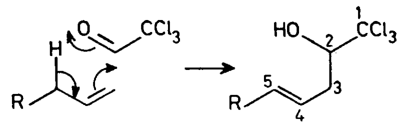
Ene Reaction of Chloral with Olefins Catalysed by Lewis Acids, and some Applications in Organic Synthesis

By G. BRYON GILL* and BRIAN WALLACE
(*Department of Chemistry, The University, Nottingham* NG7 2RD)

Summary Chloral has been found to react with representative examples of mono-, 1,1-di-, and 1,2-di-alkyl-substituted ethylenes to afford ene adducts in synthetically useful yield, and under mild conditions, when a Lewis acid is employed in catalytic quantities to enhance the reaction rate; the usefulness of these reactions is demonstrated by various transformations of the 1-hydroxy-2,2,2-trichloroethyl unit.

THE synthetic potential of the ene reaction[1] is diminished because of the normal requirement for rather forcing reaction conditions; the use of temperatures in excess of 250 °C is not uncommon, even in the favourable case of the intramolecular process,[2] unless the enophile is particularly reactive. Sporadic reports of 'catalysis' by Lewis acids have appeared,[3] but there have been few attempts at a general and coherent study of such processes, and frequently the Lewis acid has been employed in quantities approaching 1 mol equiv. Snider has reported that catalytic activity is only apparent (for olefinic enophiles) when the ene component is a 1,1-dialkyl ethylene;[4a] with propiolate esters as enophiles, (2+2) cyclo-adducts are the major products with olefins other than the 1,1-dialkyl ethylenes.[4b] Our results with chloral indicate a much wider range of useful activity in the ene reaction.

The addition of chloral to olefins affords adducts of the type indicated in reaction (1),[5] rather than the Friedel–Crafts type products proposed in an earlier study.[6] Thus, the reaction affords a chiral centre at C-2, and the ^{1}H n.m.r. spectra unequivocally support the structural assignments.†



(1)

Our results with (−)-β-pinene illustrate the extent of the rate accelerations achieved with Lewis acids. Catalyst (mol %), solvent, temperature/°C, time/h, isolated yield/% of (**1**): none, neat, 95, 4, 60; $FeCl_3$ (1), neat, 20, <1, 58; $AlCl_3$‡ (1—5), CCl_4, 20, <2, 58; $SnCl_4$ (1—5), CCl_4, 20, <2, 45; $FeCl_3$ (1), CCl_4, 20, 5, 51. With the more potent catalysts, $AlCl_3$ and $SnCl_4$, the use of a solvent is necessary in order to moderate the exothermic reaction and prevent by-product formation; likewise, the use of >10 mol % of these Lewis acids affords tarry material.

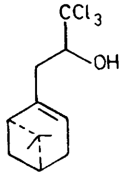
Similar reactivity was observed with limonene and with the 1-alkyl substituted ethylenic compounds hex-1-ene and oct-1-ene. In the case of hex-1-ene, for example, two ene adducts were obtained. The major isomer had the *trans*-configuration (**2**), and the 95:5 *trans*:*cis* isomer ratio indicates the high stereoselectivity in the transfer of the allylic hydrogen atom during the reaction. A consideration of steric effects and the probable co-ordination site for the

---

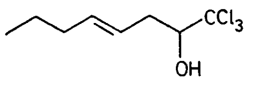
† Structural assignments are also supported by other spectroscopic data and by microanalytical results.

‡ The preferred catalyst and reaction conditions. Yields are not optimised. Reactions are readily performed on a large scale.

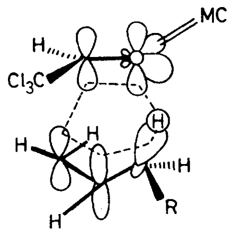
Lewis acid suggests a strong preference for the geometry of approach indicated by (**3**), in agreement with the experimental observations.§ The stereoselectivity should depend, to some degree, on the presence or absence of the Lewis acid, but unfortunately hex-1-ene and chloral react very sluggishly under thermal activation, and then only to give tarry products.



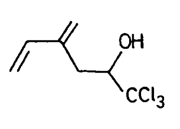
(1)



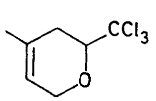
(2)



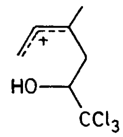
(3)



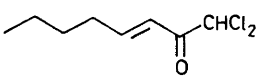
(4)



(5)



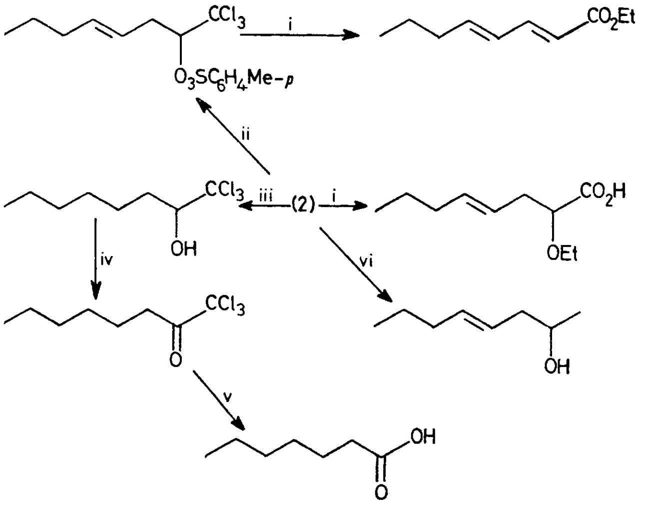
(6)



(7)

The 1,2-disubstituted ethylene, cyclohexene, also reacted with surprising ease under the catalytic conditions to give the ene adduct and a small quantity of 3-trichloromethyl-2-oxabicyclo[2.2.2]octane.[5b] The ene adduct is converted into the cyclic ether upon more-prolonged contact with the Lewis acid. The trisubstituted olefin α-pinene failed to give the ene adduct under the usual reaction conditions, and a pair of isomeric tricyclic ethers with the bornane skeleton[7] were the only products isolated. Isoprene afforded the ene adduct (**4**) and the apparent (4+2) cycloadduct (**5**), a result that has been noted previously.[8] This earlier work indicated that the (**4**) : (**5**) ratio underwent dramatic reversal from 10 : 90 in the thermal ene reaction (155 °C, 4 h) to 95 : 5 in a Lewis acid-catalysed addition ($SnCl_4$, 0 °C). However, these results over-simplify the true situation as the pyran (**5**) is labile, and its yield is readily under-estimated. Immediate (g.l.c.) analysis of the product compositions in the present study ($AlCl_3$, CCl_4, 20 °C) revealed (**4**) : (**5**) ratios of 75 : 25 and of 5 : 95 in the presence of 1 and 10 mol % catalyst, respectively. Intermediate quantities of catalyst afforded intermediate values for the (**4**) : (**5**) ratio, but the correlation was not linear. Thus, it seems likely that ether formation is a consequence of the further reaction of the ene adduct under the influence of the Lewis acid. Alternatively the observed reactions may be close to the mechanistic borderline between concerted and non-concerted reaction profiles, with the formation of the ene adduct or the ether depending subtly upon the catalyst, its concentration, and upon the structure of the olefin. With regard to the first possibility, the interaction of the ene adduct with the Lewis acid can produce a strong protonic acid (*i.e.* $ROH + AlCl_3 \rightleftharpoons ROAlCl_3^- + H^+$) and electrophilic attack on (**4**), for example, may reasonably be expected to afford (**5**) by way of the intermediate carbonium ion (**6**). Mechanistic studies are in progress; the present results point to the importance of employing low catalyst concentrations in the ene reactions of activated carbonyl compounds.

The sensitivity of the ene synthesis to the presence of functional groups is currently being investigated. Allylbenzene affords the ene adduct, but only as a minor component in the reaction mixture, and its allyloxy analogue (allyl phenyl ether) reacts by Friedel–Crafts substitution of the aromatic ring. However, α-methylstyrene was found to undergo the usual ene addition with chloral, and hence not only is the nucleophilicity of the aromatic ring important but also the position of attachment of the ring to the olefinic framework. With allyl alcohol the catalyst merely aided the formation of the chloral hemiacetal, and allyl bromide was found to react slowly to give a product of, as yet, unknown constitution. In this connection, it is of interest to note that by-products are formed in all the reactions but their identification has proven difficult because of their lability. From hex-1-ene, however, treatment of the by-product with base yields a ketone which has been assigned structure (**7**) on the basis of its spectroscopic properties. These by-products are conveniently and selectively removed by treatment with magnesium under Grignard reaction type conditions.



SCHEME. Reagents: i, EtO^-–EtOH; ii, NaH–*p*-$MeC_6H_4SO_2Cl$; iii, Pd–C–H_2; iv, CrO_3; v, OH^-–H_2O; vi, Bu^n_3SnH.

The 1-hydroxy-2,2,2-trichloroethyl unit of the ene adducts can readily be transformed into other, more useful

---

§ The stereoselectivity in the reaction of chloral with (−)-β-pinene is discussed in the following communication.

types of functionality; the chemistry of (**2**) mainly has been studied in this respect, and preliminary results are summarised in the Scheme. Chloral is therefore the synthetic equivalent, in the ene reaction, of acetaldehyde, keten, carbon dioxide (ignoring the need for the reduction of the C=C), and glyoxylic acid derivatives.

We thank the S.R.C. for financial support (to B.W.).

(*Received*, 14*th March* 1977; *Com.* 249.)

---

[1] Review: H. M. R. Hoffmann, *Angew. Chem. Internat. Edn.*, 1969, **8**, 556.

[2] J. M. Conia and P. Le Perchec, *Synthesis*, 1975, 1.

[3] For example, see: N. C. Yang, D.-D. H. Yang, and C. B. Ross, *J. Amer. Chem. Soc.*, 1959, **81**, 133; A. T. Blomquist and R. J. Himics, *J. Org. Chem.*, 1968, **33**, 1156; E. I. Klimova, N. D. Antonova, and Yu. A. Arbuzov, *Zhur. org. Khim.*, 1969, **5**, 1345; E. I. Klimova and Yu. A. Arbuzov, *ibid.*, 1968, **4**, 1787; 1969, **5**, 647; *Doklady Akad. Nauk S.S.S.R.*, 1970, **190**, 102.

[4] (a) B. B. Snider, *J. Org. Chem.*, 1974, **39**, 255; (b) 1976, **41**, 3061.

[5] (a) M. Vilkas, G. Dupont, and R. Dulou, *Bull. Soc. chim. France*, 1955, 799; (b) E. I. Klimova, N. D. Antonova, and Yu. A. Arbuzov, *Zhur. org. Khim.*, 1969, **5**, 1348.

[6] J. Colonge and A. Perrot, *Compt. rend.*, 1954, **239**, 541; *Bull. Soc. chim. France*, 1957, 204; 658.

[7] H. Fritz, C. D. Weis, and T. Winkler, *Helv. Chim. Acta*, 1975, **58**, 1345.

[8] E. I. Klimova, E. G. Treschova, and Yu. A. Arbuzov, *Doklady. Akad. Nauk S.S.S.R.*, 1968, **180**, 865.