios (2:1 and 1:1)[13] of the reactants. Similarly, the reaction of tetramethyldiaminoethane with 1,2-bis(2-chloroethoxy)ethane under similar conditions yielded in practically the same yield a linear oligomer of the same type, i.e., 3,6-dioxaoctamethylenebis((2-*N,N*-dimethylaminoethyl)dimethylammonium) dichloride (IVb), as white fine crystals.[14]

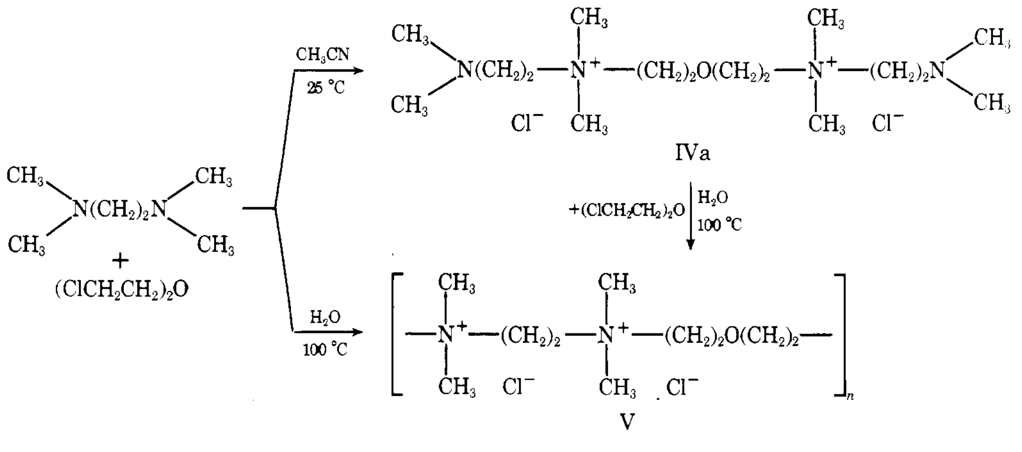


$$2\,(CH_3)_2N(CH_2)_xN(CH_3)_2 + Z(CH_2CH_2O)_pCH_2CH_2Z \longrightarrow (CH_3)_2N(CH_2)_x-\overset{CH_3}{\underset{Z^-\ CH_3}{N^+}}-(CH_2CH_2O)_pCH_2CH_2-\overset{CH_3}{\underset{CH_3\ Z^-}{N^+}}-(CH_2)_xN(CH_3)_2$$

IVa, $x = 2; p = 1;$ Z = Cl
b, $x = 2; p = 2;$ Z = Cl
c, $x = 2; p = 1;$ Z = Br
d, $x = 3; p = 1;$ Z = Cl
e, $x = 3; p = 1;$ Z = Br

The yields of the oligomers could be raised by increasing reactant concentration or reaction temperature or by changing the solvent from acetonitrile to a more polar one such as dimethyl sulfoxide.[15] However, an increase in reaction temperature resulted in a polymerization reaction. For instance,

Scheme I



the reaction of tetramethyldiaminoethane with bis(2-chloroethyl) ether under high vacuum at 80 °C yielded, together with major linear oligomer (IVa), an ionene polymer (V) which was isolated from the precipitated product as the fraction insoluble in hot acetonitrile. Its polymeric nature was ascertained by comparing its properties with those of the polymer independently prepared as described below.

When the same reaction was carried out in water at 100 °C under high vacuum, a slightly yellowish viscous solution was obtained from which, in agreement with the patent literature,[16] the same ionene polymer as above was isolated on evaporation in a high yield. The reaction of linear oligomer IVa with bis(2-chloroethyl) ether in the same manner also afforded the same ionene polymer in a nearly quantitative yield (Scheme I).

The success in our original plan prompted us to expand this study to other combinations of I and α,ω-dihalides to establish the conditions for the linear oligomerization. Preliminary results have already shown that the linear oligomers of α,ω-diamine type such as IVc, IVd, and IVe could be synthesized in acetonitrile at 25 °C, most preferably at the molar ratio of I to the dihalide of 2:1. However, an increase in the reactivity of the diamine and/or the dihalide resulted in an increasing tendency toward a simultaneous or exclusive polymerization reaction, particularly at the molar ratio of 1:1.

The rate of the linear oligomerization varied remarkably depending on x, halogen, solvent, reactant concentration, reaction temperature, and the molar ratio of the diamine to the dihalide. For instance, the reactions of I with the α,ω-dichlorides at 25 °C were carried out as long as 14 days under the conditions similar to those specified in ref 15 and yet the yields of the linear oligomers were at best moderate.[15] However, the reactions with use of the corresponding dibromides under similar conditions were in general much faster, producing the linear oligomers in yields surpassing 90% in 2 days.

The above-mentioned synthesis of the linear oligomers of the α,ω-diamine type exemplifies that the reaction mechanisms[3] already established for the x–y reactions can be altered not only by increasing the rigidity of reactants[17] but also by introducing one or more polar groups into either I or, possibly also II at appropriate positions. The linear oligomers are, however, not quite unreactive as described above and hence should provide us with an opportunity to synthesize a variety of ammonium salts of low molecular weights, if we react the oligomers with monohalides, or to synthesize ionene polymers of a new type in which two kinds of dihalide units alternate, separated by the same diamine unit, if we react the oligomers with highly reactive dihalides different from those constituting the oligomers. These being realized, a number of chemical, physicochemical, biological and other investigations may be envisioned. Studies in this direction are in progress.

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References and Notes

(1) A portion of this work was presented at the 25th Annual Meeting of the Society of Polymer Science, Japan, Tokyo, May 30–31, 1976; H. Noguchi and Y. Uchida, *Polym. Prepr. Jpn.*, **25,** 111 (1976).

(2) H. Noguchi and A. Rembaum, *Macromolecules,* **5,** 253 (1972).

(3) A. Rembaum and H. Noguchi, *Macromolecules,* **5,** 261 (1972).

(4) A. Rembaum, W. Baumgartner, and A. Eisenberg, *J. Polym. Sci., B,* **6,** 159 (1968).

(5) Note that the biological activities of the ammonium salts which are more or less structurally related to the compounds described here, e.g., decamethonium halides and polybrene (or 6–3 ionene bromide), have been well known.

(6) H. Noguchi and Y. Uchida, *J. Polym. Sci., Polym. Lett. Ed.*, in press.

(7) K. Murai and C. Kimura, *Kogyo Kagaku Zasshi,* **74,** 1842 (1971).

(8) K. Murai and C. Kimura, *Chem. Lett.*, 347 (1972); *Nippon Kagaku Kaishi,* 2096 (1972).

(9) The reactivity of the dihalide can be reduced by using a corresponding dichloride instead of a dibromide. Besides, the ether linkage so situated would reduce, though not to a great extent, the nucleophilicity or the reactivity of the terminal dimethylamino groups by the inductive effect. However, replacement of a methylene group of an α,ω-dihaloalkane with an oxygen atom results in either increase ($q = 1$) or decrease ($q > 1$) in the reactivity of the dihalide, depending on the number (q) of methylene groups between an ethereal oxygen and a halogen.

(10) The unusually fast rate in this case can be attributed to the resonance in the ionized species of the dichloride: J. B. Hendrickson, D. J. Cram, and G. S. Hammond, "Organic Chemistry", International Student Edition, McGraw-Hill Kogakusha, Ltd., Tokyo, 1970, pp 389–391.

(11) H. Noguchi and Y. Uchida, paper presented at the XXIII IUPAC International Symposium on Macromolecules, Madrid, Sept. 15–20, 1974, I. 4-14; *Prepr.*, **1,** 278 (1974).

(12) Recrystallization of the product from acetonitrile gave platelets, mp 190–192 °C dec; ^{1}H NMR (in part) τ 7.72 (s, 12 H, N–CH_3), 6.81 (s, 12 H, N^+–CH_3). Anal. Calcd for $C_{16}H_{40}Cl_2N_4O$ (IVa): C, 51.19; H, 10.74; Cl, 18.89; N, 14.92. Found: C, 51.17; H, 10.73; Cl, 18.92; N, 14.58. The melting point and the elemental analyses data were taken as reported before.[17] The 100 MHz ^{1}H NMR spectrum was recorded at room temperature on a JEOL spectrometer, Model JNM-PS-100, using D_2O as solvent and sodium 2,2-dimethyl-2-silapentane-5-sulfonate as an internal standard.

(13) Molar ratios suitable for oligomerization (2:1) and polymerization (1:1).

(14) Recrystallization of the product from acetonitrile gave prisms, mp 167–169 °C dec; ^{1}H NMR (in part) τ 7.73 (s, 12 H, N–CH_3), 6.83 (s, 12 H, N^+–CH_3), 6.27 (s, 4 H, O–CH_2CH_2–O). Anal. Calcd for $C_{18}H_{44}Cl_2N_4O_2$ (IVb): C, 51.54; H, 10.57; Cl, 16.90; N, 13.36. Found: C, 51.66; H, 10.44; Cl, 16.95; N, 13.08.

(15) Thus far, the highest yield (56%) of IVa has been attained under the following conditions: tetramethyldiaminoethane, 0.20 mol; bis(2-chloroethyl) ether, 0.10 mol; dimethyl sulfoxide, 30 ml; temperature, 25 °C; time, 14 days.

(16) (a) N. R. Eldred, German Offen., 2 048 546 (1971); *Chem. Abstr.*, **75,** 37028q (1971); S. African Patent, 69 008 949 (1970); *Chem. Abstr.*, **74,** 64844p (1971); (b) J. D. Pers and B. S. Johnson, U.S. Patent, 3 771 989 (1973); *Chem. Abstr.*, **80,** 141818m (1974).

(17) H. Noguchi and Y. Uchida, *J. Polym. Sci., Polym. Lett. Ed.*, **13,** 773 (1975).

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