Stereospecific Ring-contraction of 7,7-Dichlorobicyclo[3.2.0]hept-2-en-6-ols with Base

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The epimeric alcohols, 7,7-dichlorobicyclo[3.2.0]hept-2-en-6-*endo*- and 6-*exo*-ol (2) and (3) when treated with aqueous base undergo stereospecific ring contraction with loss of hydrogen chloride to give respectively 6-chlorobicyclo[3.1.0]hex-2-en-6-*exo*- and 6-*endo*-carbaldehyde (5) and (6): the latter exists largely as its valence tautomer. The reaction involves a bent cyclobutane ring with the reacting hydroxy- and chloro-groups disposed *trans* and diequatorially, and it has been extended to the epimeric 6-methyl derivatives (19) and (20) and a 6-nitromethyl analogue (24). The betaine (27) formed by addition of stable phosphoranes to 7,7-dichlorobicyclo[3.2.0]hept-2-en-6-one (1) does not give ring contracted products, but instead the 6-alkoxycarbonylmethylenebicyclic compound (28) by a normal Wittig reaction. Some spectroscopic properties of the starting alcohols are discussed.

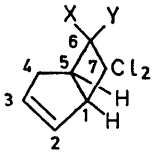
THE present work,[1] concerns the base-catalysed ring contraction of epimeric alcohols derived from the dichloroketen–cyclopentadiene adduct (1) [2] to give 6-substituted bicyclo[3.1.0]hexane derivatives; the reaction has been extended to other 2,2-dichlorocyclobutanols.[3]

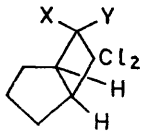
Reduction of dichloro-ketone (1) with sodium borohydride gave two epimeric alcohols in a ratio of 81:19, and the predominant isomer was assigned the 6-*endo* structure (2) on the grounds that *exo*-attack of the reducing agent would be more favourable. (Berson has shown that similar reduction of the related ketone lacking chlorine at C-7 gives 75% of *endo*-alcohol.[4]) The dichloro-alcohols were separated by chromatography or preparative g.l.c., and the n.m.r. spectra of the alcohols and their derivatives supported the assigned structures (see below). Attempts to provide chemical confirmation of these assignments by neighbouring group participation of the 6-*endo*-substituent with the olefinic double bond [5] were unsuccessful and no tricyclic compound such as (4) could be obtained from the phenylurethanes of (2) and (3) (see Experimental section).

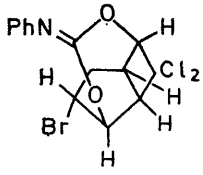
Ring Contractions.—Even under inhomogeneous conditions both *endo*- and *exo*-alcohols had reacted with 2N-sodium hydroxide within a few seconds. The *endo*-epimer (2) gave an aldehyde, C_7H_7ClO, by loss of hydrogen chloride. The n.m.r. spectrum showed an aldehyde singlet and two olefinic protons, but no CHCl signal. The aldehyde was readily oxidised (Ag_2O) to a crystalline acid, $C_7H_7ClO_2$, which proved unusually labile: melting (114°) or crystallisation from hot water led to loss of hydrogen chloride and formation of benzoic acid. These results, with the spectral data, suggest that the aldehyde has structure (5) and the acid (7). The *endo*-chlorine atom stereochemistry, is based on related results of Schollkopf and Schleyer [6] on the different rates of ring-opening of 6-*endo*- and 6-*exo*-tosyloxybicyclo[3.1.0]-hexanes: in the present case displacement of the *endo*-chlorine atom by rearside attack of the 1,5-bond of (7)

[1] Preliminary communication, P. R. Brook, *Chem. Comm.*, 1968, 565.
[2] L. Ghosez, R. Montaigne, and P. Mollett, *Tetrahedron Letters*, 1966, 399.
[3] P. R. Brook and J. G. Griffiths, *Chem. Comm.*, 1970, 1344.
[4] J. A. Berson and J. W. Patton, *J. Amer. Chem. Soc.*, 1962, **84**, 3406.
[5] For an example, see K. Bowden, B. Lythgoe, and D. J. S. Marsden, *J. Chem. Soc.*, 1959, 1662.
[6] U. Schöllkopf, K. Fellenberger, M. Patsch, P. von R. Schleyer, T. Su, and G. W. van Dine, *Tetrahedron Letters*, 1967, 3639.

on C-6, with outward disrotatory opening [7] of the cyclopropane ring leads formally to a cyclohexadienyl cation. Loss of the C-4 proton during the opening of the ring



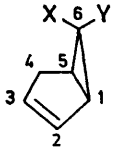


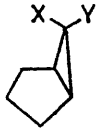


(1) XY = O
(2) X = OH, Y = H
(3) X = H, Y = OH
(19) X = OH, Y = Me
(20) X = Me, Y = OH
(24) X = OH, Y = $CH_2{\cdot}NO_2$
(27) X = O^-, Y = $CH(CO_2Me){\cdot}\overset{+}{P}Ph_3$
(28) XY = =CH·CO_2R

(10) X = OH, Y = H
(11) X = H, Y = OH

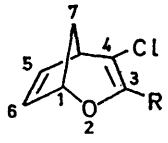
(4)





(5) X = Cl, Y = CHO
(6) X = CHO, Y = Cl
(7) X = Cl, Y = CO_2H
(8) X = CHO, Y = H
(21) X = Cl, Y = Ac
(22) X = Ac, Y = Cl
(25) X = Cl, Y = $CO{\cdot}CH_2{\cdot}NO_2$

(12) X = Cl, Y = CHO
(13) X = CHO, Y = Cl
(14) X = Cl, Y = CO_2H
(15) X = CO_2H, Y = Cl
(17) X = H, Y = CO_2H
(18) X = CO_2H, Y = H



(9) R = H (23) R = Me

$Ph_3P{=}CH{\cdot}CO_2R$
(26)

gives benzoic acid directly and the reaction may be concerted.

The 6-*exo*-alcohol (3) with sodium hydroxide gave an oil having an analysis consistent with the *endo*-aldehyde structure (6). The n.m.r. spectrum indicated that the valence tautomer (9) was clearly preferred; Dreiding and Rey [8] have shown that aldehyde (8) is the major isomer in a dynamic equilibrium with the 2-oxabicyclo[3.2.1]-octadiene valence tautomer (ratio 70 : 30). Our equilibrium mixture showed a very small aldehyde signal, and strongly favoured the 2-oxabicyclo-octadiene (9) (95 : 5 in deuteriochloroform). This shift in equilibrium must be due to the chloro-group, which will destabilise the aldehyde (6) (*cf.* chloral); the form (9) may also be stabilised by resonance of the vinyl chloride type. Characterisation of the product by oxidation of the aldehyde failed, as did attempts to trap the enol ether with tetracyanoethylene, possibly owing to the instability of the grouping –O–CH=CCl– present in (9).

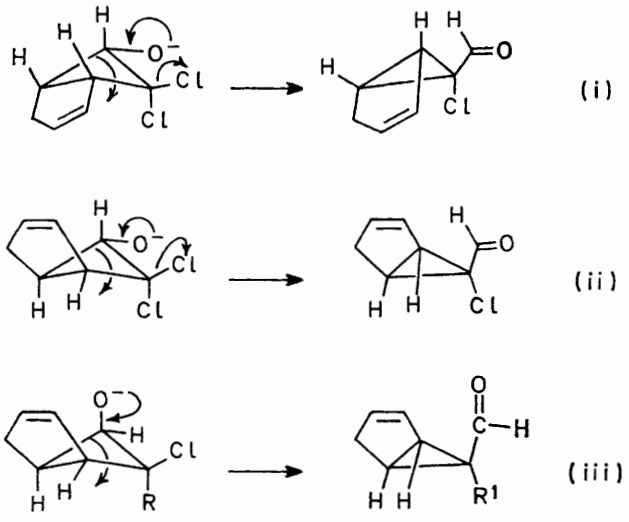
The dihydro-*endo*-alcohol (10), formed by catalytic reduction of (2), on treatment with base gave the expected aldehyde (12) and thence the corresponding α-chloro-acid (14) [pK_a (in water) 3·03]. The same acid was obtained by hydrogenation of the labile unsaturated acid (7). The dihydro-*exo*-alcohol (11) rearranged smoothly to give a different aldehyde, assumed to be the *endo*-isomer (13) and this was oxidised to the acid (15) [pK_a (in water) 2·82]. Efficient dechlorination of either of the epimeric α-chloro-acids [(14) or (15)] with sodium–liquid ammonia gave the same mixture of known bicyclo[3.1.0]hexane-6-*endo*- and 6-*exo*-carboxylic acids,[9] respectively (18) and (17), in a ratio of 68 : 32. Clearly the same C-6 cyclopropyl anion, either planar and conjugated with the carboxylate anion, or a rapidly inverting species,[10] was being formed from either acid, and protonation by ammonia from the *exo*-face was favoured to give a preponderance of *endo*-acid (18).

The isolation of these known bicyclo[3.1.0]hexane acids, when coupled with the pK_a evidence that the precursors were α-chloro-carboxylic acids provided firm chemical evidence for the course of the rearrangement. The assignment of stereochemistry was based on the valence tautomerism of the *endo*-aldehyde (6) and the lability of *exo*-acid (7), and appeared sufficiently conclusive.

Mechanism of the Ring Contractions.—The stereospecificity of the rearrangement is remarkable, and with the reasonable assumption that the 5,6-bond migrates with inversion at the terminus C-7, it is the chlorine atom *trans* to the hydroxy-group which is eliminated in all cases. In an earlier discussion of the mechanism,[1] it was suggested that a bent cyclobutane was involved with both hydroxy- and leaving chloro-groups equatorially disposed and that the main driving force was the ' push ' of the cyclobutoxide ion (silver ions in neutral solution do not catalyse the ring contraction). The electron shifts are as described in equations (i) and (ii). Recently, monochlorocyclobutanols have been shown to ring-contract in a similar fashion, provided the chloro-group can readily adopt the equatorial conformation, and reaction will still occur when the hydroxy-group is *cis* to the chlorine atom, and hence axial [equation (iii), R = H or Me].[11] In the dichloro-series this latter route [(iii), R = Cl] must be disfavoured by a considerable amount ($\Delta\Delta G^{\ddagger} \sim 14$ kJ mol^{-1}) otherwise stereospecificity would not be observed: this may be due to stereoelectronic influences for in equations (i) and (ii) the electrons can move from oxygen to C-6 in the same plane in which migration of the 5,6-bond occurs, giving good orbital overlap but this is not the situation for (iii). Further, in the conformations of the dichlorocyclobutanol ring for which reaction occurs the oxy-anion is

[7] R. B. Woodward and R. Hoffmann, *Angew. Chem. Internat. Edn.*, 1969, **8**, 801.
[8] M. Rey and A. S. Dreiding, *Helv. Chim. Acta*, 1965, **48**, 1985.
[9] J. Meinwald, S. S. Labone, and M. S. Chadha, *J. Amer. Chem. Soc.*, 1963, **85**, 582.
[10] The corresponding 6-radical may also be involved if the reduction is a two step mechanism. For a discussion of the configurational stability of cyclopropyl radicals and anions see D. E. Applequist and A. H. Peterson, *J. Amer. Chem. Soc.*, 1961, **83**, 862; H. M. Walborsky, F. J. Impasto, and A. E. Young, *ibid.*, 1964, **86**, 3283; M. J. S. Dewar and J. M. Harris, *ibid.*, 1969, **91**, 3653.
[11] P. R. Brook and A. J. Duke, *Chem. Comm.*, 1970, 652.

flanked by two chlorine atoms, raising the ground-state energy of the reactant by dipole–dipole interactions and so promoting reaction. The hydroxy-group does not act as a ' conformational anchor,' however, by preferring



the equatorial conformation and ensuring that it is the *trans*-chloro-group which is equatorial and so leaves. The same stereospecificity is observed when C-6 is substituted by a large group, such as methyl or nitromethyl (see below).

Further Ring Contractions.—In order to explore the generality of the reaction, other alcohols were obtained from the dichloro-ketone (1). Addition of methylmagnesium iodide yielded the tertiary alcohols (19) and (20) in a ratio of 67 : 33, *exo*-attack by the reagent again being preferred. No ring-contraction of the magnesium alkoxide intermediate was noted.[12] The assignment of configurations was supported by the n.m.r. spectra of the alcohols: the minor product, with the *endo*-methyl group shielded by the bonds of the cyclopentene ring, gave a methyl signal at higher field.

Base-catalysed ring contraction of either alcohol was again rapid and stereospecific. The *endo*-alcohol (19) gave the *exo*-acetyl derivative (21) with spectral data in accord with the proposed structure. Full characterisation was not achieved, because the 2,4-dinitrophenylhydrazone lost hydrogen chloride to give the corresponding acetophenone product [*cf.* the behaviour of acid (7)]. The epimeric alcohol (20) gave the valence tautomeric mixture of *endo*-methyl ketone (22) and enol ether (23), which in deuteriochloroform contained only 74% of the latter. The methyl group must stabilise the carbonyl group in (22) more than the enol ether double-bond in (23) and so shifts the equilibrium towards the ketone (22). The mixture was unstable at ambient temperatures and the n.m.r. spectrum showed marked changes after 24 h. This was possibly due to Cope rearrangement of the enol of (22) leading to a 2-chlorobicyclo[3.2.1]oct-6-en-3-one,* but the reaction was complex, and was not investigated further.

Addition of nitromethane to the dichloro-ketone (1) was catalysed by triethylamine: yields were only moderate and isolation of the amine hydrochloride suggested that the cyclobutoxide intermediate in the addition had undergone ring contraction to some extent. The distilled adduct was largely one epimer as judged by the n.m.r. spectrum, and was assigned the *exo*-nitromethyl structure (24). However, as ring contraction of one epimer could have been favoured, no conclusion should be drawn as to the original ratio of alcohols formed in the addition. Ring contraction proceeded smoothly in the normal way to yield the *exo*-nitromethyl ketone (25), isolated as the sodium salt. Mild acidification yielded the parent ketone, but if the salt was crystallised from aqueous ethanol, 2-nitroacetophenone was formed, confirming the 6-*endo*-chloro-group in (25).

Attempted addition of the strongly basic anion of dimethyl sulphoxide or non-stabilised phosphoranes to the ketone (1) led to extensive decomposition, even at low temperatures. Stabilised phosphoranes [(26; R = Me or Et] reacted smoothly to yield the Wittig product, a 6-alkoxycarbonylmethylenebicycloheptene (28). The ready reaction is probably enhanced by ring strain and the inductive effect of the chloro-groups in the starting ketone.[13] Unfortunately, no intermediate betaine (27) could be isolated for study in the ring-contraction experiments, despite variation of the conditions. Only one geometrical isomer of (28) was detected with benzene or chloroform as solvent, whilst the same product was formed to at least 96% in dimethylformamide–lithium chloride.[14] The *Z*-configuration was tentatively assigned since reduction of the alkoxycarbonyl group to hydroxymethyl caused an upfield shift of the H-5 signal in the n.m.r. spectra.[15] The lack of ring contraction of the intermediate betaine may be due to the fact that it exists as a pentacovalent phosphorus derivative.

Spectroscopic Studies of the Bicycloheptanols.—Spectral data were necessary to support the assignment of stereochemistry in the *endo*- and *exo*-series. The major differences in the n.m.r. spectra of the two series lay in the signals of H-5 and H-6, which both appeared 0·4—0·6 p.p.m. to higher field in the *exo*-derivatives (Table 1). Shielding by the bonds of the five-membered ring accounts for the effect on H-6, and this effect is still present after reduction of the double bond. Further support for the assignment comes from the width of the double-doublet signal for H-6, corresponding to $(^3J_{5.6} + {}^4J_{1.6})$, which is always greater (11—14 Hz) for *endo*- than

* A related *endo*-acetyl derivative [(22), lacking 6-Cl] after formation of its enol acetate and acid work-up is converted into bicyclo[3.2.1]oct-6-en-3-one (J. G. Griffiths, unpublished work at Leeds).

[12] J. M. Conia and J. Salaün, *Chem. Comm.*, 1970, 1358; *Accounts Chem. Res.*, 1972, **5**, 37.

[13] A. W. Johnson, ' Ylid Chemistry,' Academic Press, New York, 1966, pp. 138, 158.

[14] For a summary of the effects of lithium salts on the Wittig reaction see J. Reucroft and P. G. Sammes, *Quart. Rev.*, 1971, **25**, 139.

[15] L. M. Jackmann and S. Sternhell, ' Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry,' Pergamon, Oxford, 1969. p. 222.

for *exo*-derivatives (7—8 Hz): in cyclobutanes, *cis*-vicinal couplings are greater than *trans*,[16] and the cross-ring coupling ^4J is of the same sign as vicinal couplings only when the respective protons are *cis*.[17] The upfield shift of the H-5 signal in *exo*-derivatives is less easily understood. The explanation of shielding by the *cis* C–O bond has been ruled out in the case of planar bicyclo-[2.1.0]pentan-2-ols, where a similar effect is noted,[18] because such shielding does not occur in cyclopropanol. In the present cases, a marked preference for a bent cyclobutane ring with an equatorial hydroxy-group would give rise to a 1,3-diaxial interaction between H-5 and the 7-*exo*-Cl group in the *exo*-series, such a relationship normally gives a downfield shift to the proton signal rather than the upfield shift observed.[19]

N.m.r. studies of flexible cyclobutanes are hindered by a low energy barrier between conformations (different conformers cannot be 'frozen out' as in the case of cyclohexanes). Observed chemical shifts are expected to be time-averaged over two conformations unless there is a large anchor group present.[20] This problem is not present in i.r. studies, however: measurement of the hydroxyl stretching frequency for dilute solutions of *endo*- and *exo*-alcohols [(2) or (3)] in carbon tetrachloride did not give clear indication of the presence of OH · · · π bonding in the former case.[21] Frequencies were very similar for both compounds (Table 2), and this and the absence of unassociated hydroxyl stretch in the 3620 cm^{-1} region even for the dihydro-*endo*-alcohol (10) suggested that the major interaction is OH · · · Cl bonding in all cases. In a complementary study, the *endo*-alcohol derived from 7-*exo*-chloro-7-isopropylbicyclo[3.2.0]hept-2-en-6-one showed free hydroxyl stretch at 3627 with an associated hydroxyl at 3580 cm^{-1} due to OH · · · π bonding, whereas the *exo*-alcohol, *cis* to chlorine on the cyclobutane ring, showed only the OH · · · Cl bonded species. Clearly the technique is of use in a study of alcohols from monochloroketen adducts.

TABLE 1

H-5 and H-6 Chemical shifts (δ in p.p.m.) for bicycloheptanols

	OH (2), (3)		ODNB [a]		OTs		OPU [b]		Dihydro-OH (10), (11)		Dihydro-ODNB	
	H-5	H-6	H-5	H-6	H-5	H-6	H-5	H-6	H-5	H-6	H-5	H-6
endo	3·34	4·47	3·72	5·80	3·40	5·17	3·41	5·49	3·15	4·56	3·44	5·80
exo	2·74	4·06	3·22	5·22	3·10	4·62	3·00	5·01	2·53	3·82	3·29 [c]	5·14
Δδ	0·60	0·41	0·50	0·58	0·30	0·55	0·41	0·48	0·42	0·74	0·15	0·66

[a] ODNB = 3,5-Dinitrobenzoate. [b] PU = Phenylurethanes. [c] H-5 Signal overlaps H-1; possible error in value.

TABLE 2

OH Stretching frequencies (cm^{-1}) of bicyclo[3.2.0]-heptan-6-ols in dilute solutionl (CCl_4) †

endo-Alcohol (2)	*exo*-Alcohol (3)	Dihydro-*endo*-alcohol (10)	7-*exo*-Chloro-7-isopropylbicyclo[3.2.0]-hept-2-en-6-ols	
			endo	*exo*
3566	3566	3598	3580	3558
3592 [a] (57) [b]	3602 (41) [b]	3585 [a] (75) [b]	3627 (83)	3565 [a] (72) [b]
			3564 [a] (36)	

† Spectra were measured for 1% solutions in carbon tetrachloride, with standardisation on water-vapour peaks obtained by single beam operation of the Perkin-Elmer spectrometer. Error is estimated at ±1 cm^{-1} for peaks, with larger error for shoulders.

[a] Shoulder. [b] Percent height of largest peak.

EXPERIMENTAL

N.m.r. spectra were obtained at 60 MHz on a Varian A60 or A60 A/D Spectrometer, in deuteriochloroform unless otherwise stated. I.r. spectra were run on either a Unicam SP 200 or a Perkin-Elmer 125 spectrophotometer and u.v. spectra on a Unicam SP 800 machine.

Analytical g.l.c. involved a Perkin-Elmer F11 with a 200 ft glass capillary coated with didodecyl phthalate (DDP) unless otherwise stated, and preparative g.l.c. a Wilkins A 200 aerograph or Varian 1527 using 3/8 in columns. Kieselgel G (Merck) was used for all chromatography.[22] Organic extracts were dried with anhydrous magnesium sulphate unless otherwise stated.

Sodium Borohydride Reduction of 7,7-Dichlorobicyclo-[3.2.0]hept-2-en-6-one (1).—The ketone (5·09 g) in aqueous dioxan (50%; 20 ml) was cooled while sodium borohydride (550 mg, 2 equiv.) in water (3 ml) was added over 3 min. After a further 5 min, extraction with chloroform yielded a mixture of the 6-*endo*- and 6-*exo*-alcohols [(2) and (3)] (4·8 g) in a ratio of 81 : 19 (g.l c.). Chromatography (500 g of Kieselgel G) with benzene as eluant gave first the *endo*-epimer, then, after several mixed fractions (which were rechromatographed), the *exo*-alcohol. Preparative g.l.c. was used to obtain an analytical sample of the endo-*alcohol* (2), m.p. 31—33° (Found: C, 47·35; H, 4·5. $C_7H_8Cl_2O$ requires C, 47·0; H, 4·5%); δ 6·00 and 5·70 (2H, 2 × m, olefinic), 4·47 (1H, m, 6-H), 3·84 (1H, m, 1-H), 3·33 (1H, qd, 5-H), 2·78 (1H, s, OH), and 2·53 p.p.m. (2H, m, CH_2). The corresponding endo-3,5-*dinitrobenzoate* had m.p. 149·5—150·5° (from chloroform–methanol) (Found: C, 44·9; H, 2·75. $C_{14}H_{10}Cl_2N_2O_6$ requires C, 45·1; H, 2·9%) and the endo-*tosylate* had m.p. 109° (from benzene–petroleum) (Found: C, 50·3; H, 4·25. $C_{14}H_{14}Cl_2O_3S$ requires C, 50·45; H, 4·2%). The exo-*alcohol* had m.p. 81° (from dichloromethane–pentane) (Found: C, 47·0; H, 4·35%); δ 5·87 (2H, m, olefinic), 4·03 (1H, d, 1-H), 3·73 (1H, m, 6-H), 3·26 (1H, s, OH) 2·70 (1H, q, 5-H), and 2·48 p.p.m. (2H, m,

[16] I. Fleming and D. H. Williams, *Tetrahedron*, 1967, **23**, 2747.
[17] A. Gamba and R. Mondelli, *Tetrahedron Letters*, 1971, 2133.
[18] K. Wiberg and D. E. Barth, *J. Amer. Chem. Soc.*, 1969, **91**, 5134.
[19] For a detailed discussion of n.m.r. spectra of related bicyclo-[3.2.0]-systems see M. Rey, S. Roberts, A. Dieffenbacher, and A. S. Dreiding, *Helv. Chim. Acta*, 1970, **53**, 417.
[20] J. B. Lambert and J. D. Roberts, *J. Amer. Chem. Soc.*, 1965, **87**, 3884.
[21] L. J. Bellamy, 'Advances in I.r. Group Frequencies,' Methuen, London, 1968, pp. 84, 241.
[22] B. J. Hunt and W. Rigby, *Chem. and Ind.*, 1967, 1868.

CH_2). The corresponding exo-3,5-*dinitrobenzoate* had m.p. 119° (from methanol) (Found: C, 44·6; H, 2·3%).

Bromination of Phenylurethanes Derived from endo-*Alcohol* (2) *and* exo-*Alcohol* (3).—The *endo*-Alcohol (200 mg) was heated under reflux in carbon tetrachloride (3 ml) with phenyl isocyanate (1·5 equiv.) for 2 days and gave an excellent yield of endo-*phenylurethane*, m.p. 98° (from methylcyclohexane) (Found: C, 56·05; H, 4·1. $C_{14}H_{13}Cl_2NO_2$ requires C, 56·4; H, 4·4%). Treatment with an excess of bromine in carbon tetrachloride resulted in a rapid uptake of bromine, and hydrogen bromide was also formed indicating some substitution. A *tribromo*-endo-*urethane*, m.p. 157—158° (from chloroform-pentane), was isolated in high yield (Found: C, 31·45; H, 2·0%; 1·617 mg gave 2·659 mg silver halides. $C_{14}H_{12}Br_3Cl_2NO_2$ requires C, 31·3; H, 2·25%; 2·559 mg of silver halides).

In an attempt to involve the urethane group in neighbouring group participation, the tribromourethane (100 mg) was heated under reflux in methanol (5 ml) containing sodium carbonate (2N; 0·3 ml) for 20 min. Removal of solvent and chromatography (benzene–chloroform) gave first an oil with the characteristic smell of bicyclohexanecarbaldehydes (not characterised), then crystals of methyl *p*-bromophenylurethane, m.p. 123—125°,[23] δ 7·33 (4H, AA′BB′, aromatic), 6·91br (1H, s, NH), and 3·75 p.p.m. (3H, s, OMe).

In a similar preparation to the above, the *exo*-alcohol (3) gave a high yield of the *phenylurethane*, which was crystallised with difficulty and was purified by preparative t.l.c., m.p. 92—93° (Found: C, 56·35; H, 4·5; N, 4·45. $C_{14}H_{13}Cl_2NO_2$ requires C, 56·4; H, 4·4; N, 4·7%). Bromination yielded an exo-*tribromourethane*, m.p. 173° (from carbon tetrachloride–pentane) (Found: C, 31·15; H, 2·2%; mixed halide: 2·675 mg gave 4·391 mg silver halides; theory requires 4·236 mg).

7,7-*Dichlorobicyclo*[3.2.0]*heptan*-6-*ols*.—The *endo*-alcohol (2) (676 mg) in methyl acetate (12 ml) was hydrogenated at 1 atm over prereduced Adams catalyst (PtO_2) until uptake ceased (6 min). The crude product (680 mg), isolated in the usual way, gave the *dihydro*-endo-*alcohol* (10) (from pentane at −40°) (417 mg), m.p. 49·5—50° (Found: C, 46·45; H, 5·45. $C_7H_{10}Cl_2O$ requires C, 46·7; H, 5·6%), δ 4·56 (1H, m, 6-H), 3·18 (2H, m, 1-H and 5-H), 2·6 (1H, s, OH), and 2·27—1·10 p.p.m. (6H, remainder). The 3,5-*dinitrobenzoate* had m.p. 174—175° (from chloroform–methanol) (Found: C, 44·65; H, 3·35. $C_{14}H_{12}Cl_2N_2O_6$ requires C, 44·8; H, 3·2%).

7,7-*Dichloro*[3.2.0]*heptan*-6-exo-*ol*.—In similar fashion, the *exo*-alcohol (3) (250 mg) gave the *dihydro*-exo-*alcohol* (11), m.p. 80—81·5° (from pentane) (depressed on admixture with starting alcohol) (Found: C, 46·05; H, 5·5%), δ 3·83 (1H, m, 6-H), 3·15 (1H, t, 1-H or 5-H), 2·80—2·30 (2H, m, OH and 5-H or 1-H), and 2·2—1·3 p.p.m. (6H, m, remainder); no signal in the olefinic region. The 3,5-*dinitrobenzoate* had m.p. 156·5—157° (from chloroform–methanol) (Found: C, 44·65; H, 3·55%).

Base-catalysed Ring Contractions.—The reactions were carried out under inhomogeneous conditions by dissolving the solid alcohol in a minimum quantity of methanol and then shaking this solution with a large excess of 2N-sodium hydroxide for 1 min. Ether extraction yielded the pure aldehydes (based on n.m.r. spectra and t.l.c.).

(a) 6-endo-*Chlorobicyclo*[3.1.0]*hexane*-6-exo-*carbaldehyde*. Dihydro-*endo*-alcohol (10) (215 mg) yielded the bicyclohexane-***exo***-aldehyde (12) (127 mg, 74%), $\nu_{max.}$ 2735 and 1715 cm^{-1} (CHO), δ 9·55 (1H, s, CHO) and 2·5—1·5 p.p.m. (8H, m, remainder); 2,4-*dinitrophenylhydrazone*, m.p. 167° (from ethanol), $\lambda_{max.}$ 355 nm (Found: C, 48·15; H, 4·35; N, 18·05. $C_{13}H_{13}ClN_4O_4$ requires C, 48·1; H, 4·0; N, 17·3%).

(b) 6-exo-*Chlorobicyclo*[3.1.0]*hexane*-6-endo-*carbaldehyde*. The dihydro-*exo*-alcohol (11) (50 mg) gave the oily bicyclohexane-*endo*-aldehyde (13) (36 mg, 90%), $\nu_{max.}$ 2765 and 1706 cm^{-1} (CHO), δ 9·72 (1H, s, CHO) and 2·6—1·8 p.p.m. (8H, m, remainder); 2,4-*dinitrophenylhydrazone*, m.p. 177·5—178° (from chloroform–methanol) (Found: C, 48·2; H, 3·95; N, 17·0%).

(c) 6-endo-*Chlorobicyclo*[3.1.0]*hex*-2-*ene*-6-exo-*carbaldehyde*. The *endo*-alcohol (2) (120 mg) gave the bicyclohexene-*exo*-aldehyde (5) (70 mg, 73%), $\nu_{max.}$ 2780 and 1710 cm^{-1} (CHO), δ 9·82 (1H, s, CHO), 5·81 and 5·69 (2H, 2 × m, 2-H and 3-H), and 3·1—2·2 p.p.m. (4H, m, remainder), $\lambda_{max.}$ 206 (ε 7800) and 233sh nm (2400); 2,4-*dinitrophenylhydrazone*, m.p. 108—115° (slow decomp.) (from ethanol), $\lambda_{max.}$ 366 nm (Found: C, 49·0; H, 3·5. $C_{13}H_{11}ClN_4O_4$ requires C, 48·4; H, 3·4%).

Repeat of this ring contraction in sodium deuterioxide–deuterium oxide gave no incorporation of deuterium (n.m.r.)

(d) 6-exo-*Chlorobicyclo*[3.1.0]*hex*-2-*ene*-6-endo-*carbaldehyde and* 4-*Chloro*-2-*oxabicyclo*[3.2.1]*octa*-3,6-*diene*. The *exo*-alcohol (3) (127 mg) gave the oily valence-tautomeric mixture of endo-*bicyclohexenecarbaldehyde* (6) and *oxabicyclo*[3.2.1]*octadiene* (9) (40 mg, 40%), purified by bulb-to-bulb distillation, b.p. 60—65° at 20 mmHg, $\nu_{max.}$ 2750, 1707 (CHO), and 1620 cm^{-1} (enol ether?) (Found: C, 59·0; H, 4·95. C_7H_7ClO requires C, 59·0; H, 4·95%). The n.m.r. spectrum of the mixture in deuteriochloroform showed it to exist almost entirely as the oxabicyclo[3.2.1]octadiene structure (9), δ 6·61 (1H, dd, *J* 5·5 and 2·5 Hz, 6-H), 6·00 (1H, d, *J* 1·8 Hz, 3-H), 5·59 (1H, dd, *J* 5·5 and 2·2 Hz, 7-H), 4·92 (1H, m, 1-H), 2·83 (1H, m, 5-H), and 2·00 p.p.m. (2H, m, methylene bridge). A small peak at δ 9·47 p.p.m. (CHO) indicated ~5% of aldehyde valence-tautomer (6) present. Attempts to form crystalline derivatives with $PdCl_2$–PhCN complex, tetracyanoethylene, or 2,4-dinitrophenylhydrazine failed.

Oxidation of the Aldehydes with Silver Oxide.—As a general procedure, the aldehyde in a little methanol was added to a suspension of freshly precipitated silver oxide (5 equiv.) in water–methanol (9 : 1 v/v). After being shaken for a few minutes the mixture was filtered and the black precipitate was washed with a little 0·2N-sodium hydroxide. The alkaline filtrate and washings were washed with ether and then acidified with 2N-sulphuric acid to pH 2. Ether extraction gave the acid.

(a) 6-endo-*Chlorobicyclo*[3.1.0]*hexane*-6-exo-*carboxylic acid*. The bicyclohexane-6-*exo*-carbaldehyde (12) (117 mg) gave the corresponding 6-exo-*carboxylic acid* (14) (98 mg), m.p. 101—102·5° (from pentane at −40°), raised to 103—104° by sublimation under reduced pressure (Found: C, 52·4; H, 5·65. $C_7H_9ClO_2$ requires C, 52·4; H, 5·65%). Titration of the α-chloro-acid at 20° by the method of Albert, Brown, and Cheeseman,[24] monitoring the pH, gave a pK_a value of 3·03 ± 0·11 (monochloracetic acid gave a pK_a of 2·98 ± 0·12 by this method against a literature value of 2·86).

(b) 6-exo-*Chlorobicyclo*[3.1.0]*hexane*-6-endo-*carboxylic acid*. The bicyclohexane-6-*endo*-carbaldehyde (13) (370

[23] M. Dennstedt, *Ber.*, 1880, **13**, 229.

[24] A. Albert, D. J. Brown, and G. Cheeseman, *J. Chem. Soc.*, 1951, 474.

mg) yielded the 6-endo-*carboxylic acid* (15) (305 mg), crystallised with some loss from benzene–methylcyclohexane–pentane (to give 165 mg), m.p. 118—120° (Found: C, 52·45; H, 5·65%), pK_a 2·82 ± 0·01.

(c) 6-endo-*Chlorobicyclo*[3.1.0]*hex*-2-*ene*-6-exo-*carboxylic acid* (7). The bicyclohexene-*exo*-carbaldehyde (5) (70 mg) yielded the corresponding *exo*-acid (40 mg) containing a small amount of benzoic acid (n.m.r.). Recrystallisation from hot water gave a high yield of benzoic acid, m.p. 121·5°, and chloride ion ($AgNO_3$ test). It was convenient to use crude aldehyde (5) (960 mg) containing ~10% of the epimeric *endo*-aldehyde (6). Oxidation yielded exo-*acid* (7), m.p. 110—112° raised to 114—114·5 by crystallisation from pentane (Found: C, 52·85; H, 4·35; Cl, 22·6. $C_7H_7ClO_2$ requires C, 53·0; H, 4·45; Cl, 22·4%). Evolution of gas was noted on melting, and the cooled sample melted at 121·5° (benzoic acid).

[Similar oxidation of the *endo*-bicyclohexenecarbaldehyde (6) and its valence tautomer (9) gave only traces of acidic material, as did a combined ring contraction and oxidation using sodium hydroxide and silver oxide on the *exo*-alcohol (3).]

Catalytic hydrogenation of the bicyclohexene-*exo*-carboxylic acid (7) over platinum oxide in methyl acetate gave the dihydro-*exo*-acid (14) which was obtained previously from the dihydro-*endo*-alcohol (10) *via* the dihydro-*exo*-carbaldehyde (12) and had m.p. and mixed m.p. 102°. The two samples had identical i.r. spectra.

Dechlorination of the α-Chloro-acids.—(*a*) *endo*-Chlorobicyclohexane-*exo*-carboxylic acid (14) (230 mg) in liquid ammonia was treated with an excess of sodium to give a permanent blue colour. After 7 min excess of ammonium chloride was added. After evaporation of the ammonia, the residue was taken up in water and acidified. Ether extraction gave a mixture of bicyclo[3.1.0]hex-2-en-6-*endo*- (18) and -*exo*- (17) carboxylic acids. G.l.c. analysis of the methyl esters (CH_2N_2) indicated an *endo* : *exo* ratio of 67·8 : 32·2. A distilled sample of esters was analysed (Found: C, 68·25; H, 8·8. $C_8H_{12}O_2$ requires C, 68·5; H, 8·6%).

(*b*) Similarly, the *exo*-chlorobicyclohexane-*endo*-carboxylic acid (15) (107 mg) gave the dechlorinated *endo*- and *exo*-acids (ratio of methyl esters 68·7 : 31·3).

A made-up mixture of *endo*- and *exo*-acids in the ratio of 68 : 32 had an i.r. spectrum identical with that of the two dechlorinated products.

Bicyclo[3.1.0]*hexane*-6-exo-*carboxylic Acid.*—Bicyclo[3.1.0]hexane-6-*endo*-carboxylic acid (490 mg) was heated under reflux with acetic anhydride (3 ml) containing sodium acetate (anhydrous; 200 mg) for 18 h. The cooled mixture was cautiously added to water (50 ml) and after 3 h ether extraction gave the *exo*-acid, m.p. 61—62° in high yield. (This procedure was preferred to that of Meinwald.[10])

7,7-*Dichloro*-6-*methylbicyclo*[3.2.0]*hept*-2-*en*-6-exo- *and* -endo-*ols* [(20) *and* (19) *respectively*].—A standardised (Zerewitnoff) ethereal solution of methylmagnesium iodide (10% excess) was added dropwise to the dichloro-ketone (1) (10·0 g) in ether (200 ml). 5 Min after the addition was complete water (500 ml) was added, dropwise until obvious reaction had ceased, then all at once. The suspension was extracted with dichloromethane and the dried extracts yielded the mixture of epimeric alcohols (9·3 g). Integration of the two methyl signals at δ 1·46 and 1·37 p.p.m. in the n.m.r. spectrum showed *endo*- and *exo*-alcohols to be present in a ratio of 67 : 33. Complete separation was achieved by chromatography, benzene first eluting the 6-endo-*alcohol* (19) (4·95 g; 45%) as an oil, purified by bulb-to-bulb distillation, $\nu_{max.}$ 3605 and 1610 cm^{-1}, δ 6·18—5·61 (2H, m, olefin), 3·80 (1H, m, 1-H), 2·97 (1H, td, 5-H), 2·56—2·25 (3H, m, CH_2 and OH), and 1·46 p.p.m. (3H, s, CH_3) (Found: C, 50·2; H, 5·4; Cl, 36·85. $C_8H_{10}Cl_2O$ requires C, 49·8; H, 5·2; Cl, 36·7%). The endo-*phenylurethane* had m.p. 148—149° (Found: C, 58·4; H, 5·4. $C_{15}H_{15}Cl_2NO_2$ requires C, 57·7; H, 4·9%).

Next was eluted the 6-exo-*alcohol* (20) as needles, m.p. 80° (from methylcyclohexane) (1·83 g, 17%), $\nu_{max.}$ 3400 and 1604 cm^{-1}, δ 6·08—5·60 (2H, m, olefin), 4·00—3·68 (1H, m, 5-H), 3·18—2·78 (2H, m, 1-H and OH), 2·63—2·35 (2H, m, CH_2), and 1·37 p.p.m. (3H, s, CH_3) (Found: C, 49·65; H, 5·45; Cl, 36·45%). The phenylurethane had m.p. 115° (not analysed).

6-exo-*Acetyl*-6-*chlorobicyclo*[3.1.0]*hex*-2-*ene.*—The 6-*exo*-methylbicyclo[3.2.0]hepten-6-*endo*-ol (19) (200 mg) when treated with sodium hydroxide in the usual way for 5 min yielded the 6-*exo*-acetyl-6-chlorobicyclohexene (21) (135 mg, 83%) as an oil, $\nu_{max.}$ 1694 cm^{-1} (cyclopropyl conjugated C=O), δ 6·04—5·55 (2H, 2 × m, olefin), 3·00—2·13 (7H, m, CH_2, 1-H and 5-H, with s at 2·5, CH_3), no aromatic protons. The yellow 2,4-dinitrophenylhydrazone turned red on heating to 70—90° then melted at the same temperature as that of the acetophenone derivative (240—242°). On drying samples for analysis at 25° the colour turned from yellow to orange and analyses were high in C and N indicating loss of hydrogen chloride.

6-endo-*Acetyl*-6-*chlorobicyclo*[3.1.0]*hex*-2-*ene and the Valence Tautomer* 4-*Chloro*-3-*Methyl*-2-*oxabicyclo*[3.2.1]*octa*-3,6-*diene.*—The 6-*endo*-methyl-6-*exo*-bicyclo[3.2.0]heptanol (20) (200 mg) in methanol (0·5 ml) was shaken with sodium hydroxide (2N; 5 ml) for 2 min. The product was extracted with ether, washed with water, dried and distilled at 95° (air-bath) at 15 mmHg to yield the valence-tautomeric mixture of *endo*-acetyl derivative (22) and enol ether (23) as an oil (135 mg; 85%) (Found: C, 60·8, 61·6; H, 5·9, 5·95. C_8H_9ClO requires C, 61·4; H, 5·8%), $\nu_{max.}$ 1712 (CO) and 1645 cm^{-1} (enol ether), δ (ketone) 5·63 (m, olefin), 2·12 (s, COMe), 2·78—2·08 (extended m, remaining H); δ (enol ether) 6·50 (dd, $^3J_{6,7}$ 5·8, $^3J_{5,6}$ 2·2 Hz, H-6), 5·52 (dd, $^3J_{1,7}$ 2·5 Hz, H-7), 4·85 (m, H-1), 2·21 (m, H-5), 1·95 (m, 2 × H-8), and 1·73 p.p.m. (s, 3-Me). Integration showed the *endo*-acetyl derivative to be present as 27 ± 1% of the mixture. When the mixture was left for 1 day the n.m.r. spectrum changed markedly, indicating deep-seated rearrangement.

7,7-*Dichloro*-6-exo-*nitromethylbicyclo*[3.2.0]*hept*-2-*en*-6-endo-*ol* (24).—The dichloro-ketone (1) (6·55 g), nitromethane (15 ml), and triethylamine (4 ml) were set aside for 18 h with external cooling. Triethylamine hydrochloride (0·84 g) was filtered off and the mixture was partitioned between water and pentane–ether (50% v/v). The organic phase was washed with hydrochloric acid (0·5N) and water (twice). The solvent was removed and the black oily residue was distilled. The *nitromethyl derivative* (24) was collected between 120 and 125° at 0·1 mmHg as a yellow oil (Found: C, 40·85; H, 3·75; N, 5·5. $C_8H_9Cl_2NO_3$ requires C, 40·35; H, 3·8; N, 5·9%), $\nu_{max.}$ 3500 (OH), 1560, and 1380 cm^{-1} (NO_2), δ (CCl_4) 6·08, 5·80 (2 × m, H-2 and H-3), 4·71 (s, $CH_2{\cdot}NO_2$), 3·92 (m, H-1), 3·39 (dt, H-5), 3·20br (s, OH), and 3·0—2·2 p.p.m. (m, allylic CH_2). A small peak at δ 4·51 p.p.m. ($CH_2{\cdot}NO_2$) indicated ~7% of 6-*exo*-alcohol present.

6-endo-*Chloro*-6-exo-*nitroacetylbicyclo*[3.2.1]*hex*-2-*ene.*—

The nitromethyl alcohol (24) (1 g) in methanol (2 ml) was shaken with sodium hydroxide (2N; 15 ml) for 2 min. After the initial emulsion had dissolved, the sodium salt of the product precipitated and was filtered off and washed with a little ice–water (620 mg). Attempted crystallisation of the salt from aqueous ethanol gave 2-nitroacetophenone, m.p. 105° (Found: C, 57·25; H, 4·25; N, 8·8. Calc. for $C_8H_7NO_3$: C, 57·7; H, 4·3; N, 8·6%). The sodium salt was suspended in dichloromethane and was shaken with 0·5N-hydrochloric acid. The dried organic phase gave a high yield of exo-*nitroacetyl* derivative (25), m.p. 81° (from benzene–pentane), $\nu_{max.}$ (mull) 1702 (C=O), 1562, and 1382 cm^{-1} (NO_2), δ 5·96 and 5·72 (2 × m, H-2 and H-3), 5·79 (s, $CO{\cdot}CH_2{\cdot}NO_2$), 3·03 (m, H-1), and 2·82—2·50 p.p.m. (m, H-5 and allylic methylene) (Found: C, 47·3; H, 3·9; N, 7·4. $C_8H_8ClNO_3$ requires C, 47·1; H, 4·0; N, 7·0%).

7,7-*Dichloro*-6-*methoxycarbonylmethylenebicyclo*[3.2.0]*hept*-2-*ene*.—The dichloro-ketone (1) (5·17 g) in chloroform (12 ml) was treated with methoxycarbonylmethylenetriphenylphosphorane (26; R = Me) (9·8 g) with external cooling to 20°. After 17 h the chloroform was replaced by pentane (20 ml), triphenylphosphine oxide was filtered off, and the filtrates were evaporated to yield an oil which was distilled to give the *ester* (28; R = Me) (6·24 g), b.p. 152—155° at 15 mmHg, $\lambda_{max.}$ 227 nm (ε 11,200), $\nu_{max.}$ 1712 (CO), 1680, and 1612 cm^{-1} (C=C), δ 6·19 (d, $MeO_2C{\cdot}CH$), 6·02 and 5·80 (2 × m, H-2, H-3), 4·04 (2H, m, H-1, H-5), 3·73 (s, OMe), and 2·77 p.p.m. (2H, m, CH_2) (Found: C, 53·0; H, 5·15. $C_{11}H_{12}Cl_2O_2$ requires C, 53·45; H, 5·15%). No other geometric isomer was detected. Similar results were obtained using refluxing benzene in place of chloroform.

When the reaction was carried out in refluxing methanol for 45 min the same Wittig product was obtained in lower yield together with a mixture of *cis*- and *trans*- ring-opened methyl 2-dichloromethylcyclopent-3-enecarboxylates formed by attack of methoxide ion on the dichloro-ketone (1).

When the ketone (1) (400 mg) in dimethylformamide (6 ml) with lithium chloride (anhydrous; 160 mg) was heated on a water-bath with the phosphorane (26; R = Me) (750 mg) for 3 h the product obtained was at least 96% the same geometric isomer as above; a small peak (4%) with shorter elution time could have been the other isomer. Some unchanged ketone was also noted (g.l.c. analysis).

The corresponding *ethyl ester* Wittig product (28; R = Et) was prepared in refluxing benzene from the ethoxycarbonylphosphorane (26; R = Et): b.p. 160° at 18 mmHg, $\nu_{max.}$ 1713 and 1682 cm^{-1}, δ 6·10 (d, J 2·2 Hz, methylene CH), 5·97, 5·76 (2H, 2 × m, olefinic proton), 4·13 (q, CH_2CH_3), 4·00 (m, H-1 and H-5), 2·73 (m, allylic CH_2), and 1·28 p.p.m. (t, CH_3) (Found: C, 53·5; H, 5·15. $C_{11}H_{12}Cl_2O_2$ requires C, 53·45; H, 4·9%).

In methanol–2N-sodium hydroxide (1 : 1) both esters underwent a rapid, slightly exothermic, hydrolysis to give after 1 min a moderate yield of the corresponding *acid*, m.p. 102—104·5° [from petroleum (b.p. 60—80°)], δ 11·0 (s, OH), 6·20 (d, methylene), 6·02, 5·83 (2 × m, remaining olefinics), 4·06 (m, H-1 and H-5), and 2·78 p.p.m. (m, allylic CH_2) (Found: C, 49·95; H, 3·95. $C_9H_8Cl_2O$ requires C, 49·2; H, 3·7%).

No ring contracted acid or ester formed by initial Michael-type addition of hydroxide ion to the exocyclic double bond was detected in these experiments.

[2/2561 *Received*, 12*th November*, 1972]