Tetrahedron Letters,Vol.23,No.4,pp 391-394,1982
Printed in Great Britain

0040-4039/82/040391-04$03.00/0

EFFECT OF SUBSTITUENTS ON THE HOMO-1,4 ADDITION OF DIFLUOROCARBENE TO NORBORNADIENES

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Summary. Difluorocarbene reacts with 2-methoxy and 2-carbomethoxy-7,7-dimethylnorbornadiene to give homo-1,4 adducts only. The relative rates of addition are compared with that for 7,7-dimethylnorbornadiene and are found to be 2.63, 0.045 and 1.0 respectively. Consequently, an electrophilic process is operating. Difluoro, dichloro and dibromocarbenes react with 7,7-dimethylnorbornadiene exclusively on the *endo* face to give 1,2 and homo-1,4 adducts in ratios of ∿0.1, 0.5 and 0.7 respectively. The homo-cheletropic reaction, compared to the competing cyclopropanation, is increasingly sensitive to the bulk of the carbene partner.

Although the addition of halocarbenes to norbornadiene and its derivatives has been extensively studied,[1] the nature of the unusal homo-1,4 addition still awaits proper definition. We recently reported that the ratio of exo-1,2 to homo-1,4 adducts obtained by reaction of difluorocarbene to norbornadiene depends on the type of C2-substituent. Electron-releasing substituents gave high ratios (∿8), whereas electron-withdrawing substituents gave low ones (∿1).[2]

We originally suggested that low ratios, where much cyclobutane product was formed, arise from the nucleophilic character of the carbene as elicited by the substituent.[3] However, this interpretation is open to criticism as the ratio is ambiguous. As singlet carbenes behave as unquestioned electrophiles in the 1,2 addition[4] and because the exo-1,2/homo-1,4 ratio is greater than unity, variations in this ratio reflect mainly the effect of substituents on the electrophilic 1,2 addition. The effect of substituents on the homo-1,4 addition, namely the inverse or lesser influence on nucleophilic and electrophilic processes respectively, remains problematical when there is competition between the exo and endo faces.[5]

We now report experiments where this ambiguity is resolved. 7,7-Dimethylnorbornadienes substituted at C2 with electron-releasing (1) and withdrawing (2) substituents were prepared together with 7,7-dimethylnorbornadiene (3)[6-8] and allowed to react with difluorocarbene.[9] The presence of methyl groups at C7 hinders the exo faces of the molecule, thereby prohibiting exo-cyclopropanation. Moreover, the use of difluorocarbene provides an additional mechanistic assurance since it is the smallest and least electrophilic halocarbene.[10] In fact, only homo-1,4 adducts were formed (4, 5 and 6, Scheme 1). The relative rates of reaction are revealing (Table 1). 2-Methoxy-7,7-dimethylnorbornadiene (1) reacted fastest giving high yields of adducts. 2-Carbomethoxy-7,7-dimethylnorbornadiene (2) underwent homo-1,4 addition sluggishly in poor yield.

This result proves that the homo-1,4 addition, like the 1,2 addition, is electrophilic. Accordingly, the exchange reaction of difluorocarbene with the diene moiety needs to be revised. The precise trajectory adopted by the carbene on approaching the endo face of norbornadiene should be, as calculations[11] have suggested, such that the repulsion between the doubly occupied σ

Scheme 1

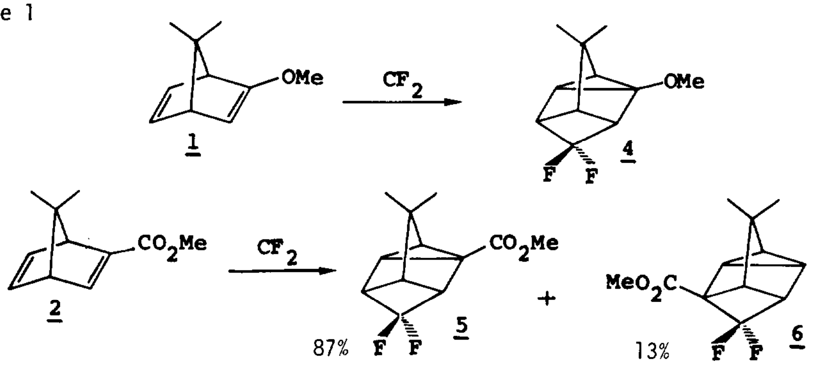
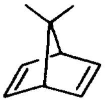


Table 1. *Relative rates of addition of difluorocarbene to 7,7-Dimethylnorbornadiene (3) and its 2-methoxy (1) and 2-carbomethoxy (2) derivatives (ref. 9)*

Diene	1	2	3
k_{rel}	2.63	0.045	1.0

Table 2. *Proportion of carbene adducts obtained from diene 3 on reaction with dihalocarbenes*

3	CF_2	CCl_2	CBr_2
			
1,2 Adducts	9	36	43%
Homo-1,4 adducts	91	64	57%

orbital of the carbene and the SHOMO of the diene is minimized. This implies that the ligands on the approaching carbene would be pointing *towards* the endo face. Confirmation of this orientational preference was obtained by examining the proportion of 1,2 to homo-1,4 adducts formed by difluoro, dichloro, and dibromocarbene with 7,7-dimethylnorbornadiene (3).[12] Significantly, 1,2 addition becomes greater with the increasing electrophilicity and size of the carbene (Table 2). Since cyclopropanation and cyclobutanation are both electrophilic, a σ^2 carbene on approaching the endo side of the diene exercises a subtle steric discrimination between 1,2 and homo-1,4 addition.

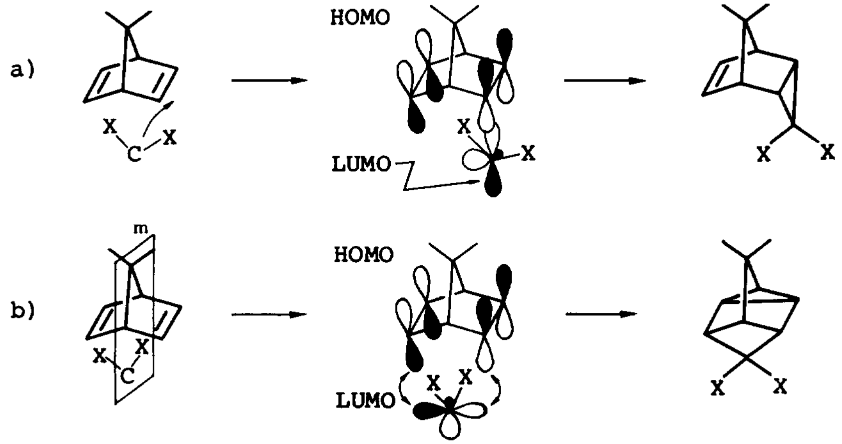


Fig. 1. *Cyclopropanation and cyclobutanation of norbornadiene by electrophilic addition of a* σ^2 *carbene* via *(a) the non-linear approach of an inverting carbene and (b) the linear approach of an inverting carbene.*

In the usual 1,2 addition the non-linear approach of the carbene is dominated by the electrophilic interaction. Consequently, the ligands project forwards to minimize the destabilizing influence arising from the HOMO of the carbene and the appropriate occupied orbital in the olefin. The carbenic carbon atom becomes increasingly carbanionic and in forming the cyclopropane undergoes a formal inversion of configuration.[13] For the exo hindered norbornadienes, all dihalocarbenes adopting the non-linear trajectory should slide onto the C2-C3 bond with similar steric ease (Fig. 1a).

The same electronic scenario obtains for the carbene during homo-1,4 addition. It linearly approaches the endo side of the homo-diene in the mirror plane bisecting the bridgeheads (m), so that both lobes of the p_z orbital enmesh with the HOMO. Initially, the ligands point towards the diene so as to minimize the HOMO-SHOMO interaction. Subsequently, the ligands fold back in the final act of cyclobutanation.[14] Such an approach should be hindering (Fig. 1b). Difluorocarbene, having the shortest carbon-halogen bonds and the smallest van der Waals radius for halogen, is the best able to undergo this process. Dibromocarbene represents the other extreme giving less homo-1,4 adducts. Further experiments and calculations to evaluate this electrophilic-linear-homo-cheletropic reaction of an inverting carbene are in progress.

Acknowledgment. We are indebted to the Swiss National Science Foundation (grant No 2.418-0.79) for the support of this work.

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5) cf. G.W. Klumpp & P.M. Kwantes, Tetrahedron Letters 831 (1981). These authors studied the partial rates of 1,2 and homo-1,4 additions of dichlorocarbene to 7-substituted norbornadienes. However, the effect of substituents reveals little differentiation and is anomalous for the exo-anti and endo-anti 1,2 additions.

6) Diene 1 was prepared from 7,7-dimethylnorborn-2-en-5-one (ref. 7) by treatment with methyl orthoformate in methanol followed by the action of triethylamine and aluminum chloride (ref. 8). Diene 2 was obtained by the Diels-Alder addition of methyl acetylenecarboxylate to 5,5-dimethylcyclopenta-1,3-diene (cf. ref. 7). For the preparation of the parent diene 3 see ref. 7.

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(Received in Germany 27 July 1981)