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ACETOLYSIS OF THE TRIFLUOROMETHANESULPHONATES OF *SYN*-12-HYDROXYALDRIN AND *SYN*-12-HYDROXYISODRIN AND THEIR DIHYDRO DERIVATIVES

REDUCTION IN NEIGHBOURING DOUBLE BOND PARTICIPATION EFFECTED BY CHLORINE SUBSTITUENTS

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Abstract—Acetolysis rates of the trifluoromethanesulphonates of two geometric isomers of hexachlorotetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodeca-4,9-dien-12-ol (**6**, **8**; *syn*-12-hydroxyaldrin, *syn*-12-hydroxyisodrin) and of two geometric isomers of hexachlorotetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodec-9-en-12-ol (**7**, **9**; *syn*-12-hydroxy-4,5-dihydroaldrin, *syn*-12-hydroxy-4,5-hydroisodrin) have been determined. The results show that neighbouring double bond participation by a —ClC=CCl— grouping that is juxtaposed to an incipient secondary carbenium ion (> CH · OSO$_2$CF$_3$) is negligible compared with that seen in the non-chlorinated prototypes containing an analogously-situated —CH=CH— grouping (e.g. **4**). The products of acetolysis of **8** and **9** were acetates of the original carbocyclic ring system, but the acetolysis of **6** at 64° yielded, as the sole rearranged product, a hexachloropentacyclo[7.2.1.0^{2,8}.0^{3,5}.0^{4}]dodecen-6-yl acetate (**10**). The major products of acetolysis at 64° of **7** were a mixture of two isomeric hexachlorotetracyclo[6.3.1.0^{2,9}.0^{3,7}]dodecen-11-yl acetates (**17**, **18**) and a hexachloropentacyclo[6.4.0.0^{2,10}.0^{3,7}.0^{9,11}]dodec-4-ene (**15**); these were each formed *via* an initial bridging reaction and subsequent rearrangement steps. The factors that dictate the nature of products formed from each compound are discussed, and probable pathways to each are delineated.

We have recently reported the first total synthesis of **3**, a minor mammalian metabolite of DIELDRIN (HEOD).[1] In the key step, the trifluoromethanesulphonate of *syn*-12-hydroxydieldrin (**1**) was subjected to acetolysis at 95° to yield a labile bridged acetate, **2**, which was readily converted *in situ* into the bridged ketone, **3**. The corresponding tosylate, however, was found to be inert to acetolysis at 120° for 7 days.[1] From this result it was clear that the presence of the chlorine substituents and/or the epoxy group in **1** had resulted in a large rate retardation in the neighbouring double bond participation, for the brosylate of the non-chlorinated tetracyclic prototype, **4**, had been observed by Winstein and Hansen[2] to react readily at 50° to yield mainly (88%) a bridged acetate, **5**. Although rate and product data for variously substituted alkenes attesting to neighbouring double bond participation are well known,[3] only a few examples of such participation by the less nucleophilic chlorinated alkenes are known, and all data relate to product studies.[4] We have therefore conducted rate—and product—studies of the acetolysis of **7** with a view to determining the magnitude of the rate retardation in neighbouring double bond participation due to the chloro substituents therein. This compound, **7**, lacks the epoxy group of **1**, and thus a direct comparison can be made between its rate of acetolysis and that of its non-chlorinated prototype, **4**. The geometric isomer of **7** has also been studied, since this alkene, **9**, provided a useful reference compound in which the inductive effects of the pentachlorinated moiety would be operative but bridging of the chlorinated alkene grouping was precluded. The acetolyses of the alkenes **6** and **8** corresponding to **7** and **9** have also been studied, with a view to determining the effect of the extra alkene grouping on the rate and products of the solvolyses. We here describe the preparation of **6**, **7**, **8** and **9** from *syn*-12-hydroxyaldrin§ (**6**; OH for OSO$_2$CF$_3$) and *syn*-12-hydroxyisodrin§ (**8**; OH for OSO$_2$CF$_3$) which were available from a previous synthesis,[5] the identification of the major products of their acetolyses, and discuss the possible pathways leading to them. We also comment on the observed acetolysis rates.

RESULTS

Preparation of substrates and reference compounds. Authentic samples of acetates were prepared from the corresponding alcohol by treatment with acetic anhydride/pyridine and were characterized by their spectral data (NMR, IR, MS). The trifluoromethanesulphonate derivatives were prepared from the corresponding alcohol by the standard procedure.[7] Dihydro compounds were prepared *via* hydrogenation of the corresponding alkene.

Kinetic studies. The rates of acetolysis of **6**, **7**, **8** and **9** (Table 1) were determined under pseudo-first-order

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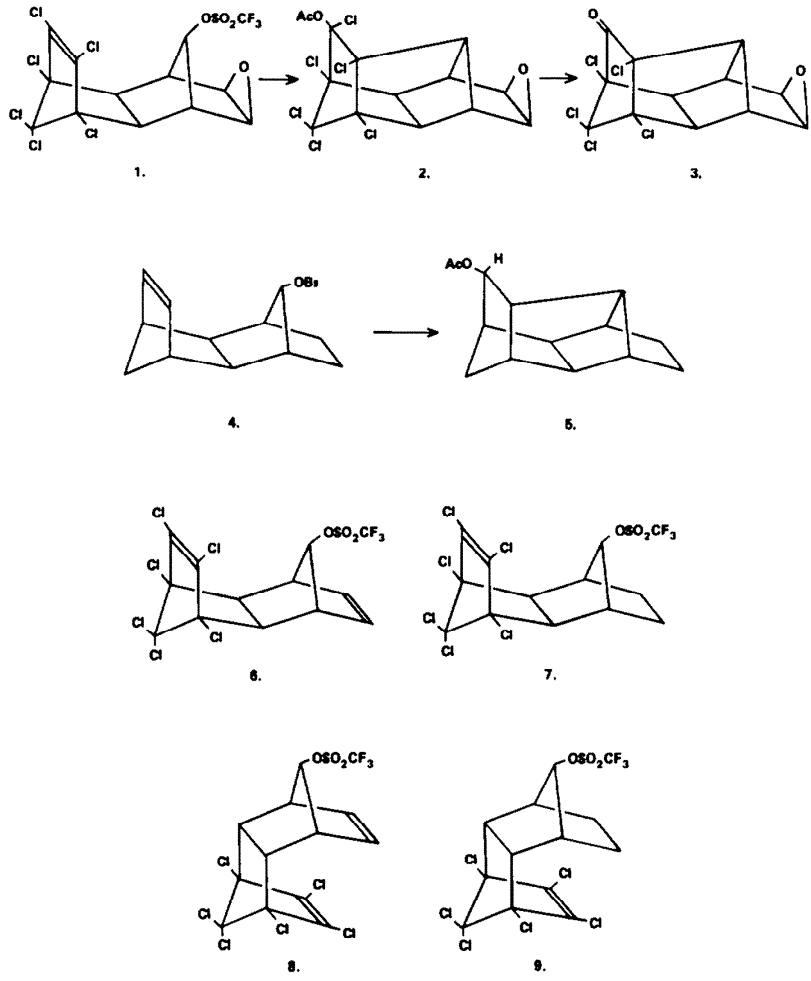
§ The systematic names of these compounds are very lengthy. Here, in line with current usage,[6] trivial names using aldrin and isodrin as parent compounds are used, with substituents numbered according to the numbering system of their von Baeyer-IUPAC systematic names.



conditions in 0.03 M solutions of sodium acetate in glacial acetic acid containing 1% acetic anhydride.[8] For **6** and **7** the rate constants at 64° were obtained by following the disappearance of the triflates by GLC. Because the rates of acetolysis of **8** and **9** were very much slower, the rate constants could not be obtained in the same manner. However, from the amounts of **8** and **9** recovered from their acetolysis mixtures after 300 hr and 220 hr respectively approximate values for the rate constants at 118° were obtained. Also included in Table 1 are extrapolated literature rate data[7] for 7-norbornanyl triflate.

Product studies. The products obtained from the acetolyses of **6**,**7**, **8** and **9** are shown in Schemes 1–4 respectively.

Table 1. Rates and relative rates of acetolysis of trifluoromethanesulphonates (triflates)

	10^5 k_{obs} (sec^{-1})		k_{rel}	
Compound	64°	118°	64°	118°
6	3.1		72	
7	10.4		240	
8		*ca* 0.005		*ca* 0.001
9		*ca* 0.02		*ca* 0.0007
7-norbornanyl triflate	0.43*	28*	1	1

* Extrapolated data from reference 7.

Acetolysis of the triflate of *syn*-12-hydroxyaldrin (**6**) at 64° yielded a single acetate. The structure of this compound, **10**, was deduced from its spectral characteristics. Its IR spectrum showed a band at 1605 cm^{-1}, which is characteristic of the ClC=CCl group, and another at 1745 cm^{-1} due to the acetate group. The absence in the PMR spectrum (Fig. 1) of any bands due to olefinic protons and the relatively high-field resonances of three of the protons (δ 1.70–2.25 ppm) suggested the presence of a 3-membered ring. This was substantiated by the appearance of a double doublet (J = 7 and 4 Hz) at 5.10 ppm, which is very characteristic of an *exo* proton geminal to an oxygen function in tricyclo[3.2.0.0.^{2,7}]heptane derivatives (**12** X = OR).[9] Moreover the coupling constants of the protons of **10** were very similar to those of **12**, though the extent of splitting of many of the signals of **10** was much lessened as would be expected of a derivative of **12** that contained two distal *exo*, *exo* substituents in the form of a fused ring. By-products of this reaction were sought by TLC and GLC, but none were found. The spectral properties of the corresponding alcohol (**10**; OH for OAc) were also consistent with the above assignment. This compound was obtained during chromatography over alumina of the crude acetolysis product. The on-column hydrolysis of the acetate (**10**) may have occurred *via* an $A_{AL}1$ mechanism with the 'bishomo-

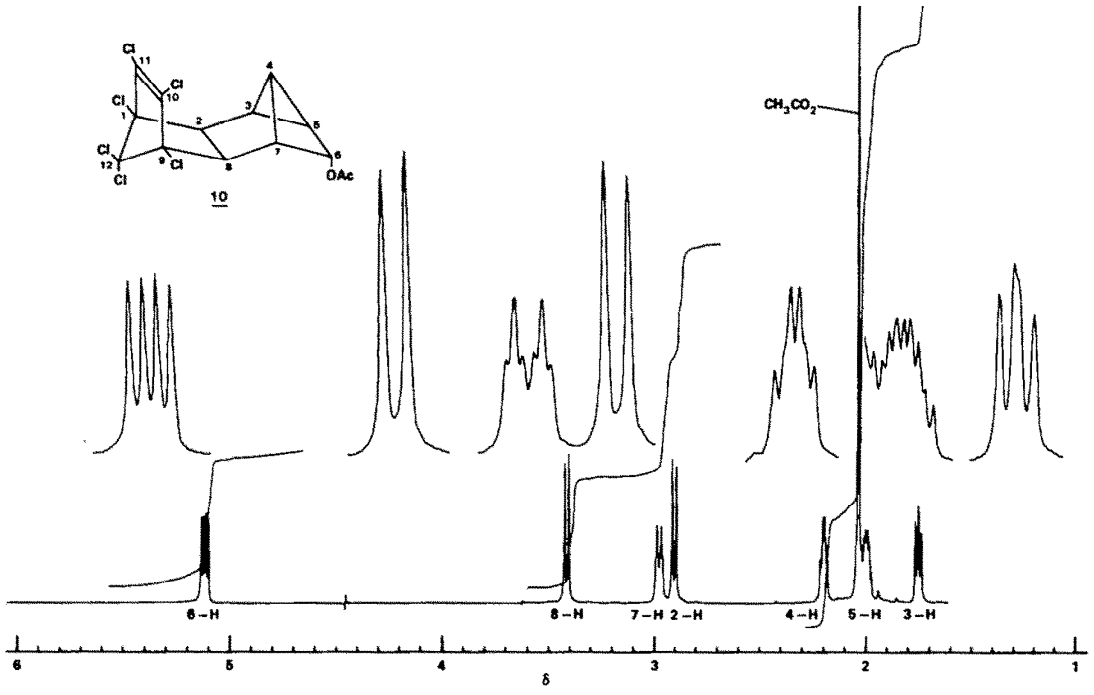
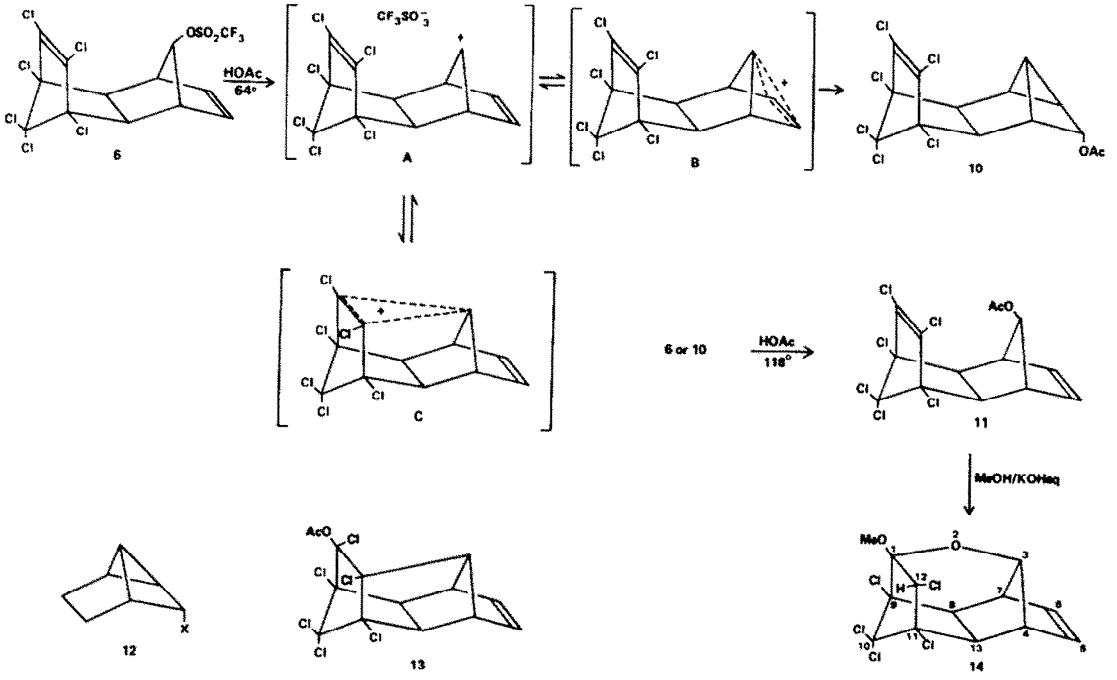


Fig. 1. The PMR spectrum ($CDCl_3$) of the acetolysis product, **10**, of the trifluoromethanesulphonate of *syn*-12-hydroxyaldrin (**6**).

cyclopropenyl' cation B as intermediate (Scheme 1). When acetolysis of **6** was conducted at 118°C an isomeric acetate was formed. Monitoring of the reaction mixture showed that **10** was an intermediate, and indeed **10** rearranged under the same treatment to the same product. The structure of this isomer was readily assigned as *anti*-12-acetoxyaldrin (**11**) by virtue of its symmetrical nature as adduced from its PMR spectrum and its non-identity with the known[10] isomeric *syn* compound (**6**; OAc for OSO_2CF_3). The *anti* assignment of the acetoxy grouping was confirmed by the isolation of a bridged ether (**14**) when the acetate (**11**), in the hope of effecting saponification to the corresponding alcohol, was treated with 90% methanolic potassium hydroxide. The structure of **14** was deduced from its spectral data, notably its ^1H- and



Scheme 1.

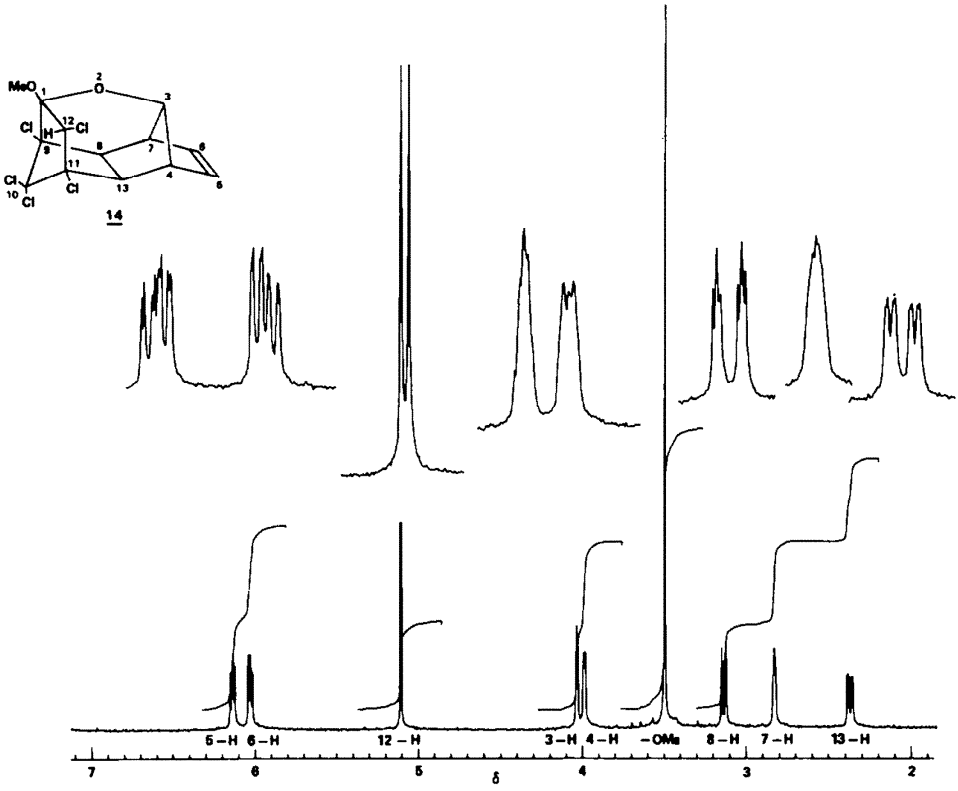
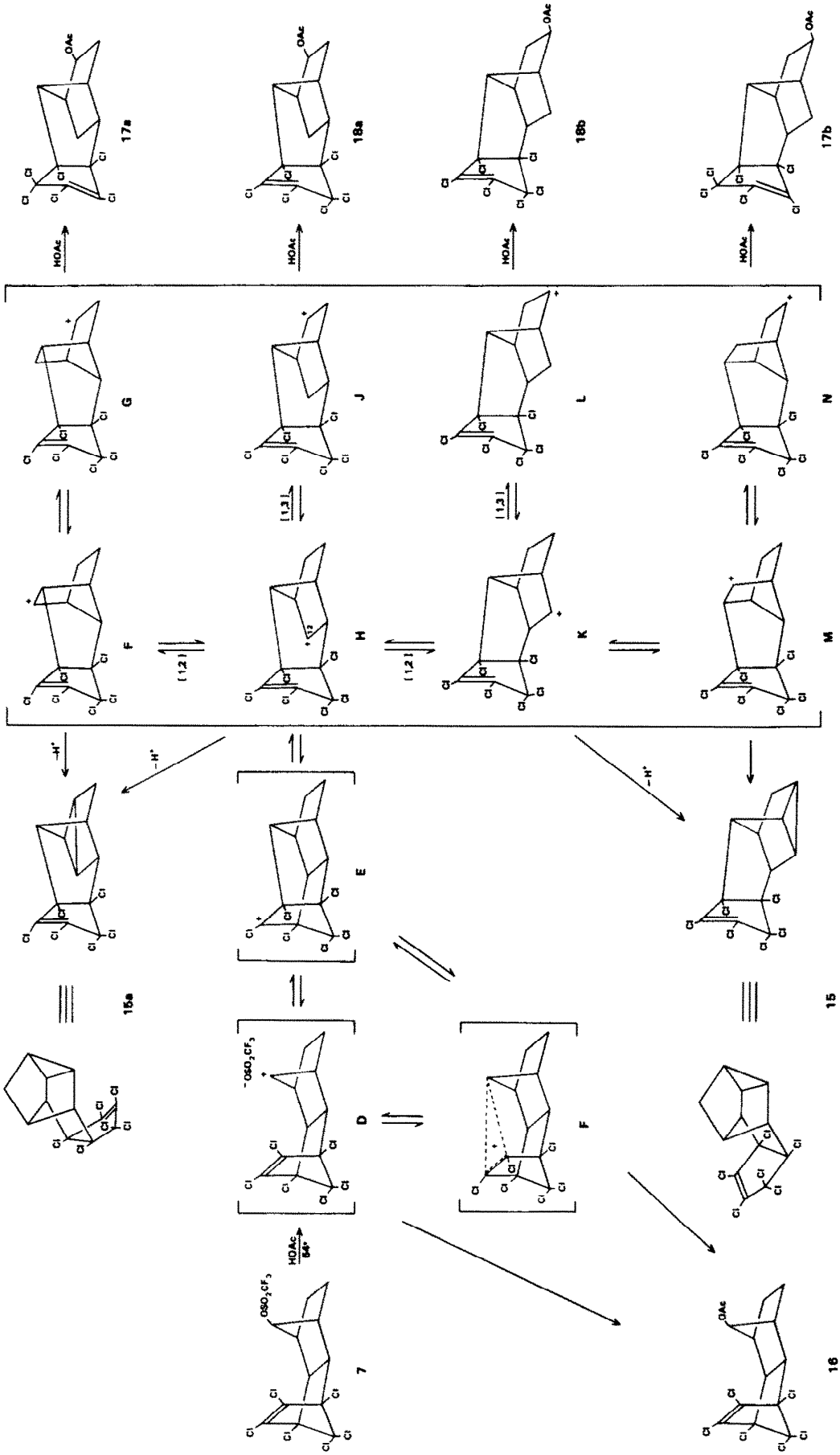


Fig. 2. The PMR spectrum ($CDCl_3$) of the bridged ether (**14**) formed by base treatment of *anti*-12-acetoxyaldrin (**11**).

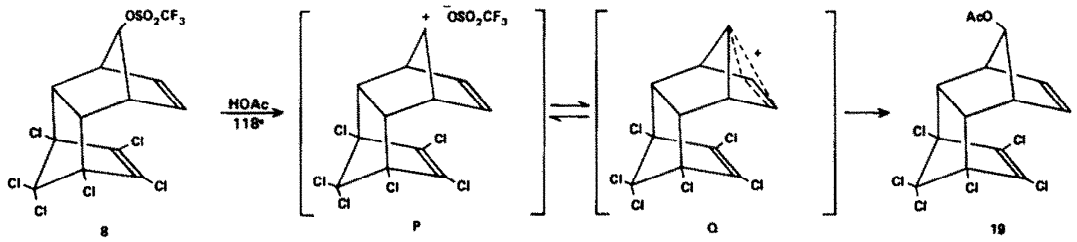
^{13}C-NMR spectra. The CHCl grouping was assigned the configuration shown in **14** by virtue of the presence of a 'W' coupling (J = 2.5 Hz) between the CHCl proton and one of the bridge protons (Fig. 2). This product was presumably formed *via* methanolysis of initially-formed α-chloro ether (**14**; Cl for OMe), the product of transannular addition of the 12-hydroxy group to the juxtaposed double bond. In this initial process, protonation of the intermediate carbanion formed by addition of the 12-oxyanion to the double bond must have occurred on its *exo* face; poor accessibility of the *endo* position and the presence of the bridging oxygen atom are two possible factors contributing to this regioselective protonation. Precedent for this bridging reaction and regioselective *exo* protonation exists: a recent report[11] has described the t-butoxide-catalysed formation of an analogous bridged ether from the 'inside' alcohol corresponding to **4** (OH for OBs). There, though, the oxyanion addition to the weakly electrophilic alkene grouping (—CH=CH—) required stronger conditions (80°/24 hr) than those (25°/16 hr) that were sufficient for the oxyanion addition to the more electrophilic —CCl=CCl— grouping in **11**.

By contrast, acetolysis at 64° of **7**, the dihydro derivative of **6**, yielded four major products (**15–18**; Scheme 2). These were readily separated into two fractions by column chromatography (Al_2O_3). The more polar fraction was further separated into two components by preparative TLC on silica. One of these latter two components was *syn*-12-acetoxy-4,5-dihydroaldrin (**16**; 22%), identified by comparison with authentic material. The other was found to be a 3:1 mixture of two acetates (25%) which were not separable by TLC or GLC. The mixture gave a band in the IR spectrum at 1622 cm^{-1} (ClC=CCl) and a molecular ion at *m/e* 422 (6 Cl atom pattern) in the mass spectrum. The PMR spectrum (Fig. 3) showed, in addition to a singlet at δ 2.05 (CH_3CO_2—), two sets of nine one-proton signals in the ratio 3:1. The splitting patterns for the two sets were the same, and after extensive decoupling experiments on the signals from the major component, three discrete fragments between which no coupling greater than 2 Hz was observed were identified, *viz* —$CHCH_2CH$—, —$CHCH_2CHOAc$— and —CH. The only skeleton consistent with these PMR data was a 5-*exo*,7-disubstituted-2-*exo*-acetoxynorbornane (Fig. 3). On the basis of all the spectral information, the structures of the two components of the 3:1 mixture could be assigned no further than being two of the acetates **17a**, **17b**, **18a**, **18b**.

The less polar fraction was shown to consist of a single pentacyclic chlorohydrocarbon (46%) by TLC, GLC, and PMR, and it was assigned structure **15** on the basis of the following data. It exhibited a band in the IR spectrum at 1626 cm^{-1} (ClC=ClC), but none in the carbonyl region, and gave a molecular ion at *m/e* 362 (6 Cl atom pattern) in the mass spectrum. The PMR spectrum (Fig. 4) showed: a broad doublet (J = 4.9 Hz) at 1.31 ppm (two cyclopropyl protons) that was coupled with a double triplet at 1.48 ppm (one cyclopropyl proton); an AB system at 1.63 and 1.72 ppm (J = 11.4 Hz) due to a methylene group; and three broad singlets at 2.55, 2.78 and 2.83 ppm due to the remaining methine protons. The assignments shown in Fig. 4 were deduced from extensive decoupling experiments. As can be seen from Scheme 2, **15** is a tricyclene derivative to which is fused, centro-symmetrically, a hexachlorinated cyclo-



Scheme 2.



Scheme 3.

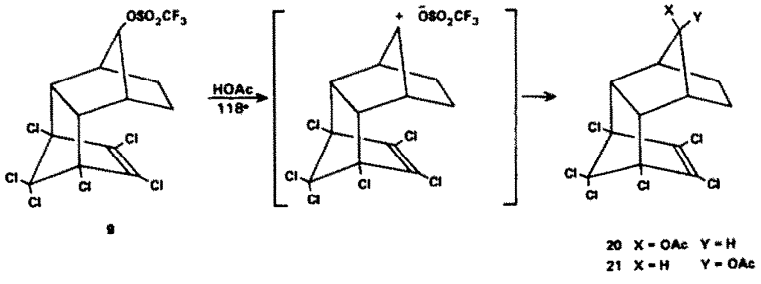
pentene ring system. In **15**, the bridgehead chlorine atoms are seen to be juxtaposed and equidistant from two of the cyclopropyl hydrogens (9- and 10-H) which in the PMR spectrum resonate at the same frequency. An alternative structure for **15** in which the non-symmetrical chlorinated cyclopentene ring was juxtaposed towards these two hydrogens (**15a**) seemed less likely on the basis of the congruent PMR data. (This congruency persisted when solvent C_6D_6 was used instead of $CDCl_3$, even though virtually all of the signals were markedly shielded or deshielded, i.e. $\Delta\,\delta$ (C_6D_6—$CDCl_3$) $\simeq \pm 0.5$ Hz; this essentially ruled out an arbitrary coincidence of the shifts of these two protons in $CDCl_3$, and confirmed their near-identity of environment.)

The sole product of acetolysis of the triflate of *syn*-12-hydroxyisodrin (**8**) was *anti*-12-acetoxyisodrin (**19**), which was identified by comparison with an authentic sample. The corresponding dihydrotriflate (**9**) also yielded the acetate of inverted configuration, i.e. *anti*-12-acetoxy-4,5-dihydroisodrin (**20**), but only as a minor (16%) product. The major (84%) product was the acetate of retained configuration, **21**. These products were characterized by comparison with authentic samples.

DISCUSSION

The rate of acetolysis of **4** is faster by a factor of $10^{10.6}$ than that of 7-norbornanyl brosylate.[2] This attests to neighbouring group participation on a scale comparable to that seen in the legendary *anti*-7-norbornenyl derivatives, where rate enhancements are *ca* 10.[11] The rate of acetolysis of the hexachlorinated tetracyclic triflate, **7**, however, was found to be only about 10^2 greater than that of 7-norbornanyl triflate (Table 1). This modest rate enhancement could be due either to vestigial neighbouring double bond participation, or to steric decompression in the acetolysis of **7**.

The dehydro derivative of **7**, **6**, has a similar rate of acetolysis to that of **7** (Table 1), and this is in dramatic contrast to the rate difference of 10^5 between 7-norbornanyl and *syn*-7-norbornenyl tosylates.[12] Furthermore, whilst the major product from *syn*-7-norbornenyl tosylate involves rearrangement to a bicyclo[3.2.0] system,[9] none of the corresponding rearranged product from **6** was detected, and therefore less than 1% of this product can have been formed. Clearly the pathway predominant in the acetolysis of *syn*-7-norbornenyl tosylate, *viz* the rate-enhancing formation of an allylically stabilized carbenium ion leading to a [3.2.0] system, has been retarded by the fused hexachlorinated fragment in **6** by a factor of at least 10^5. The sole (> 99%) product of the acetolysis of **6** (at 64°) was the pentacyclic acetate, **10**. The probable pathway to this product is shown in Scheme 1. The non-classical ion, **B**, is the progenitor of **10** and is formed from the ion pair **A**. Ion **C**, the non-classical ion derivable by neighbouring double bond participation in the acetolysis could be involved, but is not required to account for the product. The non-classical ion **B** is analogous to that formed in the solvolysis of *anti*-7-norbornenyl derivatives, and its fate provides an interesting comparison with that of its prototype. There the sole product of acetolysis is the *anti*-7-acetate,[13] though in studies with a range of nucleophiles and solvents Winstein *et al.* and others[14] have shown that in some cases very small yields of tricyclic products of structure **12** are formed. Those studies revealed that the C_7 to C_2 reactivity of the non-classical ion was *ca* 300:1. In ion **B** distal approach by solvent at the apical carbon is presumably hindered by the chlorinated fragment, and exclusive attack at "C_2" occurs to yield the *endo* acetate, **10**. This prevention of distal attack may not be wholly steric, for neighbouring double bond participation in **B** could have led to non-classical ion **C**. If so, **10** may have been formed by solvent attack at the most accessible position of the equilibrating non-classical ions **B** and **C**. The solvolytic reactivity of the



Scheme 4.

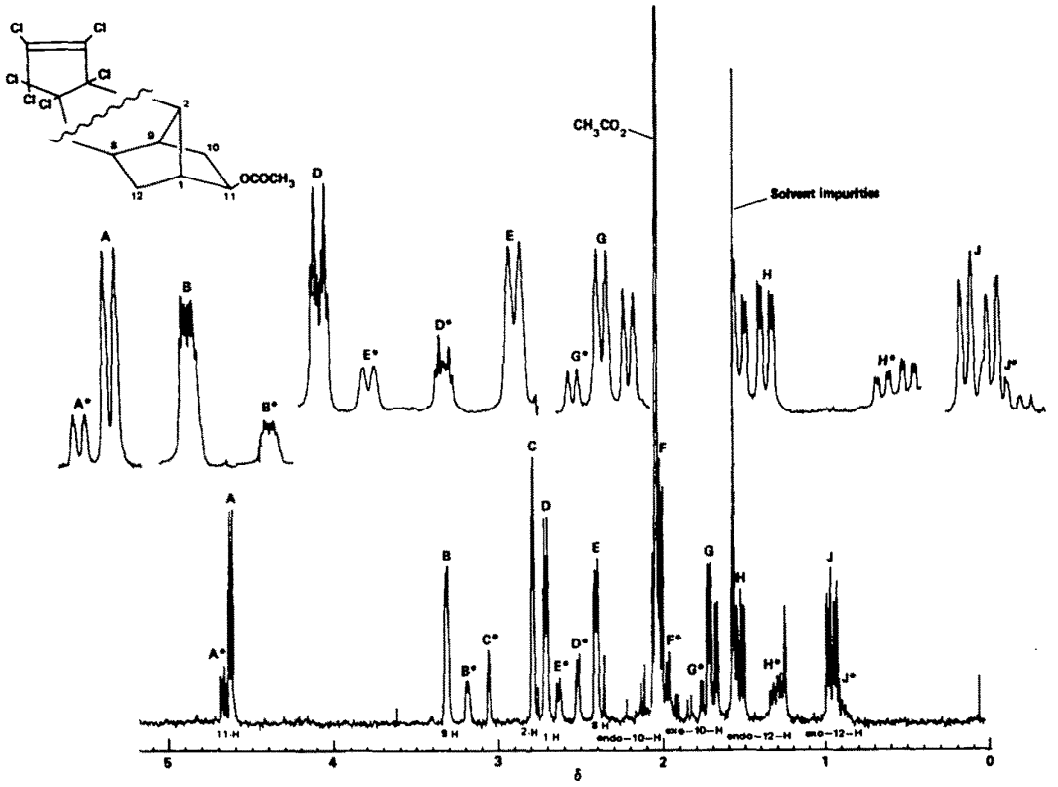


Fig. 3. The PMR spectrum ($CDCl_3$) of the 3:1 mixture of two acetates formed in the acetolysis of the trifluoromethanesulphonate of *syn*-12-hydroxy-4,5-dihydro-aldrin (7). The chemical shifts of the major and minor products are denoted, respectively, by A–J and A*–J*.

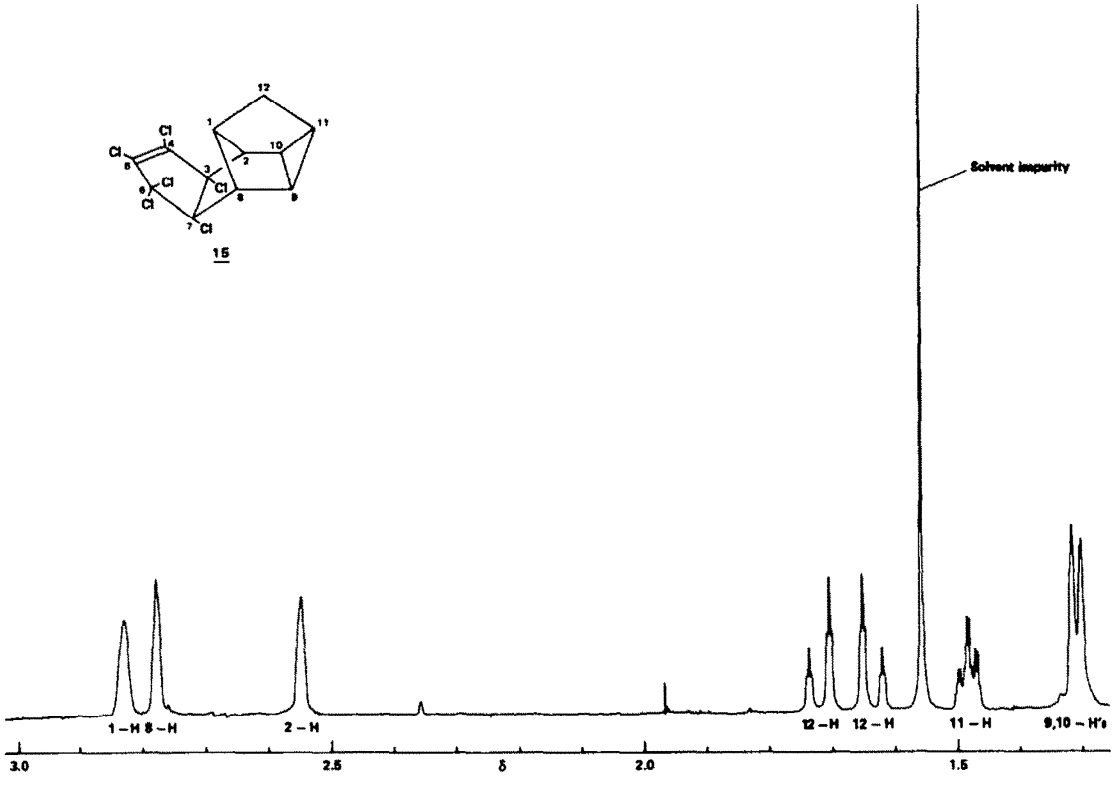


Fig. 4. The PMR spectrum ($CDCl_3$) of the chlorohydrocarbon (15) formed in the acetolysis of the trifluoromethanesulphonate of *syn*-12-hydroxy-4,5-dihydroaldrin (7).

prototypes of **10**, the tricyclo derivatives **12**, is very high, being 10^{16} greater than that of 2-*endo* substituted norbornanes.[9] Indeed, the *p*-methoxybenzoyl derivative of *endo*-tricyclo[3.2.0.0.^{2,7}]heptan-6-ol (**12**, R = O·CO·C_6H_4OMe) suffered ready solvolysis at 25°.[9b] Acetate **10** is a distally *exo,exo*-disubstituted derivative of **12** and it was recovered from a reaction at 65°. Although its solvolysis would be expected to be slower owing to inductive effects than its prototype (**12**, X = OAc), it seemed feasible that more severe solvolytic conditions would lead either to a bridged acetate (**13**), formed *via* non-classical ion **C**, or to the product of apical attack of non-classical ion **B** (the *endo* attack of which leading only to reversion to starting material). Accordingly, **10** was subjected to acetolysis at 118°. It was found to be labile, but none of the bridged product (**13**) was detected. The sole product was *anti*-12-acetoxyaldrin (**11**), the product of apical attack upon non-classical ion **B**. In summary the non-chlorinated double bond of **6**, whilst having no involvement in the rate-determining step of the acetolysis, has an overriding influence on the product-forming pathways, yielding, *via* ready formation of ion **B** from **A** or **C**, products **10** or **11** according to the temperature.

For **7**, the dihydro derivative of **6**, the acetolysis products are more complex, and result from extensive rearrangement reactions. Probable pathways to the products (**15–18**) obtained are shown in Scheme 2. The initial ionization gives the ion pair **D** (or the non-classical ion **F**; cf. Scheme 1). Attack on this intermediate by solvent on the less hindered side of the apical carbon gives the acetate of retained configuration (**16**; 22%) but the major pathway to products is *via* the rearranged ion **H**. This ion, formed either directly from **D** or *via* ion **E**, undergoes a [1, 2]-sigmatropic rearrangement to ion **K**, which loses a proton to give the chlorohydrocarbon **15** as the major product (46%). This rearrangement pathway is somewhat surprising since it involves the relative movement of two bulky portions of the molecule and the migration of an electron-poor σ-bond, and must be accounted for by the release of the strain that arises from the proximity of the chlorinated ring and the C-12 methine grouping in **H**. Inspection of models reveals that an analogous steric interaction is particularly great in the chlorohydrocarbon corresponding to **15** which would arise by the loss of a proton from **H**, which may explain why none of this product (**15a**) is observed. Ions **H** and **K** are too sterically hindered for direct attack by solvent to occur. However, both can undergo [1, 3]-hydride shifts to give **J** and **L** respectively, which may then yield the acetates **18a** and **18b**. An alternative pathway open to **H** and **K** involves the well-known [1, 2]-sigmatropic rearrangement of the norbornane skeleton. Thus ion **H** could be converted to **F** which, after a [1, 3]-hydride shift (to **G**) and solvent attack, yields the acetate **17a**. (Depicted in Scheme 2 as the enantiomer of the product formed from **G**, for ease of comparison with **18a**.) In the same way **K** could be converted *via* ions **M** and **N** into **17b**. (Again, depicted as its enantiomer.) The only difference between **17a** and **18a**, and between **17b** and **18b**, lies in the position of the double bond in the chlorinated ring. It should be noted that although these alternative pathways lead to two acetates **17a** and **17b** that are non-identical with **18a** and **18b**, the chlorohydrocarbons formed by proton loss from **F**, and from **M** are identical with those derived, respectively, from **H** and **K**. It can be seen that there are then, in principle, four acetates derivable from ion **H**, *viz* **17a**, **17b**, **18a**, **18b**, but only two (combined yield 25%) have been observed. Unfortunately it has not been possible on the evidence available to assign to either of them any one of these four structures unambiguously.

The rates of acetolysis of **6** and **7**, relative to 7-norbornanyl triflate, may be affected by three factors: the inductive effect of the hexachlorinated fragment, which would be expected to decrease the rates; possible neighbouring group participation of the dichlorinated double bond, which would increase them; and steric interaction between the chlorinated double bond and the hydrogen at C-12, which would also increase them. Some further information regarding the effect of the hexachlorinated fragment on the rates of solvolysis is available from studies on the acetolyses of **8** and **9**, geometrical isomers of **6** and **7** in which the said fragment is located on the underside of the norbornane ring systems. Since neither steric decompression nor neighbouring double bond participation is possible, the rates of acetolysis of **8** and **9** should provide a unique measure of the extent of the electron-withdrawing properties of the hexachlorinated fragment. Both **8** and **9** were found to be much less reactive than 7-norbornanyl triflate, and, because of their unreactive nature, only estimates of their rates of acetolysis were possible. At 118°, **8** and **9** were *ca* 500-fold and *ca* 1400-fold, respectively, less reactive than 7-norbornanyl triflate (Table 1). The sole acetolysis product of **8** was the acetate of inverted configuration, **19**, and this was probably formed from the ion pair **P** *via* the non-classical ion **Q** (Scheme 3). Again, the non-chlorinated double bond (as in the acetolysis of **6**) has a dominating influence in the product-forming pathway by interacting with the ion pair in **P**. By contrast, the acetate of retained configuration, **21**, was the major acetolysis product of **9**, though the acetate of inverted configuration, **20**, was also formed. Gassman and Richmond[15] also observed a mixture of products of retained and inverted configuration in the acetolysis of 7-norbornanyl tosylate.

The rate datum for **9** can also be compared, guardedly, with that of **7**. Using the relative rate factors of each that were determined using 7-norbornanyl triflate as reference (Table 1), **7** is more reactive towards acetolysis than **9** by a factor of *ca* 10^5. Accepting that **9** is a better model than norbornanyl triflate for assessing whether neighbouring double bond participation in the acetolysis of **7** is occurring or not, the estimate of the rate enhancement of 10^5 is still not large enough to affirm this point. A similar doubt exists regarding the explanation of the rate enhancement of *ca* 10^3 of the saturated counterpart of **4** over 7-norbornanyl brosylate.[16] There the increase in rate could be due either to steric decompression caused by the 'inside' hydrogen, or to neighbouring group participation involving a non-classical hydrogen-bridged species. Winstein and Hansen[16] preferred the latter explanation, since the intervention of the bridged species better explained the products of the reaction, all of which resulted from an intramolecular 1,5-hydrogen shift.

Although conclusions regarding the reasons for the rate enhancements observed are equivocal, these studies have shown that the introduction of chlorine

substituents into a molecule drastically alters both rates and sites of reactivity. Since chlorine substituents may easily be removed from compounds of this type, these reactions may be useful as prototypes for the synthesis of difficulty-accessible polycyclic hydrocarbons.

EXPERIMENTAL

Methods: M.ps were determined on a Kofler hot-stage and are uncorrected. IR spectra were recorded for solns in CH_2Cl_2 or CCl_4 on a Unicam SP200 spectrophotometer. ^{13}C and ^1H-NMR (Table 2) were obtained for solns in $CDCl_3$ using a Bruker WH-360 spectrometer operating at 90.5 MHz and 360 MHz respectively. Chemical shifts are reported in order of increasing δ (ppm), with multiplicities: s = singlet; d = doublet; dd = double doublet; dt = double triplet; t = triplet; q = quartet; m = multiplet; br = broad signal. Mass spectra were recorded on a Kratos MS50 spectrometer operating at 70 eV. Thin-layer chromatography (TLC): plates (alumina, 60 F_{254}, type E or silica gel, 60 F_{254}) were obtained from E. Merck. Chlorinated compounds were detected on TLC as black spots when the plates were sprayed with a soln of $AgNO_3$ (1 g) in water (5 ml), 2-phenoxyethanol (10 ml) and acetone (185 ml) containing 1 drop of 100 vol H_2O_2 and exposed to UV light.[17] GLC; solns in ether or hexane were injected directly onto a 5% OV1 column 1.1 m × 9 mm (Column A) or onto a 5% OV210 column 1.1 m × 9 mm (Column B) using a Pye-104 chromatograph equipped with a flame-ionization detector. Quantitative GLC was achieved using a Perkin–Elmer peak integrator. Retention times are listed in Table 2.

Materials. Alumina ("CAMAG" MFC) and silica gel (MFC, 100–200 mesh) for column chromatography were obtained from Hopkin and Williams. The alumina was deactivated to Brockman activity II[18] prior to use. Trifluoromethanesulphonic anhydride was purchased from Aldrich and was stored at 4° in a desiccator over self-indicating silica gel. Pyridine was dried over BaO, distilled and stored over calcium hydride. All other reagents were 'Analar' grade (BDH Chemicals). Hexane refers to the hexane fraction from petroleum, b.p. 67–70° (BDH). *syn*-12-Hydroxyisodrin, *anti*-12-hydroxyisodrin, and *syn*-12-hydroxyaldrin, were prepared as previously described.[5]

Kinetic studies. Each triflate (**6**, **7**, *ca* 0.02 mmole) was dissolved in the acetolysis mixture[8] (0.03 M anhyd NaOAc in glacial AcOH containing 1% Ac_2O prepared 1 week before use; 10 ml) and heated in a thermostat oil bath at 64°. Aliquots (0.5 ml) of the mixtures were removed at set intervals, quenched with hexane (0.5 ml) and shaken with water (1 ml). The treated aliquots were left tightly stoppered for 0.5 hr at room temp to allow partitioning between the phases to come to equilibrium. The concentration of triflate in the hexane layer was determined by GLC via direct injection onto column A. In duplicate runs, good straight-line plots of log (concentration) against time were obtained over 7 and 10 half-lives for **6** and **7** respectively. In the acetolysis of **6** the rate of appearance of the product, **10**, was determined in a like manner to be the same as the rate of disappearance of **6**.

4,5-*Dihydro*-syn-12-*hydroxyaldrin* (**7**; OH for OSO_2CF_3). *syn*-12-Hydroxyaldrin (560 mg; 1.44 mmole) was dissolved in EtOAc (50 ml) containing glacial AcOH (2 ml) and was stirred vigorously under H_2 over 10% Pd—C (200 mg). The reaction ceased after 40 ml of H_2 had been taken up (theoretical uptake = 32 ml). The catalyst was filtered off and washed with EtOAc (2 × 15 ml). The combined filtrate and washings were concentrated to small bulk (*ca* 1 ml), treated with toluene (20 ml) and re-concentrated to dryness. The residual yellow gum (540 mg) did not smell of AcOH. Recrystallization from

Table 2. Proton magnetic resonance (PMR) chemical shift data and gas-liquid chromatography (GLC) retention times of 12-oxygenated derivatives of aldrin, dihydroaldrin, isodrin and dihydroisodrin

Compound		PMR shift data in δ (ppm) (solvent = $CDCl_3$)					GLC relative retention times*	
		2 (7)	3 (6)	4 (5)	12	OH/ $OCOCH_3$	Column A	Column B
syn-12-hydroxyaldrin	**6**; OH for OSO_2CF_3	2.74	3.05	6.32	4.19	2.13	1.00	1.00
syn-12-acetoxyaldrin	**6**; OAc for OSO_2CF_3	2.78	3.16	6.15	4.95	1.94	1.21	
syn-12-trifloxyaldrin	**6**	2.87	3.33	6.29	5.13	—	1.54	
anti-12-acetoxylaldrin	**11**	3.06	3.12	6.30	4.66	2.17	3.50	
syn-12-hydroxydihydroaldrin	**7**; OH for OSO_2CF_3	2.73	2.30	x 2.10 n 1.20	4.08	1.50	1.12	
syn-12-acetoxydihydroaldrin	**16**	2.75	2.51	x 1.96 n 1.22	4.83	2.03	1.27	
syn-12-trifloxydihydroaldrin	**7**	2.85	2.70	x 2.11 n 1.45	4.99	—	0.79 0.90	
syn-12-hydroxyisodrin	**8**; OH for OSO_2CF_3	3.31	3.10	6.08	3.97	—	1.19	
syn-12-acetoxyisodrin	**8**; OAc for OSO_2CF_3	3.36	3.25	5.97	4.63	1.98	1.55	1.69
syn-12-trifloxyisodrin	**8**	3.33	3.45	6.04	4.72	—	1.14	1.98
anti-12-hydroxyisodrin	**19**; OH for OAc	3.61	3.86	5.92	3.85	—	1.49	
anti-12-acetoxyisodrin	**19**	3.45	3.05	5.98	4.53	2.07	1.27	1.50
syn-12-hydroxydihydroisodrin	**21**; OH for OAc	3.05	2.42	x 1.76 n 1.53	4.10	1.59	1.37	
syn-12-acetoxydihydroisodrin	**21**	3.13	2.62	x 1.66 n 1.55	4.73	2.07	1.63	1.96
syn-12-trifloxydihydroisodrin	**9**	3.10	2.84	x 1.79 n 1.69	4.87	—	1.20	1.83
anti-12-acetoxydihydroisodrin	**20**	3.37	2.55	1.54	4.96	2.09	1.38	1.62

* Relative to *syn*-12-hydroxyaldrin, which had retention times on Column A at 210° of 2.3 min and on Column B at 215° of 2.9 min.

pentane gave **7** (OH for OSO_2CF_3), as colourless prisms, m.p. 137.5–138° (lit.[19] m.p. 134.5–135°); IR: ν(CCl_4) 3640 (OH) and 1600 cm^{-1} (ClC=CCl); NMR: δ(^{1}H) ppm 1.20 (qbr J = 7 Hz; *endo*-4 (5)-H), 1.50 (sbr; OH), 2.10 (dbr, J = 7 Hz; *exo*-4 (5)-H), 2.30 (q, J = 3 Hz; 3(6)-H), 2.73 (s; 2(7)-H), 4.08 (sbr; 12-H); m.s.: *m/e* 345 ($M^+ - Cl$), 310 ($M^+ - 2Cl$), 309 ($M^+ - Cl$—HCl).

syn-12-*Acetoxyaldrin* (**6**; OAc for OSO_2CF_3). This previously described[10] compound was prepared from *syn*-12-hydroxyaldrin by treatment with Ac_2O/pyridine. Normal work up and recrystallization of the crude product from petroleum spirit (40–60°) gave **6** (OAc for OSO_2CF_3) as needles, m.p. 120–121° (lit.[8] m.p. 126–128°); m.s.: *m/e* 420 (M^+).

syn-12-*Acetoxy*-4,5-*dihydroaldrin* (**16**). Acetylation with Ac_2O/pyridine of **7** (OH for OSO_2CF_3) yielded **16**, m.p. 127–128° (sublimed) (lit.[18] m.p. 132–132.5°); IR: ν (CCl_4) 1730 (C=O), 1600 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm 1.22 (m; *endo*-4 (5)-H), 1.96 (m; *exo*-4 (5)-H), 2.03 (s; CH_3CO), 2.51 (sbr; 3 (6)-H), 2.75 (s; 2 (7)-H), 4.83 (s; 12-H); MS: *m/e* 422 (M^+), 387 (M – Cl), 327 (M – Cl—CH_3CO_2H).

Aldrin-syn-12-*triflate* (**6**). Trifluoromethanesulphonic anhydride (0.9 ml; 5.3 mM) was added dropwise at 0° to a stirred soln of *syn*-12-hydroxyaldrin (500 mg; 1.3 mmole) in dry pyridine (4.0 ml) in a flame-dried flask over 1 hr. The resultant deep-red, viscous soln was left to stand at 4° overnight and was then poured, with vigorous stirring into ice/water (50 ml). The yellow suspension was extracted with $CHCl_3$ (3 ×) and the extracts were dried (Na_2SO_4) and concentrated to small bulk (*ca* 5 ml). The concentrate was treated with toluene (50 ml) and concentrated to dryness to remove pyridine. Recrystallization from MeOH gave **6** as colourless microcrystals, m.p. 118.5–120° (dec). (Found: C, 30.6; H, 1.2; Cl, 40.8; F, 10.0%. $C_{13}H_7O_3SCl_6F_3$ requires: C, 30.4; H, 1.4; Cl, 41.5; F, 11.2%); IR: ν (CCl_4) 1600 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm 2.87 (s; 2 (7)-H), 3.33 (q, J = 2 Hz; 3 (6)-H), 5.13 (m; 12-H), 6.29 (m; 4 (5)-H); MS: *m/e* 510 (M^+), 457 ($M^+ - Cl$).

4,5-*Dihydroaldrin*-syn-12-*triflate* (**7**). The procedure used for the preparation of aldrin *syn*-12-triflate (**1**) was followed using 4,5-dihydro-*syn*-12-hydroxyaldrin (300 mg; 0.78 mmole), trifluoromethanesulphonic anhydride (0.75 ml) and pyridine (4.0 ml). Normal work-up gave the crude triflate as a yellow solid (330 mg), which was recrystallized from MeOH to give **7** (220 mg) as colourless crystals, m.p. 87–90°. (Found: C, 30.2; H, 1.7; Cl, 40.9; F, 10.6%. $C_{13}H_9O_3SCl_6F_3$ requires: C, 30.3; H, 1.8; Cl, 41.3; F, 11.1%); IR: ν (CCl_4) 1597 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm 1.45 (m; *endo*-4 (5)-H), 2.11 (m; *exo*-4 (5)-H), 2.70 (q, J = 2 Hz; 3 (6)-H), 2.85 (s; 2 (7)-H), 4.99 (m; 12-H); MS: *m/e* 512 (M^-), 477 ($M^+ - Cl$).

4,5-*Dihydro*-syn-12-*hydroxyisodrin* (**9**; OH for OSO_2CF_3). A soln of *syn*-12-hydroxyisodrin (350 mg; 0.92 mmol) in EtOAc/AcOH (2:1; 37 ml) was hydrogenated at room temp and pressure over 5% Pd—C (70 mg) until one mole-equiv of H_2 had been consumed (3 hr). The mixture was filtered through silica gel, and azeotroped with toluene *in vacuo* to yield a crystalline product. Recrystallization from MeOH gave **9** (OH for OSO_2CF_3) (247 mg; 70%) as needles, m.p. 187–188°. (Found: *m/e* 379.8851; $C_{12}H_{10}OCl_6$ requires: 379.8862); IR: ν (CCl_4) 3600 (OH), 1600 cm^{-1} (ClC=CCl); NMR: δ(^{1}H) ppm 1.53 (dbr, J = 10 Hz; *endo*-4 (5)-H), 1.59 (br; OH), 1.76 (dbr, J = 10 Hz; *exo*-4(5)-H), 2.42 (m; 3(6)-H), 3.05 (sbr; 2(7)-H), 4.10 (sbr; 12-H); MS: *m/e* 380 (M^+), 362 ($M^+ - H_2O$), 345 (M – Cl).

anti-12-*Acetoxyisodrin* (**19**). This previously described[10] compound was prepared from *anti*-12-hydroxyisodrin by treatment with Ac_2O/pyridine. Normal work-up and recrystallization of the crude product from MeOH gave **19** as platelets m.p. 218–219° (lit.[10] 217–218°); MS: *m/e* 420 (M^+), 360 (M – CH_3CO_2H), 325 (M – Cl—CH_3CO_2H).

syn-12-*Acetoxyisodrin* (isomer of **19**). This previously described[10] compound was prepared from *syn*-12-hydroxyisodrin by treatment with Ac_2O/pyridine. Normal work-up and recrystallization of the crude product from methanol gave 1,8,9,10,11,11-hexachloro-2,3-7,6-*endo*-2,1-7,8-*endo*-tetracyclo[6.2.1.1^{3,6}.0^{2,7}]dodeca-4,9-dien-*syn*-12-yl acetate as colourless needles, m.p. 171–173° (lit.[10] 172–173°); MS: *m/e* 420 (M^+), 385 (M – Cl), 360 (M – CH_3CO_2H), 325 (M – Cl—CH_3CO_2H).

anti-12-*Acetoxy*-4,5-*dihydroisodrin* (**20**). Using the conditions employed for the hydrogenation of *syn*-12-hydroxyisodrin, *anti*-12-acetoxyisodrin was reduced and the product was recrystallized to give **20** as platelets, m.p. 199° (dec). (Found: *m/e* 421.8965; $C_{14}H_{12}O_2Cl_6$ requires: 421.8968); IR: ν (CCl_4) 1743 (CO), 1600 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm 1.54 (sbr; *exo* and *endo*-4 (5)-H), 2.09 (s; CH_3CO), 2.55 (sbr; 3 (6)-H), 3.37 (dd, J = 3, 2 Hz; 2 (7)-H), 4.96 (t, J = 2 Hz; 12-H); MS: *m/e* 422 (M^+), 387 (M – Cl), 327 (M – Cl—CH_3CO_2H).

syn-12-*Acetoxy*-4,5-*dihydroisodrin* (**21**). Using the conditions employed for the hydrogenation of *syn*-12-hydroxyisodrin, *syn*-12-acetoxyisodrin was reduced and the product was recrystallized from hexane to give **21** as platelets, m.p. 197–200°. (Found: *m/e* 421.8962; $C_{14}H_{12}O_2Cl_6$ requires: 421.8968); IR: ν (CCl_4) 1741 (CO), 1600 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm 1.55 (dbr, J = 10 Hz; *endo*-4 (5)-H), 1.66 (dbr, J = 10 Hz; *exo*-4 (5)-H), 2.07 (s; CH_3CO), 2.62 (m; 3 (6)-H), 3.13 (m; 2 (7)-H), 4.73 (sbr; 12-H); MS: *m/e* 422 (M^+), 387 (M – Cl), 327 (M – Cl—CH_3CO_2H).

Isodrin-syn-12-*triflate* (**8**). To a stirred soln of *syn*-12-hydroxyisodrin (100 mg; 26 mmol) in dry pyridine (1 ml) at 0° was added dropwise over 20 min trifluoromethanesulphonic anhydride (0.25 ml; 1.5 mmol). The mixture was stirred for 1 hr at 0° and 5 hr at room temp, then partitioned between iced water (25 ml) and CH_2Cl_2 (5 ml) and, with vigorous stirring, acidified to pH 2 with conc HCl. The separated aqueous layer was extracted with CH_2Cl_2 (4 × 5 ml), and the combined organic phase was dried over $NaSO_4$ and concentrated *in vacuo* to give the crude product (100 mg; 75%). Recrystallization from MeOH gave **8** as colourless platelets, m.p. 107° (dec). (Found: *m/e* 509.8203; $C_{13}H_7O_3SCl_6F_3$ requires: 509.8199); IR: ν (CCl_4) 1603 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm 3.33 (dd, J = 1.5, 1 Hz; 2 (7)-H), 3.45 (m; 3(6)-H), 4.72 (sbr; 12-H), 6.04 (m; 4(5)-H); MS: *m/e* 510(M^+), 475(M – Cl), 341(M – HCl—CF_3SO_2), 325 (M – HCl—CF_3SO_3).

4,5-*Dihydroisodrin*-syn-12-*triflate* (**9**). To a stirred soln of 4,5-dihydro-*syn*-12-hydroxyisodrin (51 mg; 0.13 mmol) in dry pyridine (3 ml) was added dropwise over 20 min trifluoromethanesulphonic anhydride (0.6 ml; 3.6 mmol). The mixture was stirred for 1 hr at 0° and 5 hr at room temp and worked up as for **8**. Recrystallization of the crude product from MeOH gave **9** (44 mg; 64%) as needles, m.p. 203–209°. (Found: *m/e* 511.8349; $C_{13}H_9O_3Cl_6SF_3$ requires: 511.8355); IR: ν (CCl_4) 1600 cm^{-1} (CCl=CCl); NMR: δ (^{1}H) ppm 1.69 (dbr, J = 10 Hz; *endo*-4 (5)-H), 1.79 (dbr, J = 10 Hz; *exo*-4 (5)-H), 2.84 (m; 3 (6)-H), 3.10 (sbr; 2 (7)-H), 4.87 (sbr; 12-H); MS: *m/e* 512 (M^+), 477 (M – Cl), 327 (M – Cl—CF_3SO_3H), 291 (M – Cl—CF_3SO_3H—HCl).

Acetolysis of **6**

(a) *At* 64°. Aldrin-*syn*-12-triflate (200 mg; 0.39 mmole) was treated with 0.03 M NaOAc in 99:1 AcOH/Ac_2O (13.3 ml) plus anhyd NaOAc (833 mg; 10.3 mmole) for 24 hr at 65°. The mixture was then allowed to cool, poured into ice/water (150 ml) and extracted with CH_2Cl_2 (4 × 25 ml). The combined extracts were dried over Na_2SO_4, concentrated to *ca* 5 ml and azeotroped with toluene (2 × 25 ml) to remove AcOH. Evaporation of the toluene gave a yellow oil (168 mg) showing only one major peak on GLC and one major spot on TLC. The oil solidified on standing and was recrystallized twice from hexane to yield **10** as colourless crystals (100.6 mg; 63%) m.p. 103–105°. (Found: C, 39.5; H, 2.3; Cl, 50.1%. $C_{14}H_{10}O_2Cl_6$ requires: C, 39.8; H, 2.4; Cl, 50.3%); IR: ν (CCl_4) 1745 (CO), 1605 cm^{-1} (ClC=CCl); NMR: δ (^{1}H) ppm (see Fig. 1) 1.75 (dd, J = 6, 4.5 Hz; 3-H), 2.00 (dddd, J = 6, 5, 4, 2 Hz; 5-H), 2.05 (s; CH_3CO), 2.20 (ddd J = 5, 4.5, 2.5 Hz; 4-H), 2.91 (d, J = 6.5 Hz; 2-H), 2.98 (ddd, J = 8, 2.5, 2 Hz; 7-H), 3.42 (d, J = 6.5 Hz; 8-H), 5.10 (dd, J = 7, 4 Hz; 6-H); δ (^{13}C) ppm 20.6 (d, J = 200

Hz; C-4 or 5), 21.2 (q, J = 132.5 Hz; CH_3CO), 22.7 (d, J = 190 Hz; C-5 or 4), 25.8 (d, J = 165 Hz; C-3), 42.3 (d, J = 155 Hz; C-7), 53.3 (d, J = 150 Hz; C-2, 8), 64.0 (d, J = 170 Hz; C-6), 79.7 (s; C-1 or 9), 82.0 (s; C-9 or 1), 103.2 (s; C-12), 128.6 (s; C-10 or 11), 131.1 (s; C-11 or 10), 170.3 (s; CO); MS: *m/e* 385 ($M^+ - Cl$), 43 (CH_3CO^+).

Repeat of the acetolysis of **6** (30 mg; 0.6 mmole) with 2 ml of the acetolysis mixture gave, after work-up as above, a colourless gum (28.3 mg). Chromatography of this product over alumina (30 g) in hexane/diethyl ether (3:1) yielded a forerun of starting material (**6**; 1 mg) and then a colourless crystalline solid (20 mg; 88%), m.p. 118–122°. Recrystallization of this solid from MeOH gave **10** (OH for OAc) as colourless rhombs, m.p. 120–122°. (Found: C, 37.6; H, 2.1; Cl, 55.3%. $C_{12}H_8OCl_6$ requires: C, 37.8; H, 2.1; Cl, 55.8%); IR: ν (CH_2Cl_2) 3650 (OH), 1605 cm^{-1} (ClC=CCl); NMR: δ (^1H) ppm 1.68 (sbr; OH), 1.68 (dd, J = 6, 4 Hz; 3-H), 1.90 (m; 5-H), 2.06 (m; 4-H), 2.80 (dt, J = 2.5, 7 Hz; 7-H), 3.16 (d, J = 6.5 Hz; 2-H), 3.43 (d, J = 6.5 Hz; 8-H), 4.40 (dd, J = 7, 4 Hz; 6-H); MS: *m/e* 343 ($M^+ - Cl$), 108 ($C_7H_8O^+$).

(b) *At* 118°. Aldrin-*syn*-12-triflate (15 mg; 0.03 mmole) was reacted for 5 days at 118° with 0.03 M sodium acetate in 99:1 AcOH/Ac_2O (1 ml) plus NaOAc (62.5 mg; 0.76 mmole). The procedure and work-up used were as for the 65° acetolysis. The yellow crystalline product (6.5 mg; 70%) was recrystallized from MeOH to give **11** as platelets, m.p. 165–167°. (Found: *m/e* 384.9117; $C_{14}H_{10}O_2Cl_5$ ($M^+ - Cl$) requires: 384.9123); IR: ν (CCl_4) 1745 (CO), 1605 cm^{-1} (ClC=CCl); NMR: δ (^1H) ppm 2.17 (s; CH_3CO), 3.06 (sbr; 2 (7)-H), 3.12 (sbr; 3 (6)-H), 4.66 (s; 12-H), 6.30 (sbr; 4 (5)-H); MS: *m/e* 420 (M^+), 385 ($M^+ - Cl$), 327, 308, 289, 261, 235.

Under similar conditions (**10**) also yielded (**11**) as the sole product.

Bridged ether (**14**). *Anti*-12-acetoxyaldrin (**11**) (30 mg) was dissolved in 1 N KOH in 90/10 v/v MeOH/water (10 ml). The soln was allowed to stand overnight at room temp, then diluted with water (30 ml) and extracted with diethyl ether (3 × 10 ml). The combined ether extracts were washed with water (2 × 10 ml), dried over $MgSO_4$ and evaporated to yield **14** as yellow crystals (24.9 mg; 93%). Recrystallization from MeOH gave **14** as colourless crystals, m.p. 156–158°. (Found: *m/e* 338.9507; $C_{13}H_{12}O_2Cl_4$ ($M^+ - Cl$) requires: 338.9513); IR: ν (CCl_4) 2850 cm^{-1} (OMe); NMR: δ (^1H) ppm (Fig. 2) 2.38 (dd, J = 8.0, 2.5 Hz; 13-H), 2.82 (brs; 7-H), 3.14 (brd, J = 8 Hz; 8-H), 3.50 (s; OMe), 3.98 (brm; 4-H), 4.03 (brs; 3-H), 5.11 (d, J = 2.5 Hz; 12-H), 6.03 (dd, J = 6, 3.5 Hz; 6-H), 6.13 (ddd, J = 6, 4, 0.9 Hz; 5-H); δ (^{13}C) ppm 40.25 (d, J = 148.9 Hz; C-4 or 7), 44.0 (d, J = 156.3 Hz; C-4 or 7), 49.7 (d, J = 153.3 Hz; C-8 or 13), 51.4 (q, J = 146.6 Hz; OMe), 52.0 (d, J = 153.8 Hz; C-8 or 13), 69.3 (d, J = 141.0 Hz; C-12), 84.3 (d, J = 166.0 Hz; C-3), 132.4 (d, J = 173.4 Hz; C-5 or 6), 136.5 (d, J = 175.8 Hz; C-5 or 6); MS: *m/e* 339 (M − Cl), 303, 267, 239.

Acetolysis of **7**. The triflate of **7** (124 mg; 0.24 mmol) and anhyd NaOAc (500 mg; 6.1 mmol) were dissolved in the acetolysis mixture (10 ml), and stirred under N_2 at 64° for 24 hr. The mixture was allowed to cool, poured into ice/water (100 ml) and extracted with CH_2Cl_2 (3 × 100 ml). The combined extracts were washed with water (100 ml) and concentrated *in vacuo* to give an oil which was azeotroped *in vacuo* with toluene (2 × 10 ml) to remove residual AcOH. The oil was chromatographed on silica gel. Elution with 10% ether in hexane yielded from the early fractions a pure (by GLC, TLC) sample (40 mg; 46%) of **15** as an oil. (Found: C, 39.4; H, 2.1; Cl, 58.0%. $C_{12}H_8Cl_6$ requires: C, 39.5; H, 2.2; Cl, 58.3%); IR: ν (CCl_4) 1626 cm^{-1} (ClC=CCl); NMR: (see Fig. 4) δ (^1H) ppm 1.31 (dd, J = 4.9, 0.7 Hz; 9-H, 10-H), 1.48 (tbr, J = 4.9 Hz; 11-H), 1.63 (dt, J = 11.4, 1.3 Hz; 12-H), 1.72 (dt, 11.4, 1.5 Hz; 12-H), 2.55 (sbr; 2- or 8-H), 2.78 (sbr; 2- or 8-H), 2.83 (sbr; 1-H); MS: *m/e* 362 (M^+), 327 (M − Cl), 291 (M − Cl—HCl), 186 ($M - C_3Cl_4$). From later fractions a yellow oil (59 mg) was isolated. This was subjected to preparative TLC on silica, using toluene as eluent. Two products were isolated. The first was a white solid (22 mg, 21%), which was identical in all respects (m.p. GLC, TLC, IR, NMR) with **16**. The second was a 3:1 mixture of isomeric acetates, which was isolated as an oil (25 mg, 25%) which subsequently crystallized. The 3:1 mixture which could not be resolved by TLC (SiO_2–toluene) or GLC (Column A), contained either both isomers (**17a, 17b**) of 3,4,5,6,6,7-hexachlorotetracyclo[6.3.1.$0^{2,9}$.$0^{3,7}$]dodec-4-en-*exo*-11-yl acetate, both isomers (**18a, 18b**) of 3,4,4,5,6,7-hexachlorotetracyclo[6.3.1.$0^{2,9}$.$0^{3,7}$]dodec-5-en-*exo*-11-yl acetate, or one isomer of each alkene (four possible combinations: **17a, 18a**; **17a, 18b**; **17b, 18a**; **17b, 18b**). (Found: C, 39.4; H, 2.8; Cl, 49.7%. $C_{14}H_{12}O_2Cl_6$ requires: C, 39.6; H, 2.8; Cl, 50.0%); IR: ν (CCl_4) 1738 (C=O), 1622 cm^{-1} (ClC=CCl); NMR: δ (^1H) ppm (chemical shift of minor component in brackets; see Fig. 3) 0.94 (0.90) (dd, J = 15, 6 Hz; *exo*-12-H), 1.53 (1.31) (ddd, J = 15, 6, 2 Hz; *endo*-12-H), 1.69 (1.74) (dd, J = 15, 6 Hz; *exo*-10-H), 2.03 (1.99) (dd, J = 15, 6 Hz; *endo*-10-H), 2.05 (s; CH_3CO_2), 2.40 (2.65) (dbr, J = 6 Hz; 8-H), 2.70 (2.51) (dbr, J = 6 Hz; 1-H), 2.78 (3.04) (sbr; 2-H), 3.31 (3.18 (dbr, J = 6 Hz; 9-H), 4.62 (4.67) (d, J = 6 Hz; 11-H); MS: *m/e* 422 (M^+), 387 (M − Cl), 372 (M − Cl—HOAc).

Acetolysis of isodrin-syn-12-*triflate* (**8**). A soln of isodrin-*syn*-12-triflate (50 mg; 0.1 mmol) in the acetolysis mixture (total volume 5.2 ml) was heated for 300 hr at 118°. During this time samples totalling 0.4 ml were removed and analysed by GLC on columns A and B. The sole product of the reaction was *anti*-12-acetoxyisodrin (by comparison with authentic samples of both the *syn* and *anti* isomers); however, the rate of reaction was too slow to allow its rate constant to be determined from these analyses. After 300 hr, the remaining mixture (4.8 ml) was poured into water (10 ml) and extracted with CH_2Cl_2 (3 × 5 ml). The organic extracts were combined, dried over Na_2SO_4 and concentrated *in vacuo*, and the crude product was separated by preparative TLC (SiO_2; EtOAc as eluent) to give the starting material (27.3 mg, 59%) and **19** (7.5 mg, 20%) as the only recovered product.

By assuming that pseudo-first-order kinetics prevailed the yield of recovered starting material was used to determine an approximate value of the rate constant for the acetolysis (see Table 1).

Acetolysis of 4,5-*dihydroisodrin*-syn-12-*triflate* (**9**). A soln of **9** (56.1 mg; 0.11 mmol) in the acetolysis mixture (total volume 30 ml) was heated for 220 hr at 118°. The mixture was then quantitatively analysed by GLC (Columns A and B) and found to contain residual triflate (480 mg; 85.6%), *syn*-**21** (5.7 mg; 12.2%), and *anti*-**20** (1.0 mg; 2.1%). By assuming that pseudo-first-order kinetics prevailed these results were used to determine an approximate value for the rate constant for the acetolysis (Table 1).

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REFERENCES

[1] C. T. Bedford and E. H. Smith, *J. Agric. Food Chem.* **26**, 911 (1978).
[2] S. Winstein and R. L. Hansen, *Tetrahedron Letters* 4 (1960).
[3] B. Capon, *Quart. Rev.* **18**, 45 (1964); *Organic Reaction Mechanisms*. Annual Surveys of the Literature, Wiley, London (1965–1982).
[4] C. W. Bird, R. C. Cookson and E. Crundwell, *J. Chem. Soc.* 4809 (1960); P. T. Lansbury, *Acc. Chem. Res.* **5**, 311 (1972); P. T. Lansbury and R. C. Stewart, *Tetrahedron Letters* 1959 (1973).
[5] C. T. Bedford and R. K. Harrod, *Chemosphere* 163 (1973).
[6] C. T. Bedford, *Pesticide Sci.* **5**, 473 (1974).
[7] T. M. Su, W. F. Sliwinski and P. von R. Schleyer, *J. Am. Chem. Soc.* **91**, 5386 (1969).
[8] S. Winstein, E. Grunwald and L. L. Ingraham, *J. Am. Chem. Soc.* **70**, 821 (1948).
[9a] J. Lhomme, A. Diaz and S. Winstein, *J. Am. Chem. Soc.* **91**,

1546 (1969); [b]J. Tufariello and R. J. Lorence, *Ibid.* **91**, 1548 (1969).
[10] L. T. Byrne, A. R. Rye and D. Wege, *Austr. J. Chem.* **27**, 1961 (1974).
[11] R. A. Pfund, W. B. Schweizer and G. Ganter, *Helvetica Chim. Acta* **63**, 674 (1980).
[12] S. Winstein and E. T. Stafford, *J. Am. Chem. Soc.* **79**, 505 (1957).
[13] S. Winstein and M. Shatavsky, *J. Am. Chem. Soc.* **78**, 592 (1956).
[14] *Hydride ion*: P. R. Story, *J. Am. Chem. Soc.* **83**, 3347 (1961); H. C. Brown and M. M. Bell, *Ibid.* **85**, 2324 (1963); *Methoxide ion*: H. Tanida, T. Tsuji and T. Irie, *Ibid.* **88**, 864 (1966); A. Diaz, M. Brookhart and S. Winstein, *Ibid.* **88**, 3133 (1966); *Cyanide ion*: H. Tanida and Y. Hata, *J. Org. Chem.* **30**, 977 (1965); *Benzyloxide ion*: J. Tufariello, T. F. Mich and R. J. Lorence, *J. Chem. Soc. Chem. Commun.* 1202 (1967).
[15] P. G.Gassman and G. D. Richmond, *J. Am. Chem. Soc.* **90**, 5367 (1968).
[16] S. Winstein and R. L. Hansen, *J. Am. Chem. Soc.* **82**, 6206 (1960).
[17] K. G. Krebs, D. Heusser and H. Wimmer, *Thin-layer Chromatography* (Edited by E. Stahl), 2nd Edn, p. 878. Springer-Verlag, Berlin, (1967).
[18] H. Brockman and H. Schodder, *Chem. Ber.* **74**, 43 (1941).
[19] J. Haywood-Farmer, H. Malkus and M. A. Battiste, *J. Am. Chem. Soc.* **94**, 2209 (1972).