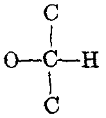
dichloroacetylene-etherate azeotrope distilled at 32° and 387 ml. (d_{20} 0.952) was collected. The azeotrope contained 55.4% dichloroacetylene and 44.6% of ether as determined by vapor chromatographic analysis. There was 0.435 g. of dichloroacetylene per ml. of azeotrope. The yield of dichloroacetylene was 71%.

The reaction of dichloroacetylene with ether. The ultraviolet light irradiation of 550 ml. of dichloroacetylene etherate (azeotrope, contained 1.8 moles of dichloroacetylene) was over a period of 30 hr. The unchanged dichloroacetylene and ether were distilled and recovered, showing that 0.6 mole of dichloroacetylene was consumed. By vacuum distillation of 200 g. of the higher boiling products it was found that it contained 68 g. (34% of the crude mixture) of *α-(1,2-dichlorovinyl)diethyl ether,* $CHCl=CCl-CH(CH_3)-O-CH_2CH_3$, b.p. 57–58° at 20 mm., n_D^{25} 1.4524.

Anal. Calcd. for $C_6H_{10}OCl_2$: C, 42.6; H, 5.9; Cl, 42.0; mol. wt., 169. Found: C, 42.1; H, 5.8; Cl, 41.8; mol. wt., 170.

The second product (52 g., 26% of the crude mixture) was *α,α'-bis(1,2-dichlorovinyl)diethyl ether,* $CHCl=CCl-CH(CH_3)-O-CH(CH_3)-CCl=CHCl$, b.p. 104–5° at 6 mm., n_D^{25} 1.5070.

Anal. Calcd. for $C_8H_{10}OCl_4$: C, 36.4; H, 3.7; Cl, 53.8; mol. wt., 264. Found: C, 35.2; H, 3.4; Cl, 53.5; mol. wt., 250. The infrared spectra of the two compounds contained, aside from other characteristic absorption bands, a band near 3.27 μ, characteristic of $H-C=$, and bands near 3.43 and 7.5 μ, characteristic of a tertiary hydrogen,



such as found in isopropyl ethers.

α-Chloroethynyldiethyl ether, $Cl-C\equiv C-CH(CH_3)-O-CH_2CH_3$, was prepared by passing an ether solution of $CHCl=CCl-CH(CH_3)-O-CH_2CH_3$ through a tube filled with potassium hydroxide–calcium oxide (10:1) kept at 160–180°. There was a 50% recovery of the starting material and the yield of product was 35% (70% conversion), b.p. 53–54° at 55 mm., n_D^{25} 1.4305.

Anal. Calcd. for C_6H_9ClO: C, 54.3; H, 6.7; Cl, 26.9; mol. wt., 132. Found: C, 52.0; H, 6.6; Cl, 27.9; mol. wt., 126. The infrared spectrum showed the triple bond absorption peak of medium intensity at 4.5 μ.

1,1,1,2,3-Pentachloropropene, $Cl_3C-CCl=CClH$. Dichloroacetylene (166 g., 1.75 moles) in 380 ml. of ether solution was refluxed for 7 hr. with 600 g. (3 moles) of bromotrichloromethane in the presence of 5 ml. of *t*-butyl peroxide, while ultraviolet light irradiated. The reflux temperature rose from 50 to 64° during that time. The reaction mixture was distilled. There was a 29% recovery of dichloroacetylene-etherate, 89% recovery of bromotrichloromethane, and the crude reaction product weighed 302 g. Thus the reaction involved 116 g. (1.22 moles) of dichloroacetylene, 134 g. (0.8 mole) of ether, and 70 g. (0.35 mole) of bromotrichloromethane indicating that some of the dichloroacetylene reacted with ether. During the distillation of the crude reaction product, there was a copious evolution of hydrogen halide. A total of 146 g. (46% yield based on consumed dichloroacetylene) of $CCl_3-CCl=CHCl$ was collected, b.p. 56° at 6 mm., n_D^{25} 1.5285.

Anal. Calcd. for C_3HCl_5: C, 16.7; H, 0.5; Cl, 82.8; mol. wt., 214. Found: C, 17.0; H, 0.6; Cl, 82.1; mol. wt., 213. The compound was previously prepared[4] by the dehydrochlorination of $Cl_3C-CCl_2-CH_2Cl$, b. 59–60° at 6 mm., n_D^{20} 1.5286.

Tetrachloropropyne, $Cl_3C-C\equiv C-Cl$. A mixture of 40.4 g of $Cl_3C-CCl=CHCl$ and 22 g. of ether was swept with preheated nitrogen through a tube filled with potassium hydroxide-calcium oxide (10:1) flakes kept at 140–180°. The condensate contained 4 g. of starting halide and 11 g. (33% yield, redistilled) of $Cl_3C-C\equiv C-Cl$, b.p. 58–60° at 50 mm.; n_D^{20} 1.5100.

Anal. Calcd. for C_3Cl_4: C, 20.2; Cl, 79.8; mol. wt., 178. Found: C, 20.5; Cl, 80.2; mol. wt., 172.

The infrared spectrum shows a strong triple bond band at 4.5 μ.

1,4-Bis(thiocyano)butane-2, $N\equiv C-S-CH_2CH=CH-CH_2-S-C\equiv N$. Thiocyanogen was prepared from lead thiocyanate in 74% yield as previously described.[5] The addition of dichloroacetylene-etherate (0.1 mole) to thiocyanogen (0.04 mole) in ether produced, after the removal of ether and dichloroacetylene, 5.6 g. (80% yield) of the yellow $NCSCH_2CH=CHCH_2SCN$, m.p. 83–84°.

Anal. Calcd. for $C_6H_6N_2S_2$: C, 42.3; H, 3.5; N, 16.5. Found: C, 42.3; H, 3.5; N, 16.8.

This compound was previously described[6] as the product of reaction of 1,4-dibromobuten-2 with NH_4SCN, m.p. 83°. The infrared spectrum of our product confirmed the structure.

Acknowledgment. We wish to acknowledge the assistance of Mr. T. S. Wang of our Spectroscopic Laboratory.

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(4) A. N. Nesmeyanov, R. K. Freidlina, and U. I. Firstov, *Izvest. Akad. Nauk. U.S.S.R., Otdel. Khim, Nauk.*, **1951**, 505; *Chem. Abstr.*, **46**, 7034 (1952).

(5) E. Söderback, *Ann.*, **419**, 217 (1919); *Chem. Abstr.*, **14**, 1808 (1920).

(6) J. v. Braun, and G. Lemke, *Ber.*, **55**, 3549 (1922).

Fluorination of Some Nitriles and Ketones with Bromine Trifluoride[1]

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In connection with a general investigation of the reaction of bromine trifluoride and organic compounds, the selective fluorination of several substances has been observed. Fluorination of organic compounds by the vigorous fluorinating agent bromine trifluoride previously had been confined to the relatively non-selective fluorination of compounds containing a large percentage of halogen.[2]

The fluorinations reported here were carried out in a solution of hydrogen fluoride or iodine pentafluoride.[3] Some preliminary experiments with

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(1) This research was carried out under Army Ordnance Contract DA-01-021-ORD-5135.

(2) A. A. Banks, H. J. Emeleus, R. N. Hazeldine, and Y. Kerrigan, *J. Chem. Soc.*, 2188 (1948); E. T. McBee, V. V. Lindgren, and W. B. Liggett, *Ind. Eng. Chem.*, **39**, 370 (1947); R. E. Florin, W. J. Pummer, and L. A. Wall, *J. Research Natl. Bur. Standards*, **62**, 107 (1959) [*Chem. Abstr.*, **52**, 19928 (1959)].

(3) The usefulness of anhydrous hydrogen fluoride as a solvent for fluorinations involving halogen fluorides, particularly chlorine trifluoride, has been noted (Gall and Inman, U. S. Pat. **2,702,306**), but no controlled selective fluorination was recorded.

acetonitrile and methyl ethyl ketone were carried out in iodine pentafluoride,[4] but because of the greater ease of handling of hydrogen fluoride, and because the melting point of iodine pentafluoride (*ca.* 10°) did not permit efficient cooling of the reaction mixture, hydrogen fluoride appeared to be the solvent of choice. In general, the fluorinations were conducted either by adding a solution of bromine trifluoride in hydrogen fluoride to a solution of the organic compound in the same solvent at about −20°, or by addition of the undiluted organic compound to bromine trifluoride in hydrogen fluoride, again at about −20°. An excess of bromine trifluoride was used in most cases. Attempts to conduct these reactions at lower temperatures (−70° or below) occasionally led to initial inhibition of the reaction, and a vigorous and even uncontrollable fluorination upon warming.

Product gases were removed by sweeping the reaction mixture with a helium stream; the gases were scrubbed in soda lime and Drierite towers and the products collected in traps cooled to −196°. This immediate removal of volatile material from the fluorination medium undoubtedly accounted for much of the selective fluorination observed.

Acetonitrile, when dissolved in hydrogen fluoride (or iodine pentafluoride), was converted cleanly to 1,1,1-trifluoroethane by bromine trifluoride. Conversion of the nitrile functions of chloroacetonitrile and propionitrile to a trifluoromethyl methyl group also was accomplished readily utilizing the trifluoride in hydrogen fluoride; the halohydrocarbons were isolated in yields of 70–90%.

$$R{-}CN + BrF_3 \xrightarrow{HF} R{-}CF_3$$

$$R = CH_3,\ {-}CH_2Cl,\ CH_3CH_2{-}$$

Apparently this fluorination, at least as conducted in these experiments, was successful only when the trifluoromethyl compound produced was of sufficient volatility (b.p. <10°) to escape readily from the reaction mixture and thus avoid further fluorination. The butyronitrile and isobutyronitrile fluorinations were less successful than those mentioned above. At least six products were produced in the butyronitrile reaction as indicated by a vapor phase chromatogram of the crude product (29% yield), although one component, which may have been 1,1,1-trifluorobutane, comprised 66% of the chromatogram peak areas. The major product of the isobutyronitrile fluorination appeared to be the expected 2-(trifluoromethyl)propane (66% yield, purity about 80%). β-Chloropropionitrile gave products more highly fluorinated than the desired 1,1,1-trifluoro-3-chloropropane.

A very small amount of nitrous oxide was obtained in the α-chloroacetonitrile and butyronitrile fluorination, but there was no other indication of the fate of the nitrogen atom of the nitriles.

Several ketones were fluorinated in this same manner. Acetone was converted to 2,2-difluoropropane (90%), but the other ketones examined underwent fragmentation. Methyl ethyl ketone, when added to an excess of bromine trifluoride, gave a mixture of 1,1-difluoroethane and 1,1,1-trifluoroethane,[5] and methyl isopropyl ketone gave the trifluoroethane and 2,2-difluoropropane:

$$CH_3COCH_3 + BrF_3 \longrightarrow CH_3CF_2CH_3$$

$$(CH_3)_2CHCOCH_3 + BrF_3 \longrightarrow CH_3CF_2CH_3 + CF_3CH_3$$

$$CH_3CH_2COCH_3 + BrF_3 \longrightarrow CH_3CHF_2 + CF_3CH_3$$

These fragmentation reactions probably proceeded by conversion of the acetyl fragment to trifluoroethane and of the alkyl fragment to the *gem*-difluoro compound; however, only about 50% of the products expected on this basis were isolated. Polymer formation usually occurred in the ketone fluorinations, and some ketone, or fragments derived from it, may have been incorporated into this polymer.

The mechanism of the fluorinations is unknown. A possible route by which a nitrogen or oxygen atom could be replaced by fluorine atoms is that initiated by coordination of bromine trifluoride and the carbonyl or nitrile group. Such a mechanism has been outlined for fluorinations with sulfur tetrafluoride.[6] In view of the Lewis acid character of iodine pentafluoride[7] such a postulate is not unreasonable for bromine trifluoride.

EXPERIMENTAL

Apparatus. Mass spectra were obtained with a Consolidated Model 620 Mass Spectrometer. Vapor phase chromatography was carried out with a Perkin-Elmer Vapor Fractometer Model 154-C using column D (2-meters) at 25°. All infrared spectra were recorded on samples in the vapor phase. The F^{19} NMR spectra were obtained using a Varian Associates Model V-4300B spectrometer with a 40 Mc. probe.

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(4) Nitriles undergo no reaction with iodine pentafluoride (other than complex formation); however, ketones were attacked by the pentafluoride. This interaction, at 30–50°, was not vigorous and no gaseous material was produced.

(5) The amount of trifluoroethane produced apparently depended on reaction conditions. An initial experiment in which sixty-six mmoles of bromine trifluoride was added to twenty-two mmoles of methyl ethyl ketone at −60° and then allowed to warm to 0° produced ten mmoles of gas, m.w. 66.5; its infrared and mass spectra indicated it was mainly 1,1-difluoroethane. Addition of sixty-six mmoles of bromine trifluoride to thirty-three mmoles of the ketone in hydrogen fluoride at −20 to +20° produced thirty mmoles of gas, m.w. 58. The infrared and mass spectra and the vapor phase chromatogram identified this product as a 3:2 mixture of 1,1-difluoroethane and ethyl fluoride.

(6) W. R. Hasek, W. C. Smith, and V. A. Engelhardt, *J. Am. Chem. Soc.*, **82**, 543 (1960).

(7) A. F. Scott and J. F. Bunnett, *J. Am. Chem. Soc.*, **64**, 2727 (1942); T. E. Stevens, *Chem. & Ind.* (*London*), 1090 (1958).

Bromine trifluoride[8] and hydrogen fluoride[8] were handled in a system fabricated from copper, brass, and Kel-F. A vacuum pump, protected by copper towers containing soda lime and calcium carbonate, was attached, *via* a series of traps constructed from 1 × 6 in. Kel-F test tubes, directly to the hydrogen fluoride and bromine trifluoride cylinders. A source of helium was available near each cylinder connection.

Procedure. In some preliminary experiments and in the acetonitrile fluorinations reported below the organic material was placed in the Kel-F test tube and hydrogen fluoride (or iodine pentafluoride, also attached directly to the system) was condensed on the material. After the system was filled with helium, the solution was warmed and stirred magnetically, and was then cooled to −196° while bromine trifluoride was condensed on the upper walls of the test tube *in vacuo.* The vacuum was removed, the system filled with helium, and the helium flow was then vented through copper towers containing soda lime and Drierite and was led into the cooled glass collecting traps. No halogen fluoride or hydrogen fluoride was ever observed to pass through the towers. The bromine trifluoride on the walls of the test tube was then allowed to melt and flow into the solution below. Products entrained by the helium stream were collected in the cold traps; organic material remaining in the reaction vessel was isolated after pouring the contents on ice.

In all other experiments outlined below the reaction vessel was a 250-ml. high temperature polyethylene bottle with a screw cap; attachment to the system was made by a machined brass screw top. Bromine trifluoride was condensed in a Kel-F test tube of calibrated volume, warmed as described,[8] its volume noted, and then dissolved in hydrogen fluoride by condensing the acid in the tube and warming to effect solution. When the trifluoride was to be added to the organic compound, the organic material was placed in the polyethylene bottle and dissolved in hydrogen fluoride carried in by a helium stream. The trifluoride was moved from the test tube to the reaction vessel by helium pressure. If the compound to be fluorinated was to be added to bromine trifluoride in hydrogen fluoride, the trifluoride in solution was added to the polyethylene reaction vessel only after additional hydrogen fluoride had been condensed into the polyethylene bottle. Exit gases were collected as described above.

Fluorination of acetonitrile. A mixture of 0.87 g. (0.021 mole) of acetonitrile and 10 ml. of anhydrous hydrogen fluoride in a 60 ml. Kel-F test tube was cooled in a liquid nitrogen bath while bromine trifluoride, about 0.05 mole, was condensed on the walls of the tube *in vacuo.* The cooling bath was removed and the hydrogen fluoride solution allowed to melt. The flow of bromine trifluoride from the wall of the tube into the solution was controlled with a Dry Ice bath; a vigorous reaction occurred as the trifluoride contacted the solution. The exit gases from the test tube were swept by a helium stream through soda lime and Drierite towers and through traps cooled to −196°. Expansion of the material trapped at −196° gave 381 ml. (STP) (0.017 mole, 81%) of 1,1,1-trifluoroethane. The identity of the trifluoroethane was established by its mass spectrum and infrared spectrum.[9] Its molecular weight[10] was 83.5 (calcd., 84).

When the fluorination was conducted as described above, except that 8 ml. of iodine pentafluoride was the solvent, 1,1,1-trifluoroethane (80%) was obtained also. The infrared and mass spectra of this product were identical with those obtained previously.

Propionitrile. Five milliliters (*ca.* 0.10 mole) of bromine trifluoride in 30 ml. of anhydrous hydrogen fluoride in a 250-ml. polyethylene bottle was stirred magnetically and cooled by a −15° bath, while 3.0 ml. (0.0425 mole) of propionitrile was added dropwise. The exit gases from the reaction mixture were collected as described above. The reaction mixture then was stirred at +15° until most of the hydrogen fluoride had evaporated.[11] The cold traps collected 822 ml. (STP) of 1,1,1-trifluoropropane (86%). The product was identified by its mass spectrum and infrared spectrum[9]; its molecular weight was 97 (calcd., 98). A vapor phase chromatogram of the trifluoropropane revealed it was contaminated by trace amounts of two unidentified materials.

α-Chloroacetonitrile. A mixture of 2.38 g. (0.0315 mole) of α-chloroacetonitrile and 50 ml. of anhydrous hydrogen fluoride in a 250 ml. polyethylene bottle was stirred magnetically and cooled by a −20° bath while 0.10 mole of bromine trifluoride in 15 ml. of hydrogen fluoride was added dropwise. Exit gases were collected as usual. After addition of the bromine trifluoride the mixture was stirred 2 hr. at 0–10°, then the bromine trifluoride and hydrogen fluoride were poured on ice and discarded. The cold traps collected 498 ml. (STP) of 1,1,1-trifluoro-2-chloroethane (70%). A vapor phase chromatogram of the product indicated the presence of two impurities; peak area ratios were 7:5:88. The product was fractionated *in vacuo* through −130° and −196° baths. The fraction trapped at −196° (6.5% of sample) was mainly nitrous oxide; identification was made by infrared and mass spectra. The fraction retained at −130° possessed the infrared[9] and mass spectra expected of 1,1,1-trifluoro-2-chloroethane. Vapor phase chromatography revealed the presence of one minute impurity. The molecular weight of the fractionated sample was 117.9 (calcd. 118.5).

Isobutyronitrile. The procedure outlined for chloroacetonitrile was followed for the addition of 0.075 mole of bromine trifluoride to 2.0 ml. of isobutyronitrile. The cold traps collected 336 ml. (STP) (0.015 mole) of gas of molecular weight 115.8. A vapor phase chromatogram exhibited four peaks; the major peak area comprised 82% of the total. A sample of the gas was fractionated *in vacuo* through −76°, −130° and −196° traps. The major fraction (79%) retained at −130° undoubtedly was mainly 2-trifluoromethylpropane. The major peak area from the chromatogram comprised 89% of the total area; two impurities were present. Its molecular weight was 111.8 (calcd. 112). The major mass spectrum m/e peaks and relative intensities were: 112, 0.75; 93, 2.9; 77, 3.3; 69, 5.8; 65, 14.5; 43, 100; 41, 29.5; 27, 26.5. The F^{19} NMR spectrum exhibited a doublet at 56 and 67 c.p.s. lower field than external trifluoroacetic acid; a very weak, unresolved resonance centered at *ca.* 288 c.p.s. higher field also was present.

Acetone. Two milliliters of acetone was added to 4 ml. of bromine trifluoride in 40 ml. of hydrogen fluoride cooled to −15° in the manner described above for propionitrile. There was obtained 564 ml. (STP) of 2,2-difluoropropane (93%), vapor pressure 760 mm. at 2.5°, reported[12] b.p. −0.1°. Its molecular weight was 80.3 (calcd., 80). The infrared spectrum of the gas exhibited the splitting of the 1380 cm.$^{-1}$

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(8) Obtained from the Matheson Company. The hydrogen fluoride was used as received; bromine trifluoride was pumped *in vacuo* from the cylinder and condensed in a Kel-F trap cooled in Dry Ice, then warmed to 50° in a helium stream. The first samples removed from the cylinder appeared to contain bromine pentafluoride.

(9) Infrared spectrum identical with that of an authentic specimen as recorded by A.P.I. Research Project 34, *Catalog of Infrared Spectral Data.*

(10) All molecular weights reported are the average of two or more determinations.

(11) This procedure should be used with caution. If bromine trifluoride and the organic material concentrate in the reaction vessel an explosion hazard exists. Such a residue of the bromine trifluoride-methyl propyl ketone reaction, from which the cooling bath had been removed, underwent a sudden exothermic reaction that terminated in a violent explosion.

(12) A. V. Grosse and C. B. Linn, *J. Am. Chem. Soc.*, **64,** 2289 (1942).

band characteristic of *gem*-dimethyl compounds; C—F absorption at 1180–1250 cm.$^{-1}$ was present in the spectrum as were three triplets centered at 989, 908, and 731 cm.$^{-1}$ The major mass spectrum peaks were at 65 (intensity 100), 51 (CF_2H^+, rearrangement peak, 3.8), and 45 (8.5). The proton NMR spectrum had only the triplet expected for the difluoropropane; the F^{19} NMR spectrum had five fluorine resonance bands at 230 to 310 c.p.s. higher field than external trifluoroacetic acid. Apparently two of the seven bands expected for the difluoropropane structure were hidden by the background. Vapor phase chromatography confirmed the purity of the sample.

When the reaction was carried out by adding the bromine trifluoride to the acetone (2.0 ml.) in hydrogen fluoride, 2,2-difluoropropane (548 ml., 91%), containing a trace of 1,1,1-trifluoroethane (by v.p.c. analysis) was obtained.

Methyl ethyl ketone. A solution of 4 ml. of bromine trifluoride in 40 ml. of hydrogen fluoride was treated dropwise with 3.0 ml. (0.0335 mole) of methyl ethyl ketone in the usual fashion. The cold traps collected 688 ml. (STP), (0.0307 mole) of gas. The infrared and mass spectra (strong 69 and 65 m/e peaks) revealed a mixture of 1,1-difluoroethane and 1,1,1-trifluoroethane. Only two peaks were present in the vapor phase chromatogram; 46% of the peak area was due to the difluoroethane and 54% was due to the trifluoroethane. The retention times were the same as those of authentic samples.

Methyl isopropyl ketone. From the addition of 4 ml. of bromine trifluoride to 3.0 ml. (0.028 mole) of methyl isopropyl ketone there was obtained 715 ml. (STP), (0.032 mole) of gas. The infrared and mass spectra identified this as a mixture of 2,2-difluoropropane and 1,1,1-trifluoroethane. The trifluoroethane comprised 59% of the vapor phase chromatogram peak area; the other 41% of the area was due to the difluoropropane. Trace amounts of three impurities were revealed by this chromatogram. A portion of the sample was fractionated *in vacuo* through −130° and −196° traps. The 2,2-difluoropropane was retained at −130°; its infrared spectrum was identical with that of the material produced in the acetone fluorination. 1,1,1-Trifluoroethane, identified by infrared[9] and mass spectra, was retained at −196°.

Acknowledgment. Mr. Al Kennedy obtained the mass spectral data reported here; Dr. Keith S. McCallum and Mrs. Carolyn Haney supplied the infrared and NMR spectra. Their splendid cooperation is acknowledged gratefully.

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Synthesis and Spectral Properties of the Dideuterosuccinic Acids

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In connection with some biosynthetic studies, *meso*-2,3-dideuterosuccinic acid, DL-2,3-dideuterosuccinic acid, and 2,2-dideuterosuccinic acid have been synthesized. The infrared spectra of these compounds have been found to differ from one another and from unlabeled succinic acid. The infrared spectra of their dimethyl esters are also distinguishable one from another. In addition, the infrared spectrum of tetradeuterosuccinic acid differs from that of the dideutero- and unlabeled succinic acids.

2,3-Dideuterosuccinic acid has been prepared previously.[2–5] Table I summarizes the infrared spectra of the deutero- and unlabeled succinic acids, and Table II summarizes the infrared spectra of their dimethyl esters. As can be seen from the tables, the differences in the spectra are most marked in the region between 7–15 μ.

EXPERIMENTAL

Materials and methods. Deuterium gas in purity greater than 99.5% was obtained from the General Dynamics Corp. Liquid Carbonic Division, 767 Industrial Road, San Carlos, Calif. *Palladium* (10%) on carbon powder was obtained from Baker and Company, Inc., Catalysts, Lot No. 4838. *Fumaric acid:* Eastman (98 + %). *Maleic anhydride:* Eastman White Label. *Succinic acid:* Mallinckrodt AR, after crystallizations from acetonitrile, m.p., 192–193°. *Ethyl acetate:* Merck reagent ethyl acetate was distilled freshly from calcium hydride before each catalytic reduction. *Acetonitrile:* Fisher Certified Reagent, was refluxed for 12 hr. over calcium hydride and distilled. *Tetradeuterosuccinic acid* was kindly supplied by Dr. T. T. Tchen. *Deuterium chloride:* Phosphorus oxychloride (5 ml.) was added to 5 ml. of quinoline, freshly distilled over calcium hydride, and distilled through a small Vigreux column. The distilled phosphorus oxychloride from the middle fraction (1.43 ml. or 2.4 g.) was added to 7.5 ml. of deuterium oxide. This mixture was then distilled through a small Vigreux column and the constant boiling deuterium chloride of approximately 20% concentration was collected.

Melting points were taken on a Fisher-Johns Melting Point Apparatus on 18 mm. circular micro cover glasses. They are uncorrected.

Deuterium analyses.[6] All samples were diluted with unlabeled carrier to contain to a final concentration between 0.05 and 0.15 atom per cent excess deuterium. Samples equivalent to about 3 mg. of water were burned in a standard microcombustion train packed with wire-form cupric oxide (Mallinckrodt AR); the water of combustion from each sample was collected in an individual zinc train by freezing with Dry Ice; the zinc train was evacuated to about 0.1 mm. of mercury, sealed, and heated for at least 30 min. at 430° in a tube furnace. The zinc train was then connected directly to a Consolidated-Nier model 20-201 isotope ratio mass spectrometer. The instrument was calibrated during each set of analyses with heavy water samples of known concentrations.

Infrared spectra and nuclear magnetic resonance spectra. Infrared spectra were taken on a Perkin-Elmer, Model 21, infrared spectrophotometer in the region 2–15 μ. Samples of

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[1a] Predoctoral Fellow, National Science Foundation (1 year) and National Heart Institute (2 years). [1b] Supported from Grants-in-Aid from U. S. Public Health Service, National Science Foundation, and the Eugene Higgins Trust Fund of Harvard University.

[2] M. T. Leffler and R. Adams, *J. Am. Chem. Soc.*, **58**, 1552 (1936).

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[4] E. O. Weinmann, M. G. Morehouse, and R. J. Winzler, *J. Biol. Chem.*, **168**, 717 (1947).

[5] D. Rittenberg, S. Ratner, and H. D. Hoberman, *J. Am. Chem. Soc.*, **62**, 2249 (1940).

[6] Method similar to that of San Pietro (ref. 7).

[7] A. San Pietro in S. P. Colowick and N. O. Kaplan (Eds.), *Methods in Enzymology*, Vol. IV, Academic Press, Inc., New York, 1957, p. 479.