(e) Stereoisomerization *via* the BF₃ Complex.—A solution of 10 mg. of the all-*trans* compound in 50 ml. of hexane was shaken mechanically, in darkness, with 2 ml. of distilled boron trifluoride etherate for 10 min. Then the hypophase was light brown, indicating the presence of a complex. The latter was broken up immediately by intense shaking with 10 ml. of 95% methanol for 1–2 min. The colorless hexane solution was washed methanol-free, dried and evaporated completely. The residue was dissolved in 100 ml. of hexane and 25 ml. of this solution was developed with the same solvent on a 35 × 3.7 cm. lime–Celite column until the following sequence obtained:

67	empty section
80	strong blue fl.: unchanged all-*trans*
2	empty interzone
6	fairly strong blue fl.: *cis*-I
35	empty interzone
17	weak greenish-blue fl.: *cis*-II
25	empty interzone
23	very weak bluish fl.: *cis*-III
55	empty interzone
40	very faint bluish fl.: destruction products

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The Friedel–Crafts Reaction with Trimethylene Oxide and n-Propyl Ether

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Trimethylene oxide condenses with benzene and with mesitylene in the presence of aluminum chloride to form 50–70% yields of the 3-hydroxypropyl derivative. Both in ease of reaction and lack of isomerization of the entering group, the Friedel–Crafts alkylation with this cyclic ether differs markedly from that with acyclic ethers. The reaction of n-propyl ether with benzene has been studied for comparison.

The Friedel–Crafts alkylation of aromatic hydrocarbons and phenols with ethers is a well-established reaction,[2] the best known example of which is probably the aluminum chloride-catalyzed reaction of benzene with ethylene oxide to give 2-phenylethanol. The reaction of trimethylene oxide with aromatic compounds was reported several years ago by Thiemer,[3] but no information is available regarding the reaction conditions required, the hydrocarbons used, or the structures of the products obtained, except that they were primary alcohols. Primary alcohols, however, might be obtained by introduction of either the 3-hydroxypropyl or the 2-hydroxy-1-methylethyl group on the aromatic ring. The course of this reaction is of interest in connection with other aspects of the chemistry of four-membered cyclic ethers.[4]

In the present work the reaction of trimethylene oxide with benzene and with mesitylene has been carried out under conditions similar to those usually employed for the ethylene oxide reaction, except for a longer reaction time or higher temperature. The products were 3-phenyl-1-propanol and 3-mesityl-1-propanol, isolated in 50–70% yields. In neither case was there evidence for any other aromatic alcohol being formed, and the infrared spectrum of the benzene product was identical to that of authentic 3-phenyl-1-propanol. The purity of the products and the directness of the method attaches preparative value to the reaction, especially for compounds like 3-mesityl-1-propanol.[5]

In contrast to the earlier report,[3] trimethylene

oxide was found to react at a considerably slower rate than ethylene oxide, as shown by an experiment in which an equimolar mixture of both oxides was allowed to react simultaneously with benzene. When the reaction was quenched after a relatively short time, 2-phenylethanol was the only product detectable. The use of boron trifluoride as a catalyst was unsuccessful, even at 0–10°, as it brought about polymerization of trimethylene oxide instead of alkylation.

The complete lack of isomerization of an entering primary group is unusual in a Friedel–Crafts alkylation.[6] A possible reason might be that the ether function, like the hydroxyl function in normal alcohols could cause the aluminum chloride-catalyzed alkylation to occur predominately by a displacement-type mechanism which avoids rearrangement.[7] Since the published examples of aluminum chloride-catalyzed alkylations with n-alkyl ethers have not involved alkyl groups that would be likely to isomerize,[8] the reaction of benzene with n-propyl ether was investigated here. This ether was selected because it is the simplest one capable of giving isomeric alkylbenzenes and because the length of the carbon chain is the same as in trimethylene oxide.

The reaction was carried out in the usual manner for acyclic ethers, except for the use of a shorter

(1) Department of Chemistry, Kansas State College, Manhattan, Kansas.

(2) A portion is reviewed by C. A. Thomas, "Anhydrous Aluminum Chloride in Organic Chemistry," Reinhold Publ. Corp., New York, N. Y., 1941.

(3) E. T. Theimer, U. S. Patent 2,125,968 (1938), and Abstracts, Division of Organic Chemistry, 99th Meeting of the American Chemical Society, Cincinnati, Ohio, April, 1940, p. 42.

(4) S. Searles, THIS JOURNAL, 73, 124, 4515 (1951); S. Searles and M. Tamres, *ibid.*, 73, 3704 (1951); S. Searles and C. F. Butler, *ibid.*, 76, 56 (1954).

(5) The previous preparation by J. Sordes, *Compt. rend.*, 195, 247 (1932), required five steps.

(6) (a) V. N. Ipatieff, H. Pines and L. Schmerling, *J. Org. Chem.*, 5, 253 (1940); (b) H. Pines, L. Schmerling and V. N. Ipatieff, THIS JOURNAL, 62, 2901 (1940).

(7) Such a mechanism has been discussed by H. C. Brown, *et al.*, *Ind. Eng. Chem.*, 45, 1462 (1953).

(8) For example, J. F. Norris and B. M. Sturgis, THIS JOURNAL, 61, 1413 (1939); P. E. Malson and J. H. Gardner, Abstracts, Division of Organic Chemistry, 97th Meeting of the American Chemical Society, Baltimore, 1939, p. 35. An unpublished thesis by R. F. Prindle (Ph.D. Thesis, Washington University, St. Louis, Mo., June, 1942) states that sec-butylbenzene was the only product (16% yield) obtained from the reaction of n-butyl ether, benzene and aluminum chloride, but since he did not have an efficient fractionating method or an infrared spectrum of the product, the formation of n-butylbenzene cannot be excluded. This would seem likely in view of his observation that t-butyl isopropyl ether alkylated benzene in the presence of aluminum chloride to give predominantly isopropylbenzene, contrary to carbonium ion theory.

reaction time to minimize the possibility of isomerizing an initially formed product.[9] Distillation of the product through a spinning band column and infrared analysis of each fraction showed that isopropylbenzene was the main product (8.1% yield), but that a significant amount of n-propylbenzene (1.7% yield) also was formed. A small amount of ethylbenzene (0.5% yield) also was found and probably is due to the catalytic degradation of isopropylbenzene[10] in the reaction mixture. The conclusion is that rearrangement is as extensive in the aluminum chloride-catalyzed alkylation of benzene with n-propyl ether as with n-propyl chloride, and in view of Prindle's result with n-butyl ether[6] this is probably quite typical of n-alkyl ethers.

The lack of rearrangement in the trimethylene oxide reaction suggests that it reacts by a different mechanism than acyclic ethers. Other evidence on this matter, which may be a consequence of ring strain, will be considered in a later paper.

Experimental[11]

3-Phenyl-1-propanol. (A).—Trimethylene oxide (12 g.) was added over a period of one-half hour to a well-stirred suspension of anhydrous aluminum chloride (30 g.) in benzene (450 g., thiophene-free and dried over sodium) at 10°. The reaction mixture was then allowed to warm gradually to room temperature. After standing 10 hours at room temperature it was poured into iced hydrochloric acid, washed with water and 10% sodium carbonate, dried over potassium carbonate and distilled to give 14.6 g. (52%)[11a] of 3-phenyl-1-propanol, b.p. 98–100° (2 mm.), n^{25}D 1.5237. The p-nitrobenzoate melted at 46° (lit. values, 45–46°[12] and 46.5–47.54°,[13] distinguishing it from 2-phenyl-1-propanol, the p-nitrobenzoate of which is reported to melt at 64.5–65.5°.[13] Furthermore, the infrared spectrum was identical to that of authentic 3-phenyl-1-propanol.

Also obtained in the above reaction was 1.0 g. of 3-chloro-1-propanol, b.p. 62° (15 mm.), n^{25}D 1.444 (lit.[14] b.p. 63–64° (16 mm.), n^{20}D 1.447). When the procedure was modified by quenching the reaction after one-half hour at 10°, 1.8 g. of the chloro-alcohol and 0.2 g. (0.7% yield) of 3-phenyl-1-propanol were obtained.

The following experiment also demonstrates that trimethylene oxide is considerably less reactive than ethylene oxide. A solution of ethylene oxide (8.8 g., 0.2 mole) and trimethylene oxide (11.6 g., 0.2 mole) in benzene (100 ml.) was added to a stirred suspension of aluminum chloride (54 g., 0.4 mole) in benzene (300 ml.) at 6–9° over a period of 40 minutes. After 15 minutes more the reaction mixture was poured into iced hydrochloric acid and processed in the usual manner to give 5.5 g. of a colorless oil, b.p. 100–102° (15

(9) G. Baddeley and J. Kenner, *J. Chem. Soc.*, 303 (1935), and R. Heise and A. Tohl, *Ann.*, **270**, 155 (1892), report however that n-propylbenzene is not isomerized to isopropylbenzene by treatment with aluminum chloride.

(10) *Cf.* R. J. Moore and G. Egloff, *Chem. Met. Eng.*, **17**, 61 (1917), and Norris and Sturgis, ref. 8.

(11) Microanalyses by Miss Constance Brauer and Miss Joyce Sorenson.

(11a) NOTE ADDED IN PROOF.—In later work a 70% yield was obtained.

(12) W. R. Kirner, THIS JOURNAL, **48**, 1111 (1926).

(13) L. F. King, *ibid.*, **61**, 2386 (1939).

(14) R. Lespieau, *Bull. soc. chim.*, [5] **7**, 254 (1940).

mm.), 219–220° (752 mm.), n^{25}D 1.5270, and no appreciable higher boiling fraction. The infrared spectrum of the product was practically identical to that of 2-phenyl-1-ethanol and gave no indication of the presence of an appreciable amount of 3-phenyl 1-propanol.

(B).—Trimethylene oxide (10.8 g.) was bubbled from a heated tube into a well-stirred suspension of aluminum chloride (30 g.) in benzene (500 ml.) heated under reflux, during a period of 50 minutes. After one hour more of refluxing, the hydrogen chloride evolution had nearly ceased and the reaction mixture was quenched and processed as described in (A). The product consisted of 18 g. (71% yield) of 3-phenyl-1-propanol of somewhat lower purity than in (A); b.p. 120–125 (22 mm.), n^{25}D 1.5257.

3-Mesityl-1-propanol.—From a reaction mixture of mesitylene (50 g.), aluminum chloride (20 g.) and trimethylene oxide (8 g.), processed in the manner described above, was obtained 14.0 g. (57%) of an oil, b.p. 142° (7 mm.), which crystallized spontaneously as a white solid, m.p. 49–50° (m.p. 53.8–54° after crystallization from ligroin (lit. value, 54°[5])). The phenylurethan, crystallized from ligroin, melted at 109.5–110° (lit. value, 102°[5]).

Anal. Calcd. for $C_{19}H_{23}O_2N$: N, 4.71. Found: N, 4.84.

Alkylation of Benzene with n-Propyl Ether.—To a stirred solution of 60 g. of dry n-propyl ether (b.p. 88–89°) in 750 ml. of dry benzene, 154 g. of powdered aluminum chloride was added slowly with cooling, so that the temperature remained below 40°. After being stirred 15 hours at room temperature, followed by heating under reflux for six hours, the reaction mixture was processed as described for the trimethylene oxide condensation, except that the benzene solution of the crude product was extracted three times with 85% phosphoric acid to remove the significant quantity of unreacted ether present. Distillation through a six-inch, helices-packed Fenske column gave several fractions of monoalkylbenzenes, totaling 11.5 g. and boiling from 110–160° (748 mm.). These were separately redistilled through a four-foot Piros–Glover spinning band column, and the composition of each of the resulting fractions was calculated by use of Beer's law from the infrared spectrum and from the spectra of the pure components at at least three of the following reference points: 9.2, 9.5, 9.7, 11.0 and 12.2 μ. The spectra of the pure hydrocarbons which were used for comparison were in agreement with Infrared Spectrograms 305, 309, 313 and 314, published by the American Petroleum Institute, Research Project 44.

The fractions obtained at 750 mm. were: b.p. 133–137°, n^{21}D 1.4943, 0.2 g., identified as pure ethylbenzene; b.p. 147–149°, n^{21}D 1.4911, 0.7 g., composed of 83% isopropylbenzene and 17% ethylbenzene; b.p. 151–152°, n^{22}D 1.4909, 4.15 g., consisting of 90% isopropylbenzene and 10% n-propylbenzene; b.p. 152–155°, n^{23}D 1.4911, 1.6 g., consisting of 78% isopropylbenzene and 22% n-propylbenzene; b.p. 155–157°, $n^{23.5}$D 1.4910, 0.9 g., consisting of 85% n-propylbenzene and 15% isopropylbenzene; and b.p. 157°, n^{24}D 1.4890, 0.4 g., practically pure n-propylbenzene. In summary, the yield of each component was 0.3 g. of ethylbenzene (0.5% yield), 5.7 g. of isopropylbenzene (8.1% yield) and 1.9 g. of n-propylbenzene (1.7% yield).

Infrared absorption spectra were kindly furnished by Miss Rosalind Guy and Miss Ellen Bowen and were obtained with pure liquid samples in a 0.03-mm. cell. A Beckman Model IR2-T infrared spectrometer with rock salt optics was employed.

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