supernatant was decanted and distilled. The following diamines were prepared by this method:

1-Methylaminocyclohexanemethylamine (V. R = CH_3, R′ = H). Yield, 78%, b.p. 48–50°/0.07 mm., n_D^{25} 1.4843.

Anal. Calcd. for $C_8H_{18}N_2$: C, 67.55; H, 12.76; N, 19.70. Found: C, 67.80; H, 12.71; N, 19.45.

1-Benzylaminocyclohexanemethylamine (V. R = $CH_2C_6H_5$; R′ = H). Yield, 65%, b.p. 109–110°/0.09 mm., n_D^{24} 1.5392.

Anal. Calcd. for $C_{14}H_{22}N_2$: C, 77.01; H, 10.16; N, 12.83. Found: C, 77.25; H, 10.07; N, 12.75.

1-(2-Diethylaminoethylamino)cyclohexanemethylamine (V. R = $CH_2CH_2N(C_2H_5)_2$; R′ = H). Yield, 53%, b.p. 87–90°/0.09 mm.

Anal. Calcd. for $C_{13}H_{29}N_3$: C, 68.66; H, 12.86; N, 18.48. Found: C, 68.54; H, 12.70; N, 18.60.

1-Methylamino-N-carbethoxycyclohexanemethylamine (V. R = CH_2; R′ = $COOC_2H_6$) *hydrochloride*. A solution consisting of 7 g. of V(R = CH_3, R′ = H) and 25 ml. of ethyl carbonate was refluxed for 3 days. The excess reagent was removed under reduced pressure and the residue was taken up in 100 ml. of ether. Saturation of the ethereal solution with hydrogen chloride gave a precipitate, which was extracted with ethyl acetate to yield, upon cooling, white needles. Yield, 4.4 g. (36%), m.p. 203–205°.

Anal. Calcd. for $C_{11}H_{23}ClN_2O_2$: C, 52.68; H, 9.24; N, 11.14. Found: C, 52.70; H, 9.28; N, 11.30.

1-Benzylamino-1-carbethoxyaminomethylcyclohexane (V. R = $CH_2C_6H_5$; R′ = $COOC_2H_5$) hydrochloride. The above procedure was applied to 9.2 g. of V (R = $CH_2C_5H_5$; R′ = H). The product was recrystallized from ethyl acetate. Yield, 5.8 g. (43%), m.p. 174–176°.

Anal. Calcd. for $C_{17}H_{27}ClN_2O_2$: C, 62.46; H, 8.33; N, 8.58. Found: C, 62.61; H, 8.30; N, 8.36.

RESEARCH DIVISION
ETHICON, INC.
SOMERVILLE, N. J.

A Novel Ring System: 3,8-Diazabicyc[3.2.1]octane

EDGAR SCHIPPER[1] AND WERNER R. BOEHME

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In view of the recent publication of Cignarella and Nathansohn[2] relating to the synthesis and reactions of 2,5-disubstituted pyrrolidines we wish to report, at the present time, our experiments conducted along similar lines.

During studies leading to *N*-substituted 2,5-bischloromethylpyrrolidines — compounds possessing potent adrenolytic acitivity[3]—it became necessary to reinvestigate the v. Braun-Seemann synthesis[4] of alkyl 2,5-pyrrolidinedicarboxylates. When methyl α,α'-dibromoadipate[4] and methylamine were condensed in a molar ratio of 1:3 and the reaction mixture was subjected to distillation through a heated three-foot Vigreux column three products could be isolated. These were (a) the expected diester I (R = R′ = CH_3, R″ = OCH_3), (b) a small quantity of a material which solidified on standing and melted at 114–115° and (c) the amido ester I (R = R′ = CH_3, R″ = $NHCH_3$) which constituted the major product of the reaction. When ethyl α,α'-dibromoadipate[4] was employed in place of the methyl ester, the diester I (R = CH_3, R′ = C_2H_5, R″ = OC_2H_5) was isolated as the primary product; in addition, the solid material, m.p. 114–115°, again was formed together with some higher boiling material not obtained pure, but probably consisting of the amido ester I (R = CH_3, R′ = C_2H_5, R″ = $NHCH_3$).

Elementary analysis and molecular weight determination of the solid fraction indicated it to be a derivative of the novel "3-azatropane" ring system—*i.e.*, 3,8-dimethyl-3,8-diazabicyclo[3.2.1]octane-2,4-dione (II. R = CH_3; X = O). This structural assignment is in accord with the observation that the compound is formed from either methyl or ethyl dibromoadipate and that it can be obtained in *ca.* 50% yield by heating the amido ester I (R = R′ = CH_3, R″ = $NHCH_3$) at 180°. Furthermore, the infrared spectrum in the carbonyl absorption region exhibits two peaks (at 1727 cm.$^{-1}$ and 1677 cm.$^{-1}$) typical of a cyclic diacylimide linkage.[5]

When II (R = CH_3, X = O) was subjected to lithium aluminum hydride reduction the dibasic 3,8-dimethyl-3,8-diazabicyclo[3.2.1]octane (II. R = CH_3, X = H_2) was obtained.

Application of the v. Braun-Seemann reaction[4] to a mixture of ethyl α,α'-dibromoadipate and β-diethylaminoethylamine produced none of the expected pyrrolidine diester; instead there could be isolated by careful fractionation of the reaction mixture the azatropane derivative II (R = $CH_2CH_2N(C_2H_5)_2$, X = O) and the diamide III (R = R′ = $CH_2CH_2N(C_2H_5)_2$). When *n*-butylamine and benzylamine were used as reactants, however, the major products consisted of the respective diesters I (R = *n* - C_4H_9 or C_7H_7, R′ = C_2H_5, R″ = OC_2H_5) and the amido esters I (R = *n*-C_4H_9, R′ = C_2H_5, R″ = NHC_4H_9-*n*) and I (R = C_7H_7, R′ = C_2H_5, R″ = NHC_7H_7). All attempts to convert these amido esters to the corresponding azatropanes failed as extensive resinification took place (compare also ref. 2).

These results, as well as experiments utilizing other amines,[3] indicate that the v. Braun-Seemann reaction[4]—particularly when carried out in the absence of a solvent—may lead to reaction products other than the expected pyrrolidine diesters. Whether the observed azatropanes are true reaction products or artifacts arising during the distil-

(1) Present address: William H. Rorer, Inc., Philadelphia, Pa.

(2) G. Cignarella and G. G. Nathansohn, *Gazz. chim. ital.*, 90, 1495 (1960).

(3) E. Schipper, W. R. Boehme, M. L. Graeme, E. Chinery, and E. Siegmund, *J. Med. Pharm. Chem.*, in press (1961).

(4) J. v. Braun and J. Seemann, *Ber.*, **56**, 1840 (1923).

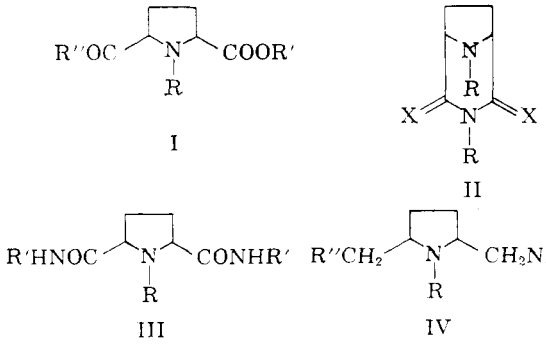
(5)(a) L. J. Bellamy, *The Infrared Spectra of Complex Molecules*, Wiley, New York, 1958, p. 221. (b) D. E. Ames and T. F. Grey, *J. Chem. Soc.*, 631 (1955).

lation of the pyrrolidine amidoesters is not known at this time.

As the formation of the azatropane moiety by the above methods appeared to be distinctly limited, other synthetic avenues of approach were examined. Some time ago Barnes and Fales[6] reported the preparation of the homologous 3,9-diazabicyclo-[3.3.1]nonane ring system by the reaction of methyl scopolinate (or isoscopolinate) and an appropriate amine. Refluxing of ethyl 1-benzyl-2,5-pyrrolidinedicarboxylate with an excess of benzylamine produced a mixture of solids (probably polymeric in nature) which could not be separated by any conventional techniques including column chromatography. When this reaction was applied to ethyl 1-methyl-2,5-pyrrolidinedicarboxylate there was obtained, in addition to a poorly melting solid, the amido ester I (R = CH_3, R′ = C_2H_5, R″ = NHC_7H_7),[2] a compound which resisted all attempts at cyclization to the desired azatropane derivative. When the above condensation was conducted in the presence of 95% ethanol the amido ester as well as a small quantity of a water soluble material was isolated which possibly was identical with Willstätter and Lessing's[7] 1-methyl-2,5-pyrrolidinedicarboxylic acid. Significantly, this material could not be converted to an anhydride by treatment with acetic anhydride.

Furthermore, when methyl 2,5-pyrrolidinedicarboxylate I (R = H, R′ = CH_3, R″ = OCH_3)—obtained by catalytic debenzylation of the corresponding 1-benzyl derivative—was subjected to the action of benzylamine, the diamide III (R = H, R′ = NHC_7H_7) proved to be the major reaction product; prolonged heating of the diamide caused extensive polymerization to a fibrous material.

In a further search for alternate pathways leading to the azatropane system the reaction between amines and the readily accessible 2,5-bischloromethylpyrrolidines[3] was examined. In the two cases studied the major reaction products consisted of the respective 2,5-bisaminomethyl derivatives IV (R = CH_3, R′ = n-C_4H_9, R″ = NHC_4H_9-n) and IV (R = C_7H_7, R′ = $CH_2CH_2N(C_2H_5)_2$, R″ = $NHCH_2CH_2N(C_2H_5)_2$). Finally, the possibility of the intramolecular cyclization of an aminomethylchloromethylpyrrolidine was explored. Lithium aluminum hydride reduction of the amido ester I (R = R′ = CH_3, R″ = $NHCH_3$) resulted in the amino alcohol IV (R = R′ = CH_3, R″ = OH) which in turn was converted to the chloro derivative IV (R = R′ = CH_3, R″ = Cl). Neutralization of the hydrochloride of this material led to replacement of the halogen by a hydroxy group, reverting the chloro compound to the amino alcohol from which it had been derived.



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EXPERIMENTAL[8a,b]

Condensations between alkyl α,α′-dibromoadipates and amines. General procedure. In accordance with the directions of v. Braun and Seemann[4] 1 mole of an alkyl α,α′-dibromoadipate was added in portions to a stirred solution of 3 moles of amine. The reaction temperature was kept below 60° by external cooling. In reactions involving methylamine or *n*-butylamine, 1.5 l. of benzene was used as solvent. After completed addition the reaction mixture was stirred at room temperature for 24 hr. and on a steam bath for 3 hr. The suspension was filtered and the precipitate and filtrate were worked up separately. The precipitate was suspended in 200 ml. of 3*N* hydrochloric acid, the insoluble portion was filtered off and discarded. The filtrate was combined with the solution obtained by acidification of the filtrate from the original reaction mixture (when a reaction solvent was used it was stripped off prior to acidification). The combined solutions were washed with ether and neutralized with 10% potassium hydroxide. The resulting oil was extracted with several portions of ether, the extracts were dried and fractionated through a heated 3-ft. Vigreux column. The following compounds were isolated:

From methyl α,α′-dibromoadipate and methylamine:

Methyl-1-methyl-2,5-pyrrolidinedicarboxylate (I. R = R′ = CH_3, R″ = OCH_3)[4], b.p. 132–135°/13 mm., solidifying and melting after a recrystallization from pentane at 34–36°. Yield, 17%.

3,8-Dimethyl-3,8-diazabicyclo[3.2.1]octane-2,4-dione (II. R = CH_3, X = O), b.p. 145–150°/13 mm., solidifying and melting after a recrystallization from pentane at 114–115°. Yield, 3%.

Anal. Calcd. for $C_8H_{12}N_2O_2$: C, 57.13; H, 7.19; N, 16.66; mol. wt. 168.2. Found: C, 57.36; H, 6.95; N, 16.59; mol. wt. 170.6.

1-Methyl-2-carbomethoxy-5-pyrrolidine(N-methyl)carboxamide (I. R = R′ CH_2, R″ = $NHCH_3$), b.p. 155–160°/13 mm., n_D^{26} 1.4775, yield, 22%.

Anal. Calcd. for $C_9H_{16}N_2O_3$: C, 53.98; H, 8.06; N, 13.99. Found: C, 54.25; H, 8.32; N, 14.19.

From ethyl α,α′-dibromoadipate and methylamine:

Ethyl 1-methyl-2,5-pyrrolidinedicarboxylate (I. R = CH_3, R′ = C_2H_5, R″ = OC_2H_5),[9] b.p. 135–140°/7 mm., n_D^{25} 4512, yield, 63%.

3,8-Dimethyl-3,8-diazabicyclo[3.2.1]octane-2,4-dione (II. R = CH_3, X = O), yield, 5%. In addition to the above diester and the azatropane derivative a higher boiling fraction (155–160°/7) mm.) was obtained in a yield of 10%, whose analysis was not quite satisfactory for the amido ester I (R = CH_3, R′ = C_2H_5, R″ = $NHCH_3$).

From ethyl α,α′-dibromoadipate and *n*-butylamine:

Ethyl 1-n-butyl-2,5-pyrrolidinedicarboxylate (I. R = *n*-C_4H_9, R′ = C_2H_5, R″ = OC_2H_5),[9] b.p. 104–105°/0.05 mm., n_D^{25} 1.4520, yield, 50%.

(8)(a) All melting points are uncorrected. (b) Analyses by Mr. E. Hoffmann and staff.

(9) A. J. Hill, Jr., and J. T. Maynard, U. S. Pat. 2,596,099 (May 13, 1952).

1-n-Butyl-2-carbethoxy-5-pyrrolidine(N-n-butyl)carboxamide (I. R = n-C_4H_9, R′ = C_2H_5, R″ = NHC_4H_9-*n*), b.p. 134–135°/0.05 mm., n_D^{25} 1.4620, yield, 23%.

Anal. Calcd. for $C_{16}H_{30}N_2O_3$: C, 64.39; H, 10.13; N, 9.39. Found: C, 64.64; H, 10.20; N, 9.55.

From methyl α,α′-dibromoadipate and benzylamine:

Methyl 1-benzyl-2,5-pyrrolidinedicarboxylate (I. R = C_7H_7, R′ = CH_3, R″ = OCH_3), b.p. 129–130°/0.05 mm., yield, 30%, n_D^{25} 1.5142.

Anal. Calcd. for $C_{15}H_{19}NO_4$: C, 64.96; H, 6.91; N, 5.05. Found: C, 65.23; H, 7.15; N, 5.24.

The still residue consisted of a high boiling material which could not be distilled without decomposition and whose structure was shown to be the amido ester I (R = C_7H_7, R′ = CH_3, R″ = NHC_7H_7) (yield, 48%) by its subsequent conversion to the amino alcohol IV (R = R′ = C_7H_7, R″ = OH).

From ethyl α,α′-dibromoadipate and benzylamine:

Ethyl 1-benzyl-2,5-pyrrolidinedicarboxylate (I. R = C_7H_7, R′ = C_2H_5, R″ = OC_2H_5),[4,6] b.p. 150–155°/0.05 mm., n_D^{26} 1.5036, yield, 48%.

1-Benzyl-2-carbethoxy-5-pyrrolidine(N-benzyl)carboxamide (I. R = C_7H_7, R′ = C_2H_5, R″ = NHC_7H_7),[2] b.p. 190–195°/0.05 mm., yield, 35%.

From ethyl α,α′-dibromoadipate and 2-diethylaminoethylamine:

3,8-Di(2-diethylaminoethyl-3,8-diazabicyclo[3.2.1]octane-2,4-dione (II. R = $CH_2CH_2N(C_2H_5)_2$, X = O), b.p. 175–180°/0.03 mm., n_D^{26} 1.4840, yield, 16%.

Anal. Calcd. for $C_{18}H_{34}N_2O_2$: C, 63.87; H, 10.29; N, 16.55. Found: C, 63.60; H, 10.13; N, 16.62.

1-(2-Diethylaminoethyl)-2,5-pyrrolidine-[N,N′-di(2-diethylamino ethyl)]dicarboxamide (III R = R′ = $CH_2CH_2N(C_2H_5)_2$), b.p. 210–215°/0.03 mm., n_D^{24} 1.4892, yield, 50%.

Anal. Calcd. for $C_{24}H_{50}N_6O_2$: C, 63.39; H, 11.08; N, 18.49. Found: C, 63.13; H, 11.03; N, 18.55.

3,8-Dimethyl-3,8-diazabicyclo[3.2.1]octane (II. R = CH_3, X = H_2) *dihydrochloride.* To a stirred suspension of 3 g. of lithium aluminum hydride in 200 ml. of ether was added dropwise a solution of 6 g. of II (R = CH_3, X = O) in 50 ml. of ether. The reaction mixture was refluxed for 16 hr., the excess hydride was destroyed by addition of 25% sodium hydroxide, and the supernatant was distilled. B.p. 57–60°/11 mm., n_D^{23} 1.4770, yield, 2.2 g. (88%). A dihydrochloride melted at 283–285° (from absolute ethanol).

Anal. Calcd. for $C_8H_{18}Cl_2N_2$: C, 45.08; H, 8.51; N, 13.15. Found: C, 44.82; H, 8.53; N, 13.12.

Methyl 2,5-pyrrolidinedicarboxylate (I. R = H, R′ = CH_3, R″ = OCH_3) *hydrochloride.* A solution containing 10.2 g. of methyl 1-benzylpyrrolidinedicarboxylate, 50 ml. of ethanol, and 2 ml. of concd. hydrochloric acid was hydrogenated in the presence of 5% palladium on charcoal catalyst and an initial pressure of 50 lbs. After completed reaction the catalyst was filtered off and the solvent was evaporated. The residual solid was recrystallized from ethanol–ethyl acetate. M.p. 191–192°, yield, 8.1 g. (99%).

Anal. Calcd. for $C_8H_{14}ClNO_4$: C, 42.97; H, 6.31; N, 6.27. Found: C, 42.90; H, 6.14; N, 6.52.

2,5-Pyrrolidine(N,N′-dibenzyl)carboxamide (III. R = H, R′ = NHC_7H_7). A mixture of 2.2 g. of methyl 2,5-pyrrolidinedicarboxylate and 10 g. of benzylamine was refluxed for 4 hr. The reaction product was dissolved in 100 ml. of 3*N* hydrochloric acid and the solution was filtered. The filtrate was made basic with 10% potassium hydroxide and the solid was collected by filtration. After drying and several recrystallizations from ethyl acetate the material melted at 179–180°; yield, 3.3 g. (79%).

Anal. Calcd. for $C_{20}H_{23}N_3O_2$: C, 71.19; H, 6.87; N, 12.45. Found: C, 71.03; H, 7.04; N, 12.72.

1-Methyl-2-carbethoxy-5-pyrrolidine(N-benzyl)carboxamide (I. R = CH_3, R′ = C_2H_5, R″ = NHC_7H_7).[2] A solution of 10 g. of ethyl 1-methyl-2,5-pyrrolidinedicarboxylate in 12 g. of benzylamine was refluxed for 16 hr. The excess benzylamine was removed under reduced pressure, the residue was extracted with boiling hexane and distilled. B.p. 160–165°/0.07 mm., n_D^{27} 1.5170, yield, 5.3 g. (43%).

The hexane extract, on evaporation yielded a solid melting over a wide range (70–90°); attempts to purify the material by column chromatography (Florosil) were not successful.

1-Methyl-2,5-pyrrolidinedicarboxylic acid. A solution consisting of 11.5 g. of ethyl 1-methyl-2,5-pyrrolidinedicarboxylate, 5.5 g. of benzylamine, and 200 ml. of 95% ethanol was refluxed for 6 hr. The solvent was stripped and the residue triturated with ether. A solid (1.5 g.) was filtered off; it was water soluble, melted at 270–273° (reported[5] for 1-methyl-2,5-pyrrolidinedicarboxylic acid, 273–274°), and its infrared spectrum exhibited the usual carbonyl stretching bands associated with carboxylic acids. The ethereal filtrate upon distillation gave 5.5 g. of 1-methyl-2-carbethoxy-5-pyrrolidine(*N*-benzyl)carboxamide.

Reactions between ethyl 1-benzyl-2,5-pyrrolidinedicarboxylate and benzylamine. A solution of 8 g. of ethyl 1-benzyl-2,5-pyrrolidinedicarboxylate in 10 g. of benzylamine was refluxed for 48 hr. The excess benzylamine was distilled and the gummy residue was extracted with boiling heptane. On cooling 2 g. of a solid appeared which melted over a wide range (40–85°). All attempts to purify the material by fractional crystallization or chromatography were unsuccessful.

3-8-Dimethyl-3,8-diazabicyclo[3.2.1]octane-2,4-dione (II. R = CH_3, X = O). Fourteen grams of I (R = CH_3, R′ = C_2H_5, R″ = $NHCH_3$) was heated at 160–180° for 5 days. The semisolid mixture was filtered and the precipitate was recrystallized from hexane. Yield 6 g. (53%), m.p. 114–115°.

The above reaction conditions were applied to the following three compounds: I (R = CH_3 and C_7H_7, R′ = C_2H_5, R″ = NHC_7H_7) and III (R = H, R′ = C_7H_7). In every instance fibrous or glassy materials resulted on heating; hexane extractions of the reaction mixtures always yielded amorphous solids possessing indefinite melting points and resisting all attempts at purification.

1-Methyl-2-hydroxymethyl-5-methylaminomethylpyrrolidine (IV. R = R′ = CH_3, R″ = OH). To a stirred suspension of 8.5 g. of lithium aluminium hydride in 350 ml. of ether was added dropwise 24.7 g. of I (R = CH_3, R′ = C_2H_5, R″ = $NHCH_3$) in 50 ml. of ether. The mixture was refluxed for 16 hr., the excess hydride was destroyed by addition of 25% sodium hydroxide and the supernatant was decanted and distilled. B.p. 121–122°/15 mm., n_D^{26} 1.4839, yield, 15 g (77%).

Anal. Calcd. for $C_8H_{18}N_2O$: C, 60.72; H, 11.47; N, 17.70. Found: C, 60.57; H, 11.43; N, 17.44.

1-Benzyl-2-hydroxymethyl-5-benzylaminomethylpyrrolidine (IV. R = R′ = C_7H_7, R″ = OH). The preceding procedure was applied to 25 g. of crude I (R = C_7H_7, R′ = CH_3, R″ = NHC_7H_7). Yield, 12 g. (55%), b.p. 162–164°/0.07 mm. (Cignarella and Nathansohn[2] report a m.p. of 54–55° for this compound).

Anal. Calcd. for $C_{20}H_{26}N_2O$: C, 77.38; H, 8.44; N, 9.03. Found: C, 77.40; H, 8.61; N, 8.95.

1-Methyl-2-chloromethyl-5-methylaminomethylpyrrolidine (IV. R = R′ = CH_3, R″ = Cl) dihydrochloride. A solution of 7.6 g. of the amino alcohol IV (R = R′ = CH_3, R″ = OH) in 60 ml. of dry benzene was saturated with hydrogen chloride gas. Thionyl chloride (10 ml.) was added and the mixture was stirred and heated at 60–70° for 5 hr. The supernatant was decanted and the solid residue was recrystallized from absolute ethanol. Yield, 9.2 g. (77%), m.p. 165–167°.

Anal. Calcd. for $C_8H_{19}Cl_3N_2$: C, 38.49; H, 7.67; N, 11.22. Found: C, 38.41; H, 7.95; N, 11.25.

Eight grams of the material was dissolved in 50 ml. of water and the solution was made basic with 10% potassium hydroxide. The basic mixture was stirred for 2 hr. and the oil extracted with ether. The extract was dried and distilled to give 4 g. of IV (R = R′ = CH_3, R″ = OH) (identified by its infrared spectrum) and 3 g. of a fraction, b.p. 140–141°/0.08 mm., which could not be identified.

1-Methyl-2,5-di(n-butylaminomethyl)pyrrolidine (IV. R = CH_3, R′ = *n*-C_4H_9, R″ = NHC_4H_9-*n*) *trihydrochloride*. A suspension consisting of 10.5 g. of 1-methyl-2,5-bischloromethylpyrrolidine,[2,3] 25 g. of butylamine, 10 g. of anhydrous potassium carbonate, and 100 ml. of absolute ethanol was stirred and refluxed for 3 days. The solvent and the excess low boiling reagents were removed under reduced pressure and the residue was suspended in 200 ml. of water. The aqueous suspension was made strongly basic with 20% potassium hydroxide and the oil was extracted with ether. The extract was dried and distilled. B.p. 88–89°/0.05 mm., yield, 6 g. (41%). The trihydrochloride melted at 300–303° dec. (from ethanol–ethyl acetate).

Anal. Calcd. for $C_{15}H_{36}Cl_3N_3$: C, 49.38; H, 9.95; N, 11.52. Found: C, 49.41; H, 10.11; N, 11.43.

1-Benzyl-2,5-di[(2-diethylaminoethylamino)methyl]pyrrolidine (IV. R = C_7H_7, R′ = $CH_2CH_2N(C_2H_5)_2$, R″ = $NHCH_2CH_2N(C_2H_5)_2$). The above reaction was applied to 10 g. of 1-benzyl-2,5-bischloromethylpyrrolidine.[2,3] B.p. 135–140°/0.05 mm., yield, 6 g. (45%).

Anal. Calcd. for $C_{19}H_{43}N_5$: C, 71.89; H, 11.34; N, 16.77. Found: C, 71.66; H, 11.13; N, 16.49.

RESEARCH DIVISION
ETHICON, INC.
SOMERVILLE, N. J.

γ-Irradiation of Polystyrene-d_1 and Styrene-d_1-Copolymers[1]

W. BURLANT AND J. NEERMAN

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The γ-ray induced degradation of polymethyl methacrylate is indicated by main chain fracture and gas evolution. Recently,[2] it was reported that (1) protection against both degradative processes can be effected by incorporating phenyl groups (as styrene units) in the polymer chain and (2) this protective effect, the precise mechanism of which is obscure at present, is not transmitted over more than one styrene unit.

Present studies with polystyrene-d_1 (labeled in the α-, β- and *p*-positions) and copolymers containing monodeuterated styrene groups indicate that free radicals derived from γ-irradiation of the more sensitive methyl methacrylate moiety of the polymer abstract H atoms from neighboring styrene units. As a result of these "secondary" radical abstraction reactions, it appears that the protecting agent itself is susceptible to decomposition. The sensitivity toward radical attack of the various carbon-hydrogen bonds in the styrene molecule has been estimated by measuring the deuterium distribution in the evolved gases.

(1) Presented at the 138th National Meeting of the American Chemical Society, New York, N. Y., September, 1960.

(2) W. Burlant, D. Green, and C. Taylor, *J. Appl. Polymer Sci.*, 1, 296 (1959).

EXPERIMENTAL

Starting materials. α-d_1-Styrene. In a dry nitrogen atmosphere, a solution of 97.8 g. (0.53 mole) of α-bromostyrene (prepared from phenylacetylene and hydrogen bromide[3]) in 200 ml. of dry tetrahydrofuran was added dropwise to a stirred mixture of 28.45 g. (1.17 moles) of magnesium turnings and tetrahydrofuran. Mild refluxing was maintained during addition. Hydrolysis of the Grignard salt then was effected by the dropwise addition of 50 ml. of deuterium oxide after which 200 ml. of water, 100 ml. of diethyl ether and a few grams of sodium chloride were added. The organic layer was separated from the water; the latter was extracted with ether-benzene solutions and the combined organic material washed with saturated sodium chloride solution. After removal of the solvents *in vacuo*, a few crystals of hydroquinone were added to the residue to minimize polymerization of the styrene during subsequent handling. After two distillations, there was obtained 15.0 g. (27%) α-d_1 styrene. This product had a b.p. at 15 mm. of 43–45°, and n_D^{20}, 1.5441. Mass spectra indicated an isotopic purity of 93%; the contaminant was ordinary styrene.

Anal. Calcd. for C_8H_7D: C, 91.38; H + D, 8.62. Found: C, 91.21; H + D, 8.44.

β-d_1-Styrene. According to a procedure similar to that described for the preparation of the α-isomer (the Grignard of β-bromostyrene was prepared in diethyl ether), there was obtained 36.8 g. (35%) of β-d_1-styrene; b.p. (10 mm.), 34–35°; n_D^{20}, 1.5432. The isotopic purity was estimated to be 97%.

Anal. Calcd. for C_8H_7D: C, 91.38; H + D, 8.62. Found: C, 91.11; H + D, 8.45.

p-d_1-Styrene. This monomer was prepared in 30% yield from *p*-d_1-bromobenzene (synthesized by deuterium oxide hydrolysis of the mono Grignard of *p*-dibromobenzene) according to the sequence of reactions employed by Overberger and Marvel[4] for structurally similar monomers; b.p. (20 mm.) 46–50°; n_D^{20} 1.5445; isotopic purity, 98%.

Anal. Calcd. for C_8H_7D: C, 91.38; H + D, 8.62. Found: C, 91.28; H + D, 8.35.

Methyl methacrylate and methyl acrylate. The commercially available monomers were redistilled under nitrogen several times before use.

Polymerization and irradiation. Appropriate mixtures of degassed monomers were polymerized thermally to less than 5% conversion. The products were reprecipitated repeatedly from benzene solution with methyl alcohol, dried *in vacuo* for 4 hr. at 100°, then analyzed for the elements to determine the composition. Each copolymer contained about 0.5 mole fraction styrene. Intrinsic viscosities, $[\eta]$, were determined in solvent benzene at 25°; all the styrene–methyl methacrylate copolymers had $[\eta] \cong 1.3$.

About 0.1-g. samples of the polymer were degassed at 80° for 1 hr. at a pressure of about 10^{-5} mm. before sealing. Mass analysis prior to irradiation failed to reveal the presence of solvent or oxygen molecules. A dose rate of 2.0×10^5 Rad per hour at the single total dose of 1.0×10^7 Rad (Co^{60} source; ferrous sulfate dosimetry) was employed for all experiments. It was assumed that 1 g. of polymer absorbed 62×10^{18} e.v. when given a dose of 1.0 Mrad.

Mass spectrometric gas analyses. The response of a mass spectrometer is proportional to the pressure of the gas in the ion source of the analyzer tube; micro quantities can be analyzed by reducing the volume of the reservoir into which the sample is expanded.[5]

For the present study, a novel micro sampling system (Fig. 1) was designed which was of small volume, contained an expansion chamber for "slightly oversize" samples and

(3) C. Dufraisse and C. Moureu, *Compt. rend.*, **171**, 960 (1920).

(4) C. Overberger and C. Marvel, *J. Am. Chem. Soc.*, **67**, 2250 (1945).

(5) J. Neerman and F. Bryan, *Anal. Chem.*, **31**, 532 (1959).