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THE REARRANGEMENT OF CYCLOPROPYL CHLORIDES TO ALLYL CHLORIDES: STEREOSPECIFICITY IN THE RECAPTURE OF THE CHLORIDE ION

Ian Fleming and E. J. Thomas

University Chemical Laboratory, Lensfield Road, Cambridge, England

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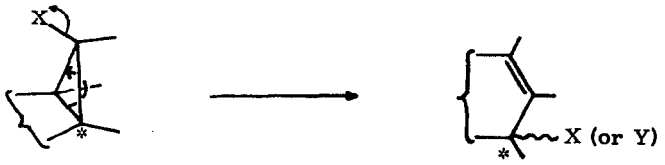
The ring-opening of halocyclopropanes[1] has been much studied recently and it is well established that a stereospecific opening of the ring is concerted with the departure of the leaving group.[2] We have now studied the stereochemistry of the second phase of the reaction — the recapture of halide ion (or capture of another nucleophile) to give the allylic system (**2**). In other words, we have been looking at the stereochemistry of the event occurring at the carbon marked * in **1** and **2**.

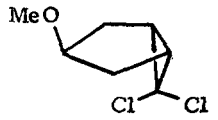


1 **2**

There have been several earlier reports of stereoselectivity at this site. In particular, the exo dihalocarbene adducts of norbornene have been found[3] to give only or mainly the 2-exo-2,3-dihalobicyclo[3,2,1]oct-3-enes, and only one diastereoisomer of the trans olefin product was obtained[4] in the solvolysis of the bromo- and dibromo-carbene adducts of some medium-sized ring olefins. In each of these cases, the stereochemistry of the event at the carbon marked * corresponds to inversion of configuration. But in none of them is it clear that the same result would not be obtained from a free allyl cation. These reactions are evidently stereoselective, but they have not been shown to be stereospecific in the sense of that word introduced by Zimmerman[5] and given wider currency by Eliel.[6,7]

The compounds we have used are the dichlorocyclopropanes (**3** and **4**), in which the methoxy group provides the stereochemical label. When the anti isomer (**3**)[8] was

heated in a sealed tube at 160° for four hours, it gave a mixture of the allyl chlorides (**5** and **6**) in the ratio 91:9. When the syn isomer (**4**) was similarly heated, it gave the same allyl chlorides in the ratio 14:86. The equilibrium mixture of the two allyl chlorides, obtained after longer heating (170°/10h), had them in the ratio 80:20. Thus, although the allyl chlorides are approaching equilibrium under the reaction conditions, they are clearly being formed, at least in part, stereospecifically.



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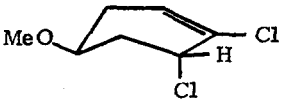

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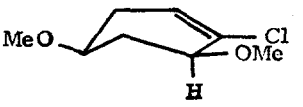

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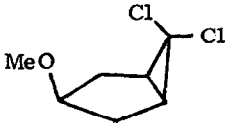

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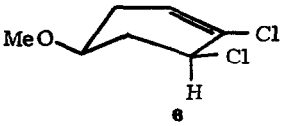

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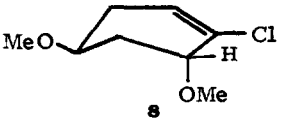

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By trapping the first-formed allyl chlorides (**5** and **6**) with other nucleophiles, we have been able to show that the rearrangement is very largely stereospecific. When the anti isomer (**3**) was heated with sodium methoxide in methanol at 100° for six hours, the methyl ethers (**7** and **8**) were obtained in the ratio of 87:13, together with some chlorobenzene. The same products in essentially the same ratio were obtained from the allyl chloride (**5**). When the syn isomer (**4**) was heated with sodium methoxide under the same conditions, the same ethers were obtained, but in the ratio 15:85, together with rather more chlorobenzene. Again, the same products in the same ratio were obtained from the corresponding allyl chloride (**6**). What is more, the parallel in the behaviour of the cyclopropyl chlorides (**3** and **4**) with the corresponding allyl chlorides (**5** and **6** respectively) is observed in a wide range of reactions (Table), even to the extent of showing SN2' products with sodium thio-phenoxide in non-polar solvents.

We conclude that the external nucleophile (MeO^-, PhS^-, etc.) does not participate in the ring-opening step. Instead it seems likely that the chloride ion does not depart irretrievably as the rearrangement proceeds but is rapidly recaptured.[9,10] The external nucleophile then serves to trap the first-formed allyl chloride, in which case we may infer that, initially, the rearrangement of the cyclopropyl chlorides (**3** and **4**) to the allyl chlorides (**5** and **6** respectively) is at least 95% stereospecific.

Reaction Conditions	Starting Material	% Reaction[a]	Product Distribution %	
			5[b]	6[b]
160° 4 hr.[c,d,e]	3	95	91	9
	5	-	94	6
	4[f]	100	14	86
	6[f]	-	19	81
			PhCl[g]	7[g]	8[g]
1N NaOMe in MeOH at 100°[c,e,h] 6 hr. for 3 and 4 15 min. for 5 and 6	3	62	41	51[i]	8
	5	100	37	57	6
	4[f]	37	69	5[i]	26
	6[f]	100	72	4	24
MeOH[c,d,e] 140° 6 hr.	3	100	0	53	47
	5	100	0	54	46
	4[f]	100	0	23	77
	6[f]	100	0	25	75
1N $AgClO_4$ in MeOH 68° 1 hr.	3	100	0	60	40
	5	100	0	62	38
	4[f]	90	0	41	59
	6[f]	100	0	46	54
			cis thioether[b,j]	trans thioether[b,k]	
0.23N PhSNa in MeOH[c,d,e,l,m] 120° 5 hr.	3	100	86	14	
	5	100	90	10	
	4[f]	100	5	95	
	6[f]	100	4	96	
PhSNa suspended in diglyme at 161°[m] 3.5 hr. for 3 and 4 5 min. for 5 and 6	3	100	12	88	
	5	100	11	89	
	4[f]	100	65	35	
	6[f]	100	65	35	

[a]Estimated from the amount of recovered starting material. [b]Estimated by n.m.r. [c]The reactions were performed in a sealed tube. [d]The results are reproducible to ±4%. [e]The results are the average of two or more runs. [f]The results are corrected for about 4% of 5 in the starting material. [g]Estimated by g.l.c. [h]The results are reproducible to ±3%. [i]Corrected for about 4% decomposition of this isomer under the reaction conditions; the product of the decomposition was anisole. [j]This product is the analogue of 7. [k]This product is the analogue of 8. [l]This reaction gives about 10% of 7 and 8, as well as the cis- and trans-thio-ethers. [m]A small amount of 1-chloro-4-methoxy-2-phenylthiocyclohexene was formed in this reaction, the amount was usually less than 5%.

FOOTNOTES AND REFERENCES

1. W. E. Parham and E. E. Schweizer, Org. Reactions, 13, 71 (1963); C. W. Jefford, Chimia, 24, 357 (1970).

2. C. H. DePuy, L. G. Schnack, and J. W. Hausser, J. Amer. Chem. Soc., 88, 3343 (1966); C. H. DePuy, Accounts Chem. Res., 1, 33 (1968).

3. W. R. Moore, W. R. Moser, and J. E. LaPrade, J. Org. Chem., 28, 2200 (1963); R. C. De Selms and C. M. Combs, ibid., 2206; E. Bergman, ibid., 2210; C. W. Jefford, S. Mahajan, J. Waslyn, and B. Waegell, J. Amer. Chem. Soc., 87, 10 (1965).

4. G. H. Whitham and M. Wright, Chem. Comm., 294 (1967); J. N. Hines, M. J. Peagram, G. H. Whitham, and M. Wright, ibid., 1593 (1968); C. B. Reese and A. Shaw, ibid., 1366 (1970); D. Duffin and J. K. Sutherland, ibid., 626 (1970).

5. H. E. Zimmerman, L. Singer, and B. S. Thyagarajan, J. Amer. Chem. Soc., 81, 108 (1959).

6. E. L. Eliel, Stereochemistry of Carbon Compounds, McGraw-Hill, New York, 1962, p. 436.

7. This distinction between stereoselective and stereospecific has not been consistently adopted by organic chemists, but it is an unusually useful distinction in the context of the work described in this paper.

8. The methods of synthesis and the proof of configuration for all the compounds discussed here will be described in a full paper.

9. Strictly speaking we have not demonstrated that the allyl chloride is a true intermediate: an ion-pair, involved in the rearrangement of the cyclopropyl chlorides and in the substitution reactions of the allyl chlorides, could be the common intermediate. Such an ion-pair must be intimate enough to preserve the distinction between the top side and the bottom side of the allyl cation, in which case it is most likely that return to the allyl chloride is at least as fast as the displacement reaction. Such return would, effectively, make the allyl chloride an intermediate.

10. Jefford[1] has drawn attention to the possibility that this type of rearrangement has a completely concerted migration of chlorine from one carbon atom to the next. Such a migration (it is a $\sigma 2s + \sigma 2a$ process[11]) requires inversion of configuration at C*. But inversion would also be expected of ionic attack at this site by the chloride ion which has just departed from the cyclopropane ring, both because the chloride ion is on this side of the ring and because inversion is normal in nucleophilic displacements. Except insofar as stereospecificity is required of the concerted reaction, our results do not distinguish between these two mechanisms.

11. For a striking example of such a process, see J. E. Baldwin and A. H. Andrist, Chem. Comm., 1561 (1970).