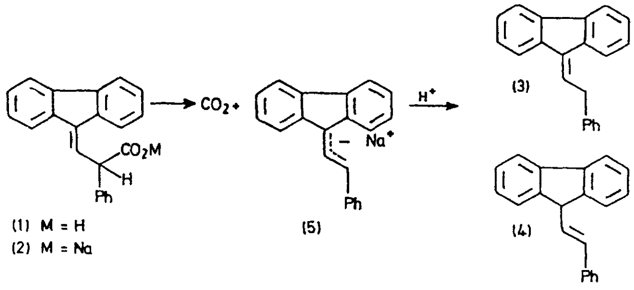
Catalysis of a Decarboxylation by a Crown Ether

By DUNCAN H. HUNTER,* WILLA LEE, and S. K. SIM
(*Department of Chemistry, University of Western Ontario, London, Ontario, Canada*)

Summary The decarboxylation of sodium 3-(fluoren-9-ylidene)-2-phenylacrylate in tetrahydrofuran is greatly accelerated ($\geqslant 10^5$) by addition of dibenzo-18-crown-6-ether and is very sensitive to the solvent, pointing to an important rôle for ion-pairing and H-bonding.

WE have observed a striking catalytic effect both of added dibenzo-18-crown-6-ether and of solvent upon the decarboxylation of the sodium salt (**2**). Both (**1**) and the salt (**2**) lose CO_2 readily to produce initially the delocalized carbanion. The rate of this spontaneous reaction is greatly enhanced by destabilization of (**2**) either by disruption of hydrogen-bonding in polar protic solvents or of ion-pairing in non-polar aprotic solvents. The easy decarboxylation of (**2**) and the large catalytic effect of crown ether point to a new decarboxylation mechanism of fairly general occurrence and applicability, and also complement recent examples of the ability of crown ethers to 'free' anions to act as much more powerful bases and nucleophiles.[2]

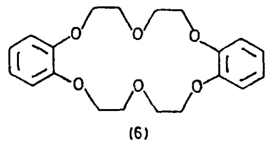


(1) M = H
(2) M = Na

(5)

(3)

(4)



(6)

The sodium salt (**2**) reacted readily when heated for 145 min in water at 80 °C. The insoluble hydrocarbons which separated after complete reaction consisted of 35% of (**3**) and 65% of (**4**). It has been observed that the NaOEt–EtOH–Me_2SO equilibration of (**3**) and (**4**) yielded > 99% of (**3**). In contrast, quenching with acid of the anion (**5**) from (**3**) or (**4**) and $KOBu^t$ in Me_2SO yielded 30% of (**3**) and 70% of (**4**). The pK_a of (**3**) was estimated to be 17·2. The similarity in percentages of (**3**) and (**4**) from decarboxylation and from anion quenching indicates an anionic intermediate in the decarboxylation. The decarboxylation is presumably facilitated by the carbanion stability.

The rate of decarboxylation† of (**2**) increased with MeOH as solvent ($t_{\frac{1}{2}}$ *ca.* 1 h at 60 °) and increased even more in MeOH–Me_2SO (50:50) ($t_{\frac{1}{2}} <$ 10 min at 20 °C). Under these conditions, the product was (**3**), consistent with methoxide-catalysed equilibration of the products. In MeCN and Me_2SO at ambient temperature, (**2**) produced an instantaneous red colour consistent with rapid formation of the carbanion (**5**). Analogous catalytic effects of solvent have been reported[4] for the decarboxylation of benzisoxazole-3-carboxylates to form *o*-cyanophenoxides. Rate changes of about 10^6 were reported in changing the medium from H_2O to Me_2SO. Analogous medium effects have also been reported for phenylcyanoacetate anions.[5] Such medium effects presumably reflect changes in the relative stability of the charge-localized carboxylate ion and the delocalized transition state for its reaction and point to a rôle for hydrogen-bonding. The hydrogen-bonded carboxylate is much slower to decarboxylate than the 'free' species.

Dissolution of (**2**) in tetrahydrofuran (THF) resulted in slow appearance of an orange-red colour which on quenching with D_2O yielded (**3**) and (**4**) each containing 1D atom/molecule at the expected position. The same orange-red colour [λ_{max} ($\epsilon \times 10^{-4}$)] 534 (1·0), 512 (2·7), and 494 (2·9) nm] was produced upon treating (**3**) with $NaNH_2$ in THF and is attributed to (**5**).

The possible rôle of ion-pairing which is common in low-polarity, aprotic solvents[6] was investigated by studying the effect of dibenzo-18-crown-6-ether (**6**) on the decarboxylation. The reaction was monitored qualitatively by the first appearance of the orange-red colour when (**6**) was added to a stirred, thermostatted solution of (**2**) in carefully dried THF under reduced pressure. By studying the effect of varying the concentration of (**2**) the appearance of the appropriate colour could be attributed to *ca.* 10% reaction using a concentration of (**2**) of 6×10^{-4}M. Although colour appeared slowly near 0 °C, solutions remained colourless at −45 °C for at least 200 min. However, addition of 1 equiv. of (**6**) resulted in immediate appearance of colour [< 5—10 s at −45 °C with a concentration of (**6**) of 5×10^{-4}M]. This time ratio (200 min to < 5—10 s) corresponds to a catalytic effect of at least 10^3. Even with [(**6**)] = 8×10^{-6}M (0·01 equiv.), colour appeared immediately suggesting the rate constant may be at least an additional 10^2 larger. Thus (**6**) may have a catalytic effect of $\geqslant 10^5$ on the decarboxylation.‡

These results show that ion-pairing is important in this decarboxylation, with the crown ether forming a complex with the sodium ion, perhaps producing a highly reactive crown-ether separated ion-pair.

The reaction of the 'free' carboxylate anion is much more rapid than that of the ion-pair. The catalytic effect of the crown ether is apparently very large and is certainly comparable in magnitude to the solvent effects noted above.

The high reactivity of (**2**) makes it an inappropriate substrate for a detailed mechanistic study. However, the second-order rate constant for complexation of Na^+ with (**6**) in a variety of solvents can be estimated to be in the range 10^5—10^6 l mol^{-1} s^{-1} at −45 °C on the basis of a n.m.r. study[7] of the effect of (**6**) on sodium tetraphenylboride. Rate constants of that magnitude in the present system and the observation of immediate colour at −45 °C with (**6**) $= 8 \times 10^{-6}$M, suggest that the rate of decarboxylation and the rate of complexation might be similar, *i.e.* complex formation may be the rate-determining step.

When dissolved in Me_2SO at ambient temperature the parent acid (**1**) immediately and quantitatively produced a mixture of 30% of (**3**) and 70% of (**4**) as shown by n.m.r. spectroscopy. This mixture suggests that even the parent acid (**1**) in Me_2SO decarboxylates preferentially through the

---

† The sample of (**2**) used was obtained from lyophilization of the titration product of (**1**) which in turn was obtained as the major carbonation product of the lithium salt of (**5**) in THF at ambient temperature. Satisfactory combustion analysis was obtained for (**1**).

‡ This analysis of the catalytic effect is based upon a model in which the complexation equilibrium lies on the side of the complexed form with equilibrium being established rapidly. On this basis, the rates of the first-order processes for the decarboxylation of complexed and uncomplexed material are being compared.

anion. This hypothesis is supported by the observation that the addition of toluene-*p*-sulphonic acid completely depresses the decarboxylation presumably by greatly reducing the carboxylate ion concentration.

We thank the National Research Council of Canada for financial support, and J. P. Guthrie for his advice.

(*Received*, 19*th August* 1974; *Com.* 1061.)

[1] Presented at the First Fall Organic Conference of the A.C.S., Cape Cod, Massachusetts, October 1973.

[2] J. N. Roitman and D. J. Cram, *J. Amer. Chem. Soc.*, 1971, **93**, 2231; D. H. Hunter and D. J. Shearing, *ibid.*, p. 2348; D. H. Hunter, Y-t. Lin, A. L. McIntyre, D. J. Shearing, and M. Zvagulis, *ibid.*, 1973, **95**, 8327; D. J. Sam and H. E. Simmons, *ibid.*, 1974, **96**, 2252; C. L. Liotta and H. P. Harris, *ibid.*, p. 2250; M. J. Maskornick, *Tetrahedron Letters*, 1972, 1797.

[3] R. Kuhn and D. Rewicki, *Tetrahedron Letters*, 1965, 3513.

[4] D. S. Kemp and K. Paul, *J. Amer. Chem. Soc.*, 1970, **92**, 2553.

[5] T. S. Straub and M. L. Bender, *J. Amer. Chem. Soc.*, 1972, **94**, 8875.

[6] M. Szwarc, 'Ions and Ion Pairs in Organic Reactions,' Wiley-Interscience, New York, 1972, vol. 1.

[7] E. Shchori, J. Jagur-Grodzinski, and W. Shporer, *J. Amer. Chem. Soc.*, 1973, **95**, 3842.