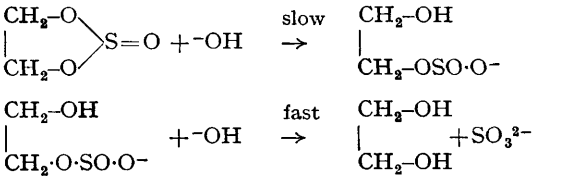
Accelerations of the Rates of Alkaline Hydrolysis of Cyclic Esters of Inorganic Oxy-acids

By P. A. BRISTOW and J. G. TILLETT*

(*Chemistry Department, University of Essex, Wivenhoe Park, Colchester, Essex*)

SEVERAL workers have previously found striking differences between the rates of alkaline hydrolysis of five-membered cyclic esters and their six-membered and open chain analogues.[1-5] Many of the cyclic esters show accelerations of about 10^6, but in the case of phosphates some of the effect has been attributed to the favourable enthalpy of activation of the hydrolysis of five-membered-ring esters.[5] For sulphites, however, Davis showed that ring strain could only be very small and could not account for the 10^3-fold rate acceleration. The cause of acceleration in sulphites can therefore be studied without confusion from ring-strain effects. We have sought an explanation for the anomalous effects observed through a study of the activation parameters, $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$.

The activation parameters, calculated[3] from previous work on sulphites, were obtained from rate measurements at two temperatures only and cannot be regarded as very precise. In this study the rates have been re-determined more accurately and values for both the enthalpy and entropy of activation have been calculated. The discovery of a transesterification intermediate in the ethylene carbonate–methanol system,[6] which indicates that strain in the ethylene carbonate ring is small, has prompted us to determine also the parameters for some carbonate hydrolyses. The results tabulated below were obtained exclusively by the pH-stat method, which we feel to be most precise for these rapid reactions. Rates were calculated from raw data assuming that hydrolysis of the first ester group (or ring-opening step) is rate determining, *i.e.*, for ethylene sulphite:



Computer analysis of the data confirms that the second step is about one hundred times faster than the first.

TABLE. *Activation parameters*[a] *for alkaline hydrolysis*

Sulphite	$\Delta H^{\ddagger}$(kcal.mole^{-1})	$\Delta S^{\ddagger}$ (e.u. at 25°)
Dimethyl	11·2	−24
Diethyl	12·0	−25
Ethylene	10·2	−15
Methylethylene	10·1	−16
Tetramethylethylene	10·1	−19
Trimethylene	12·3	−18
Tetramethylene	12·3	−24
Carbonate		
Dimethyl	13·6	−16
Ethylene	14·1	−10

[a] Values obtained from rate measurements over the range 5—50° (at least four different temperatures for each compound).

The results show that rate differences are caused mainly by differences in the entropy of activation. We interpret these differences as follows. Both dialkyl and large-ring sulphites are relatively flexible forms. This is clear from models and from their n.m.r. spectra. Free alkyl groups may rotate; the ring systems may twist and even flip. However, a five-membered ring such as ethylene sulphite must be a fairly rigid structure. This does not necessarily mean that it is strained, as shown by Davis.[3] In the transition state, we suggest, the molecule must be held rather rigidly, and thus the molecular motions of the alkyl groups and the large-ring sulphites must be suppressed. This requires a loss of entropy, which increases the free energy of activation. For ethylene sulphite, the molecule is already constrained and far less entropy loss is required in the transition state, resulting in a much lower free energy of activation. This "entropy-strain" principle has been invoked by a number of authors and is discussed by Taft.[7]

The preliminary results obtained for dimethyl and ethylene carbonate show a similar effect to sulphite esters. Ethylene carbonate shows an "entropy-strain" acceleration, although it is less marked than for ethylene sulphite. This may be because the exocyclic oxygen is free to vibrate about the ring plane, whereas in ethylene sulphite it is fixed more firmly above the ring by the lone pair on sulphur below the ring.

Very recently, Aksnes and Bergeson[8] have made the observation that the major part of the rate acceleration observed in the phospholan ring is caused by a favourable entropy of activation. This would seem to be another example of the entropy-strain principle.

Further work is in progress to determine activation parameters not now available in order to estimate the part played by entropy effects in other cyclic ester systems.

(*Received, August 10th*, 1967; *Com.* 851.)

[1] J. Kumamato, J. R. Cox, and F. H. Westheimer, *J. Amer. Chem. Soc.*, 1956, **78**, 4858.
[2] J. G. Tillett, *J. Chem. Soc.*, 1960, **37**.
[3] R. E. Davis, *J. Amer. Chem. Soc.*, 1962, **84**, 599.
[4] J. H. Heidema and E. T. Kaiser, *J. Amer. Chem. Soc.*, 1967, **89**, 460.
[5] E. T. Kaiser, M. Panar, and F. H. Westheimer, *J. Amer. Chem. Soc.*, 1963, **85**, 602.
[6] P. A. Bristow and J. G. Tillett, *Tetrahedron Letters*, 1967, 901.
[7] R. W. Taft in "Steric Effects in Organic Chemistry," ed. M. S. Newman, Wiley, New York, 1956, p. 670.
[8] G. Aksnes and K. Bergesen, *Acta Chem. Scand.*, 1966, **20**, 2508.