Mechanism of the Reaction of Dihalogeno-oxirans with Ketones Catalysed by Some Lewis Acids

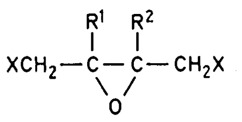
By **Valerii C. Dryuk,* Victor I. Avramenko,** and **Valerii N. Yandovskii,** The Organic Chemistry Department, Dniepropetrovsk State University, Dniepropetrovsk-10, U.S.S.R.

Kinetic studies of the reaction of substituted dihalogenoepoxybutanes with ketones catalysed by Lewis acids reveal its multicentre character. Interaction of an oxiran with a Lewis acid already complexed with a ketone (or other ligand) probably results in the formation of a donor–acceptor Lewis acid–oxiran complex. The transformation of this complex into the activated form involves attack by a ketone molecule from the solvation shell of the complex according to a ' push–pull mechanism. This step can lead to isomerisation of the oxiran as well as to the formation of a dioxolan. The formation of the Lewis acid–oxiran complex can in some cases be the rate-limiting process.

THERE are numerous reports [1] on the reaction of oxirans with oxo-compounds in the presence of Lewis acids. N.m.r. spectroscopic studies have shown the occurrence of inversion of configuration in the ring-enlargement step, and this was used as argument in favour of a mechanism involving attack of the oxo-compound upon the carbocation formed by reaction of the oxiran with the Lewis acid. Nevertheless there are a number of experimental data which still need to be explained: considerable by-product formation, dependence of the reaction course and the yield of final products to a large extent on the nature of the catalyst and reactants, *etc.* We considered that an investigation of the reaction kinetics was needed. In view of the ability of both oxirans [2] and oxo-compounds [3] to form complexes with Lewis acids, it was of particular interest to determine in detail the role of the catalyst.

RESULTS AND DISCUSSION

An investigation of reaction of the dihalogeno-oxirans (1)—(4) with acetone in the presence of tin(IV) chloride or boron trifluoride–ether complex in carbon tetrachloride was carried out at various temperatures in the range 10—40 °C with several different ratios of reactants to catalyst. The following concentration ranges were used: oxirans 1.2—1.25, catalyst 0.05—0.43, ketones 1.7—8.3 mol l^{-1}.



(1) X = Br, $R^1 = R^2 = H$
(2) X = Br, $R^1 = H$, $R^2 = Me$
(3) X = Br, $R^1 = R^2 = Me$
(4) X = Cl, $R^1 = R^2 = H$

The complex of tin(IV) chloride with acetone is virtually insoluble in carbon tetrachloride in the temperature range used, and a large excess of acetone with respect to catalyst was needed in order to carry out the reaction under homogeneous conditions. I.r. spectroscopy revealed that at 20 °C about 93% of the ketone was complexed for concentrations of tin(IV) chloride and acetone of 0.25 and 0.5 mol l^{-1}, respectively. Since oxo-compounds can form 1 : 1 or 1 : 2 complexes with Lewis acids,[3] it might be expected that for a 30—50 fold excess of the ketone the catalyst is almost completely complexed and that the adduct formed is solvated by the excess of acetone.

A plot of the initial rates of 1,3-dioxolan formation from 1,4-dibromo- (1) and 1,4-dibromo-2-methyl- (2) 2,3-epoxybutanes against tin(IV) chloride concentration (Figure 1) shows first-order dependence with respect to the catalyst.

The rate of reaction of the symmetrically substituted oxirans (1) and (4) was found not to depend on the acetone concentration in the range 1.7—6.6 mol l^{-1}, and the rate of dioxolan formation and oxiran consumption was found to be first-order with respect to oxiran concentration for 70—80% consumption of the oxiran (Figure 2). In view of this it was concluded that the interaction of the acetone–Lewis acid complex with the oxiran is probably the rate-determining step.

The question remains as to whether the attack of the oxiran is directed at the carbonyl carbon atom or at the Lewis acid. It was found that the reaction of *trans*-1,4-dibromo-2,3-epoxybutane with acetone leads to *cis*-3,4-bisbromomethyl-2,2-dimethyl-1,3-dioxolan (identified by n.m.r. spectrum). This indicates that the attack occurs on the Lewis acid, because of the inversion of the oxiran configuration, which is in accordance with literature data.[1]

One consequence of the attack of the oxiran on the

---

[1] V. N. Yandovskii, V. S. Karavan, and T. I. Temnikova, *Uspekhi Khim.*, 1970, **39**, 571; B. N. Blackett, T. M. Coxon, M. P. Hartshorn, A. I. Lewis, G. R. Little, and G. I. Wright, *Tetrahedron*, 1970, **26**, 1311.

[2] A. A. Petrov, *Zhur. obshchei Khim.*, 1940, **10**, 981; 1946, **16**, 61; M. T. Bogert and R. O. Robbin, *J. Amer. Chem. Soc.*, 1933, **55**, 1741.

[3] F. Filippini and B.-P. Susz, *Helv. Chim. Acta*, 1971, **54**, 1175; T. Dombrovski and M. Katcka, *J. Mol. Structure*, 1971, **7**, 179.

tin(IV) chloride is the formation of a considerable quantity of the ketone isomeric with the oxiran in the case of the methyl-substituted 1,4-dibromo-2,3-epoxybutanes (2) and (3). This was detected by i.r. spectroscopy and g.l.c. analysis of the products.

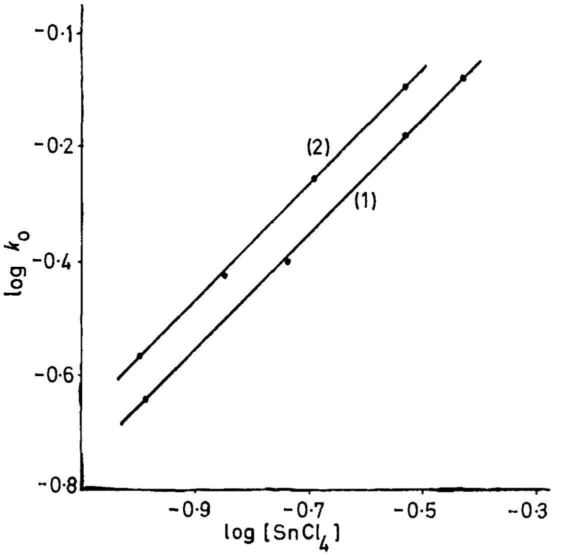


FIGURE 1 Order of reaction of oxirans (1) and (2) (1.2 mol l^{-1}) with acetone (6.0 mol l^{-1}) with respect to tin(IV) chloride in carbon tetrachloride at 30 °C (k_0 = initial rate)

Another peculiarity of the reaction of (2) and (3) is that dioxolan formation is inhibited, and ceases before full consumption of the reagents, a dark oil being precipitated. This can be explained by complexing of the products with the catalyst, it being observed that the addition of the product mixture to the reactants accelerates this inhibiting effect.

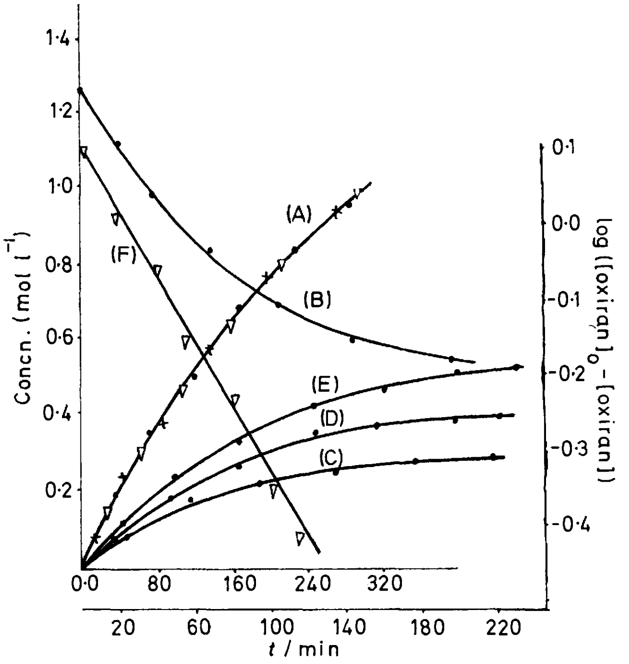


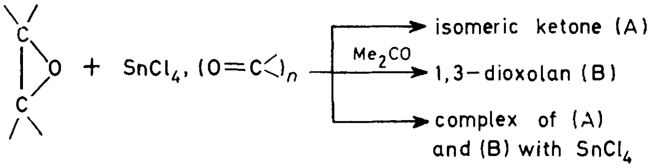
FIGURE 2 Kinetics of the reaction of oxirans with acetone and tin(IV) chloride (0.107 mol l^{-1}) at 30 °C: (A) 4,5-bisbromomethyl-2,2-dimethyl-1,3-dioxolan at acetone concentrations of 1.7 (×), 3.4 (△), and 6.6 (●) mol l^{-1}; (B) 1,4-dibromo-2,3-epoxy-2-methylbutane; (C, D, E) 4,5-bisbromomethyl-2,2,4-trimethyl-1,3-dioxolan at acetone concentrations of 4.8, 6.6, and 8.3 mol l^{-1}, respectively; (F) (right-hand scale) first-order plot for consumption of 1,4-dibromo-2,3-epoxybutane in the same reaction

Thus, the oxirans (2) and (3) can react as in Scheme 1.

This explains why the yield of dioxolan from compounds (2) and (3) increases with increase in acetone concentration (Figure 2), an effect not observed in the case of the oxirans (1) and (4), for which no isomerisation occurred. Owing to the large excess of the ketone with respect to the complex and absence of the concurrent processes, the participation of ketone in the transition state of the reactions of (1) and (4) is not revealed kinetically.

In the case of boron trifluoride–ether as catalyst some undesirable reaction of this with the ketone must occur, since no dioxolan was formed when these reagents were mixed 2 h before addition of the oxiran. This is presumably one of the reasons for the inhibition of the reaction (Figure 3).

The important feature of the dioxolan-forming reaction is that activation parameters reveal it to be a multicentre process, with a small $\Delta H^‡$ and a large negative $\Delta S^‡$ value (Table). Thus the reaction can be regarded as involving interaction of the oxiran with the Lewis acid and acetone according to a 'push-pull' mechanism. The co-ordination of the oxiran with the Lewis acid in an acetone solvation shell leads to complex formation, in which the carbon–oxygen bond of the oxiran is weakened. This weakening will be accompanied by the development of some positive charge on the carbon atom, which can then induce nucleophilic attack by a ketone molecule.



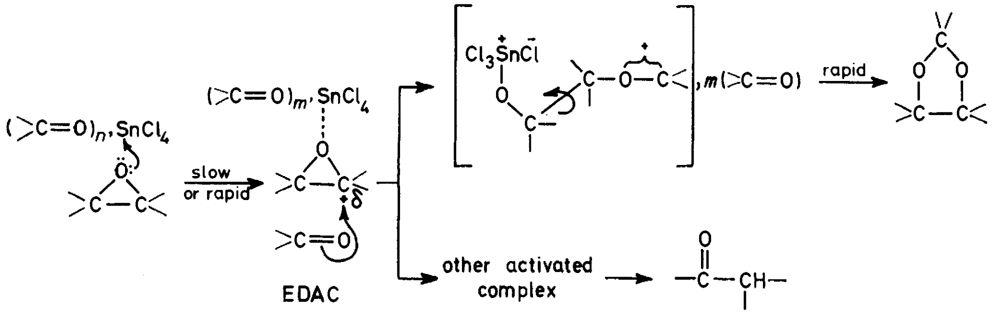
SCHEME 1

Kinetic data for the reaction of dihalogeno-oxirans with ketones [a]

Catalyst	Ketone	Oxiran	10^4k l mol^{-1} s^{-1}	$\Delta H^‡$ kcal mol^{-1}	$-\Delta S^‡$ cal mol^{-1} K^{-1}
$SnCl_4$	Me_2CO	(1)	7.00	11.7	34.0
		(2)	7.77	9.8	40.0
		(3)	0.91	15.7	25.0
		(4)	5.89	12.8	31.0
	Et_2CO	(1)	5.18	11.6	35.0
BF_3,OEt_2	Me_2CO	(1)	1.38	12.7	34.0

[a] Initial concentrations: dihalogeno-oxirans 1.2—1.25, ketones 6.6, $SnCl_4$ 0.107, and $BF_3 \cdot OEt_2$ 0.21 mol l^{-1}.

In addition some of the experimental facts indicate the formation of an oxiran–Lewis acid complex in a pre-equilibrium step followed by slow reaction of the complex with a ketone molecule from within the solvation shell. Thus, when acetone is replaced by the more bulky diethyl ketone an induction period is observed in the reaction kinetics (Figure 3). Replacement of the tin(IV) chloride by boron trifluoride causes the same effect (Figure 3). This is most probably the result of a slow co-ordination of the reagents (oxiran and ketone–Lewis acid complex) associated with substitution of the ketone in the co-ordination sphere of tin(IV) chloride and formation of an electron donor–acceptor complex (EDAC).



SCHEME 2

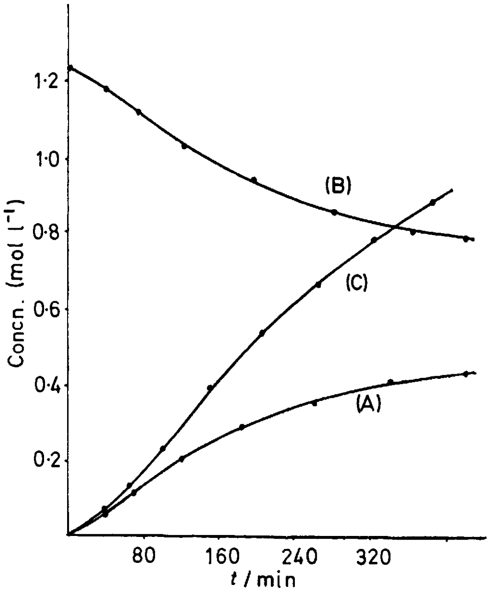


FIGURE 3 Induction periods in dioxolans formation at 30 °C: (A) 4,5-bisbromomethyl-2,2-dimethyl-1,3-dioxolan (BF_3,Et_2); (B) 1,4-dibromo-2,3-epoxybutane in the same reaction; (C) 4,5-bisbromomethyl-2,2-diethyl-1,3-dioxolan ($SnCl_4$)

The detailed mechanism for the conversion of oxiran into dioxolan can be represented as in Scheme 2. It follows from the Table that the replacement of bromine by chlorine in the oxiran (1) leads to a decrease in reaction rate and an increase in activation energy, but that methyl substitution in the oxiran produces the opposite effect. This can be explained by a change in nucleophilicity of the oxiran oxygen atom. However the presence of two methyl substituents in the oxiran considerably retards this process and increases E_a, probably through increased steric crowding during formation of the transition state. This observation offers further evidence for the multicentre character of the reaction.

EXPERIMENTAL

Materials.—*trans*-1,4-Dibromo-2,3-epoxybutane, other dihalogeno-oxirans, and corresponding dioxolans were prepared by known methods.[4] The n.m.r. spectrum of the 4,5-bisbromomethyl-2,2-dimethyl-1,3-dioxolan revealed that the *gem*-methyl groups were non-equivalent a result only consistent with the *cis*-configuration.[1]

Reagent grade ketones and carbon tetrachloride were purified as described elsewhere.[5] ' Pure ' boron trifluoride–ether complex and tin(IV) chloride were distilled under dry nitrogen and collected in a receiver supplied with an inlet cock and input sealed with a soft plastic. Solutions of Lewis acids in carbon tetrachloride were made up by weight.

Since the concentrations of tin(IV) chloride used were low, solutions in carbon tetrachloride were prepared by assuming additivity of the component volumes. The concentration of boron trifluoride was determined by the method described in ref. 6.

Kinetics.—All reactions were carried out in a sealed flask supplied with stirrer, reflux condenser, thermometer, and input with self-sealing plastic stopper for introduction of the reagents and sampling by means of a calibrated syringe. The needle of the latter was supplied with a travelling soft rubber stopper for sealing the inlet at the moment of operation.

A known volume of ketone, followed by a known weight of dihalogeno-oxiran, was added to a solution of tin(IV) chloride in carbon tetrachloride. In the case of boron trifluoride the dihalogeno-oxiran was added before the ketone. Concentrations were calculated on the basis of ideality of mixing. The mixture was stirred for 6—8 h at a particular temperature maintained to within ±0.1 °C. The reaction was monitored by following the consumption of oxiran and the build-up of dioxolan by g.l.c. Samples of the mixture were washed with aqueous 10% potassium

---

[4] M. S. Malinovskii, V. G. Dryuk, A. G. Yudasina, and N. I. Maximenko, *Zhur. Org. Khim.*, 1966, **2**, 2129; M. S. Malinovskii, V. G. Dryuk, and A. G. Yudasina, *Ukrain. Khim. Zhur.*, 1968, **4**, 377.

[5] A. Weissberger, T. A. Riddick, and W. G. Bunger, ' Techniques of Chemistry Organic Solvents,' Wiley–Interscience, New York, 1970, vol. II, pp. 791, 761.

[6] V. N. Plahotnik, V. B. Tulchinskii, and V. V. Vareh, *Avt. svid. S.S.S.R.*, No. 431445; *Bull. Izobr.*, 1974, No. 21,141: *R. Zhur. Khim.*, 1976, No. 8, 8 G191.

hydroxide before analysis. It was assumed that for each oxiran the reaction is first-order in catalyst and in oxiran. Second-order rate constants with respect to oxiran and catalyst were calculated by standard differential methods (estimated error ±5%): for compounds (1) and (4) from the first-order plots; for (2) and (3) from initial reaction rates. When an induction period occurred the apparent rate constant was calculated from the maximum rate. In all cases of rate constant determination the concentration of ketone was constant.

We thank Dr. M. Grossel for his assistance in writing this paper, and the British Council and the Dyson Perrins Laboratory for making it possible for this work to be continued.

[6/1235 *Received*, *25th June*, 1976]