

Molten Salts as a Medium for Carrying Out Organic Reactions. Epoxide-Carbonyl Rearrangement

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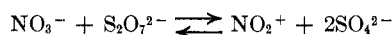
Epoxide-carbonyl rearrangements were studied using a molten salt as the reaction medium. The molten salt was supported on firebrick similar to a gas chromatography column, and the best results were obtained using a lithium bromide-rubidium bromide eutectic at 280°. The products were primarily aldehydes and ketones, and the results were compared to the same reaction carried out using lithium bromide in benzene. Results were also compared to thermal rearrangements which occurred at 280° using columns containing only firebrick.

Molten salts are becoming increasingly important for both inorganic and organic syntheses, as can be seen by the volume of recent papers.¹ Used in organic syntheses, the molten salt may be one of the reactants or a catalyst, or it may provide a unique ionic environment for the reaction. Many low-melting binary or ternary eutectic salts are easily prepared so that one has great flexibility even when working between 100 and 200°. Dry molten salts reduce undesired side reactions due to traces of water. Since organic materials generally have low solubilities in molten salts, reaction must take place at the interface between the materials, but the high temperature conditions aid in providing rapid diffusion and reaction rates.

One reaction that has created somewhat of a controversy in the past few years is the dissociation of nitrate ion in nitrate melts. It has been postulated² that the nitryl cation exists in such a melt due to the equilibrium



which lies far to the left. The equilibrium position can be shifted to the right upon addition of an oxide ion acceptor (Lux-Flood acid) such as metaphosphate or pyrosulfate ion.³

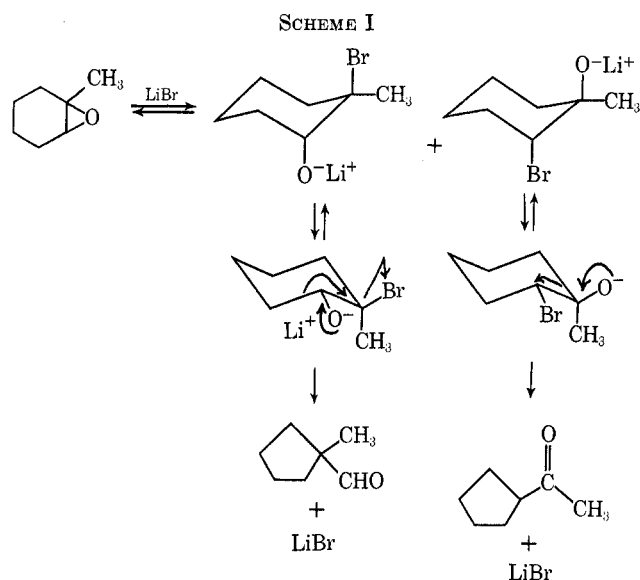


Since the literature contains work that both supports and refutes this hypothesis,⁴ we attempted to reproduce the results of Temple, Fay, and Williamson,⁵ but using the same techniques described below found only traces of nitro compounds.⁶

During this work it was realized that, when the salt was a reactant, the reaction columns may be short lived. Our attention was then turned to reactions in which the salt provided an ionic medium which might promote reactions having ionic intermediates. One such reaction is the epoxide-carbonyl rearrangement.

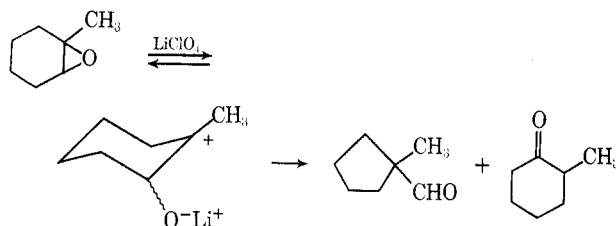
It was reported by Rickborn and Gerkin⁷ that epoxides undergo rearrangement to carbonyl compounds in benzene in the presence of lithium bromide or lithium perchlorate. Lithium bromide is insoluble in benzene but forms some type of soluble complex with tri-*n*-butyl-

phosphine oxide or hexamethylphosphoramide (HMPA). They proposed the mechanism in Scheme I.



Only those conformations having equatorial bromide give rearrangement, since they have the necessary geometry for back-side displacement.⁷

Lithium perchlorate is partially solubilized by epoxides in benzene and the mechanism that was proposed involved a carbonium ion as the intermediate.



We chose this system for our preliminary studies in the development of our molten salt reaction columns for two reasons. First, the reaction presumably proceeds by way of ionic intermediates. Second, samples and spectra of the expected products were available from the previous work.⁷ Our efforts then were directed toward the development of experimental conditions that would give rearrangement products in good yields.

Results

The heart of the reaction system was a column analogous to a gas chromatography column. The liquid phase was a molten eutectic of lithium-rubidium bro-

(1) (a) J. E. Gordon, *Tech. Methods Org. Organometal. Chem.*, **1**, 51 (1969), and references cited therein; (b) W. Sundermeyer, *Angew. Chem.*, **77**, 241 (1965), and references cited therein.

(2) R. N. Kust and F. R. Duke, *J. Amer. Chem. Soc.*, **85**, 3338 (1963).

(3) F. R. Duke and S. Yamamoto, *ibid.*, **81**, 6378 (1959).

(4) (a) L. E. Topol, R. A. Osteryoung, and J. H. Christie, *J. Phys. Chem.*, **70**, 2857 (1966); (b) P. G. Zamboni and J. Jordan, *J. Amer. Chem. Soc.*, **91**, 2225 (1969).

(5) R. B. Temple, C. Fay, and J. Williamson, *Chem. Commun.*, 966 (1967).

(6) For a more complete account of this work see J. H. Kennedy and C. Buse, *J. Inorg. Nucl. Chem.*, **33**, 1937 (1971).

(7) B. Rickborn and R. M. Gerkin, *J. Amer. Chem. Soc.*, **93**, 1693 (1971).

vide supported on firebrick. The column was placed in an oven from a gc instrument to simplify sample introduction and recovery. The operating temperature was 280°, slightly above the melting point of the eutectic. The amount of material handled in any one experiment was quite small, usually less than a milliliter. The products were separated and collected with an analytical gc and then identified by nmr or ir spectra or coinjection (gc) with known compounds. Table I lists the products obtained after passing the epoxide through the lithium-rubidium bromide column. The percentages indicate the relative amount of each component in the recovered material based on areas under gc peaks (height \times half-width). The overall recovered yield was usually on the order of 80% by weight and some loss could be attributed to trap inefficiency. No attempt was made to determine the response factors of the compounds studied, since they are all isomers with a few exceptions and would be expected to have similar response factors.

In another series of experiments, each of the epoxides was passed through a column containing only firebrick at 280°. The products were identified by gc with coinjection of available compounds and are listed in Table I. As can be seen, thermal rearrangement occurs to a considerable extent and in a few cases gives product yields similar to those from the lithium bromide rearrangement. Several attempts were made to separate thermal effects from LiBr reaction by decreasing the extent of thermal rearrangement. Dry columns containing pure lithium bromide mixed with firebrick did give similar product distributions to the molten salt columns. The rearrangement was promoted by the solid ionic salt, although this technique was not pursued because of the poor contact afforded by the solid salt particles.

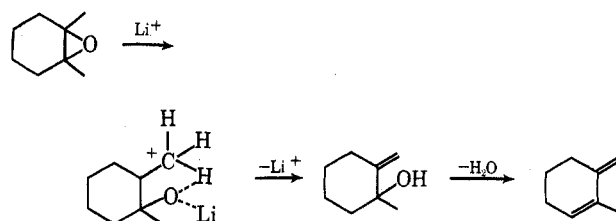
It was found that 150° was the approximate upper limit at which there was no appreciable thermal rearrangement. It was also found that the epoxides were inert toward a lithium-sodium potassium nitrate eutectic column at 150°. When the reaction column contained a small amount of lithium bromide (~2% by weight) added to the nitrate eutectic the epoxides did not react completely and the major product (~80%) was recovered starting material. The rearrangement products which were observed were the same and in approximately the same ratios as those from the lithium-rubidium bromide column. No attempts were made to increase the amount of lithium bromide in the nitrate eutectic, because this would increase the melting point of the mixture beyond 200°. Evidently, under these conditions, the diluted lithium bromide was not effective for the epoxide rearrangement.

Lithium iodide was also tried by using a lithium-potassium iodide eutectic melting at 200°. The products of rearrangement at 220° were much the same as those from the lithium-rubidium bromide rearrangement, but the iodide column slowly decomposed with the evolution of iodine. Lithium iodide is also difficult to handle because of its hygroscopic nature.

Using a lithium chlorate-perchlorate eutectic that melts at about 100° in a column at 150° it was hoped that rearrangement would occur without the accompanying thermal rearrangement. Unfortunately, none of the epoxides reacted completely under these condi-

tions and recovered yields were only about 20%. Rearrangements could be carried out at 280° using the lithium chlorate-perchlorate eutectic, and results are listed in Table II.

The lithium bromide rearrangement of 1,2-dimethylcyclohexane oxide gave a product or products that had shorter retention time on the gc than any of the other products. An nmr spectrum of the components of this gc peak showed two different kinds of olefinic protons [4.5 and 5.3 ppm (δ)]. This suggests a diene with exo- and endocyclic unsaturation. The diene can arise from the following type of mechanism.



The elimination of water would not be unexpected at such a high temperature.

Discussion

The results from the lithium bromide rearrangements show that molten salts can be used effectively as catalysts for organic reactions, giving reaction products similar to those obtained from more conventional methods. Although thermal rearrangement occurred in the absence of the molten salt, product distributions were drastically different from the rearrangement reaction in several cases (propylene oxide, 1-hexene oxide, cyclohexene oxide, 1-methylcyclohexene oxide, 1,2-dimethylcyclohexene oxide). The results did not always parallel those of Rickborn and Gerkin,⁷ which may only reflect the temperature difference. The most striking difference was the low reactivity at temperatures below 200° in molten salts, while the reaction proceeds fairly rapidly in refluxing benzene. It must be remembered, however, that the contact time was under 30 sec in the molten salt columns.

The distinct advantage of the method presented here is that there is no solvent or other material from which the crude products must be separated. The products emerge from the column as a gas and need only be condensed and separated by gc or distillation. Reaction time in the case of the lithium bromide rearrangement was faster than the column retention time of about 30 sec.

Experimental Section

Preparation of Eutectic Salts. A. LiBr-RbBr Eutectic.—The eutectic consisted of 59 mol % LiBr (4.7 g of LiBr and 5.3 g of RbBr), mp 259°.⁸

B. LiNO₃-NaNO₃-KNO₃ Eutectic.—The eutectic consisted of 30 mol % LiNO₃, 17 mol % NaNO₃, and 53 mol % KNO₃ (2.3 g of LiNO₃, 1.6 g of NaNO₃, 6.0 g of KNO₃), mp 120°.⁹

C. LiI-KI Eutectic.—The eutectic consisted of 60 wt % LiI (6.0 g of LiI and 4.0 g of KI), mp 260°.¹⁰

(8) "Eutectics with Lithium Compounds," Technical Bulletin, TD-105, Foote Mineral Co.

(9) G. J. Janz, "Molten Salts Handbook," Academic Press, New York, N. Y., 1967.

(10) R. Sridhar, C. E. Johnson, and E. J. Cairns, *J. Chem. Eng. Data*, **15**, 244 (1970).

TABLE I
REARRANGEMENT PRODUCTS















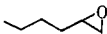













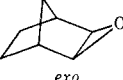


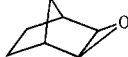

























Epoxide reactant	Registry no.	Conditions	Products
	75-56-9	LiBr Thermal	 CH ₃ CH ₂ CHO 45% 55% 2% 95%
	3203-99-4	LiBr Thermal Ref 7	 16%  47%  34% 24% 43.5% 48% 56.5%
	3203-98-3	LiBr Thermal Ref 7	 7%  38%  53% 34% 26.2% 42% 73.8%
	5076-19-7	LiBr Thermal Ref 7	 CHO 39%  47%  20% 16% 56% 100%
	1436-34-6	LiBr Thermal Ref 7	 2%  69%  29% 10% 40% 50% 60%
	1192-17-2	LiBr Thermal Ref 7	 CHO 98% 90% 100%
	286-20-4	LiBr Thermal Ref 7	 CHO 95%  3% 36% 23% 100%
	16240-42-9	LiBr Thermal Ref 7	 90%  100%  from  100%
	3146-39-2	LiBr Thermal Ref 7	 CHO 35%  15%  6% 57% 37% No reaction
	1713-33-3	LiBr Thermal Ref 7	 CHO 39%  21%  26% 36% 30% 46% 70%
	31152-30-4	LiBr Thermal	 CH ₃ 15%  CHO 34%  2%  12%  37% 49% 26% 6% 19%
	17612-36-1	LiBr Thermal Ref 7	Olefins (see text) 25%  5%  38%  27% 6% 52% 22% 100%

TABLE II
 LiClO₄ REARRANGEMENT PRODUCTS

Reactant	Products
	 93%  5%
	 62%  4%  34%
	Olefins (see text) 5%  12%  36%  46%

D. LiClO₃-LiClO₄ Eutectic.—The eutectic consisted of 70 wt % LiClO₃ (7.0 g of LiClO₃ and 3.0 g of LiClO₄), mp 97°. ³

No special procedures were used to dry the salts except for the LiClO₃, which was heated to a temperature slightly above its melting point under vacuum.

Columns.—The salts were put onto the solid support by dissolving them in water or ethanol (100%) and removing the solvent with a rotary evaporator. This process also served to mix the salts of the eutectic. The melting point of the LiBr-RbBr salt on the support was determined using differential thermal analysis. A loading of 50% was used to increase sensitivity, and the melting point was 275–280°. This value is slightly higher than the

bulk melting point and may reflect some interaction with the solid support. The coated support was packed into 5 ft × 0.25 in. o.d., 0.020 in. wall stainless steel tubing by gravity and the column was purged with helium at ~10° above the desired operating temperature for several hours.

Epoxides.—The epoxides were obtained from Dr. Rickborn, prepared from the corresponding olefins by the method of Korach¹¹ or purchased commercially. All were greater than 95% pure as determined by gc.

Rearrangements.—The epoxide as injected in 50-μl. portions onto the column until enough material was collected (~0.5 ml) for analysis. The carrier gas was helium. The products were trapped in small bulbs immersed in either a solid CO₂-acetone or ice-salt bath. The gc columns used for analysis and collection were 10 ft × 0.25 in. 10% Carbowax 20 M on 60–80 mesh Chromosorb W, 10 ft × 0.25 in. 10% Carbowax 4000 on 60–80 mesh Chromosorb W, and 15 ft × 0.25 in. 10% silicone gum rubber on 60–80 mesh Chromosorb W.

Registry No.—LiBr, 7550-35-8; LiClO₄, 7791-03-9; RbBr, 7789-39-1.

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Chlorination of Adamantane by Ferric Chloride and Antimony Pentachloride¹

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In various solvent systems, the reaction of ferric chloride or antimony pentachloride with adamantane yielded mainly chloroadamantane along with some 1,3-dichloroadamantane. High yields of hydrogen chloride and the reduced form of the salt were also obtained. With longer reaction times the chloroadamantane isomers underwent extensive interconversion. In isomerization studies carried out with the individual isomers and the metal halides, some disproportionation and chlorination occurred. Initial 1:2 isomer ratios (~6) were estimated by performing the chlorinations for short periods at higher temperatures. These values are close to the 1:2 ratios reported in the literature for radical processes involving adamantane but different from the figures for ionic ones. In the case of ferric chloride, no catalytic effect was exerted by aluminum chloride, water, or light. Photolysis enhanced the rate of the antimony pentachloride process. The ferric chloride reaction is probably a nonchain process, whereas antimony pentachloride may be involved in a radical chain sequence. A high 1:2 ratio was observed with SbCl₅-AlCl₃, indicating a polar pathway.

Relatively little attention has been devoted to the reactions of ferric chloride and antimony pentachloride with C-H linkages in organic compounds. About 10 years ago, it was reported that ferric chloride reacts with alkanes under mild conditions, with the order of reactivity being tertiary > secondary.³ Although no pure entities were isolated from the complex organic product, the reaction was characterized by evolution of hydrogen chloride and reduction of Fe(III) to Fe(II). Methylcyclohexane, which was examined in greater detail,⁴ yielded solid polymer along with a small amount

of (methylcyclohexyl)toluene. In a related area, investigations of ferric chloride and alkylbenzenes disclosed the occurrence of various competing reactions including di- and triarylmethane formation from side-chain attack.^{5–8} Ultraviolet irradiation of toluene and ferric chloride-lithium chloride in acetic acid gave benzyl chloride and ferrous chloride.⁹ In relation to functionalities other than hydrocarbons, ferric chloride

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