

## Iodoacetoxylation of 3-t-Butylcyclohexene

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Iodoacetoxylation of 3-t-butylcyclohexene with silver(I) acetate-iodine or thallium(I) acetate-iodine gives an *ca.* 3 : 1 mixture of *t*-2-iodo-*t*-3-t-butylcyclohexan-*r*-1-yl acetate and *t*-2-iodo-*c*-3-t-butylcyclohexan-*r*-1-yl acetate as the major products. The ratio is similar to that obtained for the major alcohols from reduction of the iodo-acetates with tri-*n*-butyltin hydride followed by lithium aluminium hydride, but differs from that obtained by Freppel and Richer for the vicinal diols prepared from a Woodward-Prévost reaction with 3-t-butylcyclohexene. The difference is explained by showing that solvolysis of the diaxial iodo-acetate (2) proceeds in a non-stereospecific manner.

FROM differences between the effects of thallium(I) and silver(I) salts in Prévost reactions with norbornene,<sup>1</sup> it appeared that the nucleophile might play an important role in some thallium(I)-mediated Prévost reactions. We have therefore studied the behaviour of 3-t-butylcyclohexene (1), since Bellucci and his co-workers<sup>2</sup> have suggested that electrophilic additions which occur stereoselectively *syn* to the *t*-butyl group of this substrate involve rate-determining attack by the nucleo-

phile, whereas those which occur stereoselectively *anti* to the *t*-butyl group involve rate-determining attack by the electrophile. Thus, any differences between thallium(I)- and silver(I)-mediated Prévost reactions might be more apparent with this substrate. The Prévost reaction of *t*-butylcyclohexene with silver(I) acetate has already been examined by Freppel and Richer,<sup>3</sup> who obtained data which Bellucci and his co-workers<sup>4</sup> suggest are consistent with the proposal that

<sup>1</sup> R.-C. Cambie, B. G. Lindsay, P. S. Rutledge, and P. D. Woodgate, *J.C.S. Perkin I*, 1976, 845.

<sup>2</sup> G. Bellucci, G. Berti, G. Ingrosso, and E. Mastrorilli, *Tetrahedron Letters*, 1973, 3911.

<sup>3</sup> C. Freppel and J.-C. Richer, *Tetrahedron Letters*, 1972, 2321.

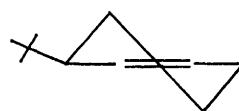
<sup>4</sup> G. Bellucci, G. Ingrosso, F. Marioni, E. Mastrorilli, and I. Morelli, *J. Org. Chem.*, 1974, **39**, 2562.

both the stereo- and the regio-selectivity of iodo-acetoxylation are determined mainly by substituent effects during the nucleophilic step. Freppel and Richer did not analyse the primary products (iodo-acetates) of this reaction but claimed that they were unstable, transforming them during the course of a Woodward-Prévost reaction<sup>5</sup> into a mixture of diols which was analysed by g.l.c. The diol composition was then taken as a measure of the iodo-acetates which in turn, was taken to indicate the ratio of *cis*-\* to *trans*-iodonium ions, *viz.* 53:47, formed in the initial step. However, the validity of this ratio is open to question if the iodo-acetates themselves have not been isolated and independently converted into diols. Since our earlier work<sup>1,6,7</sup> has shown that iodo-carboxylates are not solvolysed as readily during thallium(I)-mediated reactions, and that vicinal iodo-acetates are generally of sufficient stability to permit isolation and spectral analysis, the action of thallium(I) acetate and iodine on 3-*t*-butylcyclohexene has been investigated.

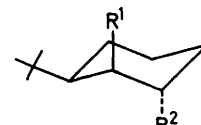
Treatment of 3-*t*-butylcyclohexene with thallium(I) acetate-iodine in either acetic acid or dichloromethane consistently gave a 3:1 ratio (<sup>1</sup>H n.m.r. analysis) of *t*-2-iodo-*t*-3-*t*-butylcyclohexan-*r*-1-yl acetate (2) and *t*-2-iodo-*c*-3-*t*-butylcyclohexan-*r*-1-yl acetate (9), which were separated by p.l.c. No evidence was obtained for the presence of *t*-2-iodo-*c*-6-*t*-butylcyclohexan-*r*-1-yl acetate (3) and *c*-2-iodo-*c*-6-*t*-butylcyclohexan-*r*-1-yl acetate (10), expected as minor products by analogy with the bromo-acetates obtained from the same substrate,<sup>8</sup> but they may well have been present in less than 5% yield and hence remained undetected by <sup>1</sup>H n.m.r. analysis (see later). Attempts were made to analyse the crude product mixture by g.l.c. but, not unexpectedly (*cf.* ref. 8), conditions were not found under which the iodo-acetates (2) and (9) were thermally stable.

The structures of the iodo-acetates (2) and (9) were assigned on the basis of spectral data. The <sup>1</sup>H n.m.r. spectrum of the major product (2) showed a broad singlet at  $\delta$  4.47 and a four-line multiplet at  $\delta$  5.14 which were assigned to the protons geminal to the iodo- and acetoxy-groups, respectively. The half-height width (6 Hz) of the signals suggested that the protons were equatorial, and thus that the substituents were both axial. The greater multiplicity of the signal at  $\delta$  5.14 indicated that the acetoxy-group was not vicinal to the *t*-butyl group, thereby ruling out the alternative possibility (3). The structure of the iodo-acetate (2) was confirmed by reduction with lithium aluminium hydride to *t*-3-*t*-butylcyclohexan-*r*-1-ol (4) and by conversion with base into the known *trans*-epoxide (15).<sup>9</sup> The <sup>1</sup>H n.m.r. spectrum of the minor product (9) showed a triplet at  $\delta$  4.15 with observed coupling constants 6 Hz and a multiplet at  $\delta$  5.13 with half-height width 13 Hz,

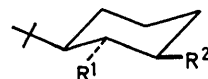
from which the iodo- and acetoxy-substituents were assigned as equatorial. The multiplicity of the signal due to the proton geminal to the iodo-group indicated that the latter was vicinal to the *t*-butyl group.



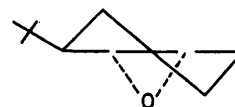
(1)



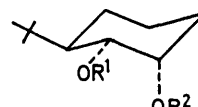
- (2)  $R^1 = I, R^2 = OAc$   
 (3)  $R^1 = OAc, R^2 = I$   
 (4)  $R^1 = H, R^2 = OH$   
 (5)  $R^1 = OH, R^2 = H$   
 (6)  $R^1 = Br, R^2 = OH$   
 (7)  $R^1 = I, R^2 = OH$   
 (8)  $R^1 = OH, R^2 = I$



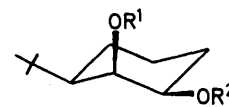
- (9)  $R^1 = I, R^2 = OAc$   
 (10)  $R^1 = OAc, R^2 = I$   
 (11)  $R^1 = OH, R^2 = H$   
 (12)  $R^1 = H, R^2 = OH$   
 (13)  $R^1 = Br, R^2 = OAc$   
 (14)  $R^1 = OH, R^2 = I$



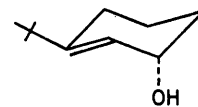
(15)



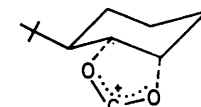
- (16)  $R^1 = H, R^2 = Ac$   
 (17)  $R^1 = Ac, R^2 = H$   
 (18)  $R^1 = R^2 = H$



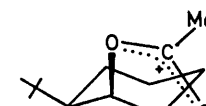
- (19)  $R^1 = Ac, R^2 = H$   
 (20)  $R^1 = R^2 = H$   
 (21)  $R^1 = H, R^2 = Ac$



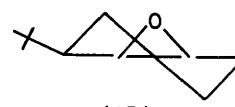
(22)



(23)



(24)



(25)

In view of their thermal instability and recognising that all four possible iodo-acetates were expected as primary products (*cf.* ref. 8), we directed our attention towards converting the crude product mixture into compounds which were amenable to g.l.c. analysis. We required that any such conversion should proceed

\* Relative to the *t*-butyl group.

<sup>5</sup> R. B. Woodward and F. V. Brutcher, *J. Amer. Chem. Soc.*, 1958, **80**, 209.

<sup>6</sup> R. C. Cambie, R. C. Hayward, J. L. Roberts, and P. S. Rutledge, *J.C.S. Perkin I*, 1974, 1120, 1858.

<sup>7</sup> P. H. Atkinson, R. C. Cambie, G. Dixon, W. I. Noall, P. S. Rutledge, and P. D. Woodgate, *J.C.S. Perkin I*, 1977, 230.

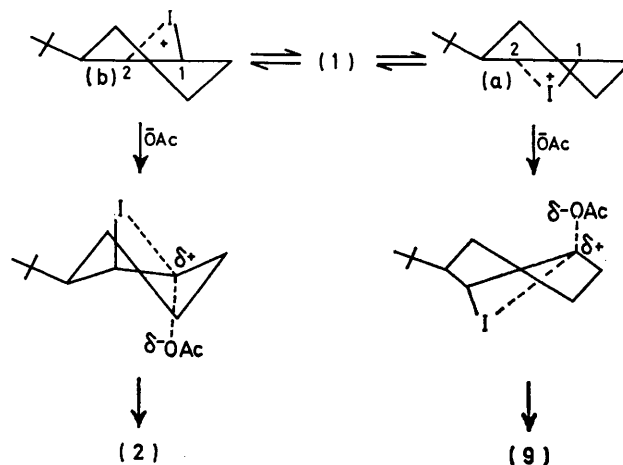
<sup>8</sup> G. Bellucci, M. Ferretti, G. Ingrosso, F. Marioni, A. Marsili, and I. Morelli, *Tetrahedron Letters*, 1972, **34**, 3527.

<sup>9</sup> J.-C. Richer and C. Freppel, *Canad. J. Chem.*, 1968, **46**, 3709.

quantitatively and without rearrangement (or with uniquely predictable rearrangement) of the functionality originally present, in order that the products might provide a valid reflection of the initial ratio of the iodoacetates. Thus, direct reduction of the crude iodoacetates with lithium aluminium hydride was not suitable, since the pure iodoacetate (2) did not afford a quantitative yield of the desired product (4): partial reduction to the iodohydrin (7), as well as some elimination to form 3-*t*-butylcyclohexene also occurred. Similarly, sodium bis-(2-methoxyethoxy)aluminium hydride gave a mixture of the alcohols (4) and (7), the epoxide (15), and the alkene (1). However, interaction of the vicinal iodo- and acetoxy-groups was avoided by reduction of the iodoacetate mixture to the corresponding acetates with a low concentration of tri-*n*-butyltin hydride.<sup>10</sup> Subsequent treatment with lithium aluminium hydride gave a  $72 \pm 3 : 2 : 4 : 22 \pm 2$  ratio of the alcohols (4), (5), (11), and (12), the first three of which were identified by g.l.c. comparison with authentic samples. A pure sample of the alcohol (12) was not available, but all four compounds ran concurrently with a mixture of the alcohols produced by reduction of a mixture of the *cis*- (6%) and *trans*- (94%) epoxides of 3-*t*-butylcyclohexene<sup>9</sup> with sodium bis-(2-methoxyethoxy)aluminium hydride. Although it is possible that the minor products (5) and (11) could have arisen from (9) and (2), respectively, by acetate migration during treatment with tri-*n*-butyltin hydride (*cf.* ref. 11), their low yields (<5%) and the close similarity of the ratio of (4) to (12) from g.l.c. to that of (2) to (9) from <sup>1</sup>H n.m.r. strongly suggests that both (5) and (11) arise from small amounts of undetected iodoacetates (3) and (10) formed during the initial iodoacetoxylation. Although there was some variation in the ratio of the alcohols over several runs, the average ratio of the major alcohols (4) and (12) was close to that obtained from <sup>1</sup>H n.m.r. analysis of the crude iodoacetate mixture and distinct from the ratio implied by Freppel and Richer.<sup>3</sup> Furthermore, repetition of the Prévost reaction with 3-*t*-butylcyclohexene using silver(I) acetate-iodine in either acetic acid at high dilution (to minimise further reaction of the iodoacetates) or dichloromethane gave results which were almost identical with those obtained using thallium(I) acetate-iodine. Thus, no difference was apparent between thallium(I)- and silver(I)-mediated reactions.

It is suggested that the iodoacetates (2) and (9) arise by the reversible formation of asymmetric<sup>12</sup> iodonium ions (Scheme). As already established,<sup>8</sup> the higher steric repulsive interaction between the attacking nucleophile and the *t*-butyl group will result in a strong preference for attack on the iodonium ions at C-1. The presumably less stable *cis*-iodonium ion (b) would be expected to react more rapidly with the nucleophile than would the *trans*-iodonium ion to give the *trans*-diaxial iodoacetate (2) as the major product by antiparallel opening. Anti-

parallel opening of the *trans*-iodonium ion (a) at C-2 would be impeded by the *t*-butyl group and hence the ion (a) would be expected to react more slowly with the nucleophile by parallel opening *via* a twist-boat conformation. That the diequatorial iodoacetate (9) is formed from (a) rather than the thermodynamically more stable<sup>8</sup> *trans*-diaxial iodoacetate (3), suggests that the second stage of the reaction is kinetically controlled.



SCHEME

In the case of bromoacetoxylation of 3-*t*-butylcyclohexene,<sup>8</sup> the major product (13) arises from the *trans*-bromonium ion corresponding to the iodonium ion (a). In order to explain their results, Bellucci and his co-workers<sup>8</sup> suggested a pathway involving irreversible formation of bromonium ion intermediates, 'the overall process being thus controlled first by the relative rates of attack *cis* and *trans* to the *t*-butyl group by positive bromine and then by that of nucleophilic attack on C-1 and C-2 of the bromonium ions.' On the other hand, the bromohydrin (6) was the major product from the action of *N*-bromosuccinimide or *N*-bromoacetamide on 3-*t*-butylcyclohexene. In this case the system behaves in a manner analogous to that of iodoacetoxylation.

In order to examine why the ratio of iodoacetates obtained above was different from that obtained by Freppel and Richer for the derived diols, the iodoacetates were examined further. Solvolysis of the diaxial iodoacetate (2) with silver(I) acetate in acetic acid at 20 °C for 24 h gave three hydroxyacetates, (16), (17), and (19), in the ratio 23 : 36 : 36.\* Solvolysis of the mixed iodoacetates (2) and (9) in benzene gave a similar mixture in which *c*-2-hydroxy-*c*-6-*t*-butylcyclohexan-*r*-1-yl acetate (19) was now the major component and from which it was isolated pure by p.l.c. Structures of the hydroxyacetates were assigned from their <sup>1</sup>H n.m.r. spectral parameters (see Experimental section). That of the hydroxyacetate (19) was confirmed by reduction with lithium aluminium hydride to

<sup>10</sup> E. J. Corey and J. W. Suggs, *J. Org. Chem.*, 1975, **40**, 2554; H. G. Kuivila, *Accounts Chem. Res.*, 1968, **1**, 299.

<sup>11</sup> S. Julia and R. Lorne, *Compt. rend.*, 1971, **273C**, 174.

<sup>12</sup> P. B. D. de la Mare, *Progr. Stereochem.*, 1953, **1**, 118.

\* The <sup>1</sup>H n.m.r. spectrum of the crude product also indicated the presence of a trace of the hydroxyacetate (21).

a product with spectral data identical with those recorded for the diol (20).<sup>13</sup> Direct comparison showed that it was not identical with the diol (18) having similar m.p. and spectral data, which was obtained by osmylation<sup>14</sup> of 3-t-butylcyclohexene. Reduction of the mixed hydroxy-acetates (16), (17), and (19) gave a 2 : 1 mixture (<sup>1</sup>H n.m.r. analysis) of the *cis*-diols (18) and (20) but after p.l.c. also afforded the allylic alcohol (22) in 10% yield. The latter appeared to originate from the diol (20) since the ratio of compounds (18) and (20) was now 3 : 1.

The hydroxy-acetates (16) and (17) presumably arise from solvolysis *via* the *trans*-dioxolan-2-ylum ion (23). The formation of the hydroxy-acetate (19) as a solvolysis product is difficult to explain, since it would be expected as a product of the *cis*-dioxolan-2-ylum ion (24) but not of the ion (23). A number of pathways to the hydroxy-acetate (19) can be postulated but no supporting evidence for any one of them is at present available.

Solvolysis of the iodo-acetate (9) with silver(I) acetate in acetic acid gave two hydroxy-acetates (19) and (21) in 58 and 21% yields, respectively. Each presumably arises from the *cis*-dioxolan-2-ylum ion (24), although the possible intervention of an *anti*-dioxolan-2-ylum ion<sup>15</sup> cannot be ruled out. Reduction of the mixture with lithium aluminium hydride gave the diol (20) as the only major product. Since the hydroxy-acetate (19) is formed from both iodo-acetates on solvolysis Freppel and Richer's ratio cannot reflect a true ratio between the *cis*- and the *trans*-iodonium ion formed in the initial step. Of interest is the fact that the current *syn* : *anti* ratio for iodoacetoxylation, *viz.* 3 : 1, is now similar to that for addition of iodine azide and of hypoiodous acid to 3-t-butylcyclohexene.<sup>4</sup>

Richer and Freppel<sup>9</sup> obtained the four t-butylcyclohexanols (4), (5), (11), and (12) by reduction of a mixture of the *cis*- and *trans*-epoxides (25) and (15) with lithium aluminium hydride, the last three alcohols also being formed by reduction of the pure *trans*-epoxide (15). If the *trans*-epoxide opened in an antiparallel manner, the alcohol (4) would arise by *syn* (to the t-butyl group) approach of the hydride ion, the consequent steric interaction thereby accounting for the low yield (maximum 50%) obtained by these workers. As expected, in the present study reduction of a 94 : 6 mixture of the epoxides (15) and (25) with the more bulky reducing agent sodium bis-(2-methoxyethoxy)aluminium hydride gave only a 34% yield of the alcohol (4). Richer and Freppel attributed the formation of the alcohol (12) to reduction of 3-t-butylcyclohexanone formed by rearrangement of the epoxide (15). They explained the formation of the alcohol (11) by postulating that the t-butyl group adopts an axial position when the *trans*-

epoxide is opened (*cf.* ref. 16) as a result of conformational inversion of the ring. A more likely possibility is that reaction occurs *via* a twist-boat-like transition state, similar to that proposed (see before) for the formation of the diequatorial iodo-acetate (9) from the *trans*-iodonium ion (a) (Scheme). Distortion of the cyclohexane ring about C-1 and C-2, while still retaining the near-equatorial disposition of the t-butyl group, would allow *syn* approach (to the t-butyl group) of the hydride ion to give attack at the preferred position, *viz.* C-1, from a pseudoaxial direction. Reversion to the more stable chair conformation would then yield the alcohol (11).

During early attempts to characterise the iodo-acetates (2) and (9), an attempt was made to convert the 94 : 6 mixture of epoxides (15) and (25) into the corresponding iodohydrins by treatment with sodium iodide-sodium acetate in glacial acetic acid-ethyl acetate. This afforded the iodohydrins (14), (7), and (8) in the ratio 58 : 18 : 24. Compound (14) could arise from the *trans*-epoxide by attack of iodide anion at C-1 *via* a twist-boat transition state analogous to that discussed earlier; compound (7) could arise by normal antiparallel opening of the *trans*-epoxide. The iodohydrin (8) is the product expected from antiparallel opening of the *cis*-epoxide (25) but since the latter constituted only 6% of the original epoxide mixture some of the iodohydrin must have arisen from the *trans*-epoxide (15).

From the <sup>1</sup>H n.m.r. spectrum of the iodohydrin (14), the measured  $J_{2\alpha,3\beta} + J_{2\alpha,3\alpha}$  value is 16.9 Hz, which implies<sup>17</sup> that there is no distortion in ring geometry and that the compound exists in a chair conformation (*cf.* ref. 14 for the analogous bromohydrin). The structure of the iodohydrin (7) was confirmed by an examination of its <sup>1</sup>H n.m.r. spectrum with use of the shift reagent Eu(fod)<sub>3</sub> in conjunction with decoupling experiments.

#### EXPERIMENTAL

General experimental details are given in refs. 6 and 18.

*Iodoacetoxylations of 3-t-Butylcyclohexene.*—(a) *In dichloromethane.* A solution of iodine (0.18 g, 0.72 mmol) in dichloromethane (35 ml) was added dropwise to a stirred suspension of silver(I) acetate (0.15 g, 0.87 mmol) or thallium(I) acetate (0.23 g, 0.87 mmol) and 3-t-butylcyclohexene<sup>9</sup> (0.10 g, 0.72 mmol) in dichloromethane (5 ml). The mixture was stirred at 20 °C for 22 h and the precipitate was removed and washed with dichloromethane (10 ml). The organic phase was washed successively with aqueous sodium disulphite, water, and brine, and solvent removed from the dried solution *in vacuo* at 20 °C. <sup>1</sup>H N.m.r. analysis of the crude products (68–77%) showed the presence of two major products (3 : 1) which were separated by multiple p.l.c. (hexane-ether, 9 : 1) into (i) t-2-iodo-t-3-t-butylcyclohexan-r-1-yl acetate (2) (Found:  $M^{+}$ , 324.0600.

<sup>13</sup> J.-C. Richer and C. Freppel, *Canad. J. Chem.*, 1970, **48**, 145.

<sup>14</sup> P. L. Barili, G. Bellucci, B. Macchia, F. Macchia, and G. Parmigiani, *Gazzetta*, 1971, **101**, 300.

<sup>15</sup> H. Paulsen, H. Höhne, and P. L. Durette, *Chem. Ber.*, 1976, **109**, 597; H. Paulsen and R. Dammeyer, *ibid.*, p. 605.

<sup>16</sup> B. Rickborn and W. E. Lamke, *J. Org. Chem.*, 1967, **32**, 537.

<sup>17</sup> C. Altona, H. R. Buys, H. J. Hageman, and E. Havinga, *Tetrahedron*, 1967, **23**, 2265.

<sup>18</sup> R. C. Cambie, R. C. Hayward, B. G. Lindsay, A. I. T. Phan, P. S. Rutledge, and P. D. Woodgate, *J.C.S. Perkin I*, 1976, 1961.

$C_{12}H_{21}IO_2$  requires  $M$ , 324.0586),  $\delta$  0.95 (s,  $CM_e_3$ ), 2.03 (s, OAc), 4.67br (s,  $W_{\frac{1}{2}}$  6 Hz, 2-H), and 5.14 (m,  $W_{\frac{1}{2}}$  6 Hz, 1-H),  $m/e$  265.0465 ( $M^{+} - OAc$ ), 264.0336 ( $M^{+} - HOAc$ ), 197.1556 ( $M^{+} - I$ ), and 138.1347 ( $M^{+} - IOAc$ ); and (ii) *t*-2-iodo-*c*-3-*t*-butylcyclohexan-*r*-1-yl acetate (9),  $\delta$  1.05 (s,  $CM_e_3$ ), 2.01 (s, OAc), 4.15 (t,  $J_{obs}$  6 Hz, 2-H), and 5.13 (m,  $W_{\frac{1}{2}}$  13 Hz, 1-H).

(b) *In acetic acid*. A solution of iodine (0.18 g, 0.72 mmol) in dry acetic acid (75 ml) was added dropwise to a stirred solution of silver(I) acetate (0.15 g, 0.87 mmol) or thallium(I) acetate (0.23 g, 0.87 mmol) and 3-*t*-butylcyclohexene (0.10 g, 0.72 mmol) in dry acetic acid (5 ml). The mixture was stirred at 20 °C for 2 h, the precipitate was removed and washed with ether, and the liquid phase was poured into water and extracted with ether. The combined extract and washings were worked up as in (a) to give a product (68%) containing a 3:1 mixture of the iodo-acetates (2) and (9).

*Reduction of t-2-Iodo-t-3-t-butylcyclohexan-r-1-yl Acetate*.—The iodo-acetate (2) (43 mg, 0.13 mmol) was reduced with lithium aluminium hydride (0.11 g, 2.77 mmol) in dry ether (13 ml) at 20 °C for 24 h. Work-up in the normal manner gave *t*-3-*t*-butylcyclohexan-*r*-1-ol (4) <sup>9</sup> (16 mg, 77%),  $\nu_{max}$  ( $CCl_4$ ) 3 650, 3 420, 975 (OH), and 1 370  $cm^{-1}$  ( $CM_e_3$ ),  $\delta$  0.83 (s,  $CM_e_3$ ), 1.25br (s, OH, exchanged with  $D_2O$ ), and 4.07br (s,  $W_{\frac{1}{2}}$  8 Hz, 1-H), and traces of *t*-2-iodo-*t*-3-*t*-butylcyclohexan-*r*-1-ol (7) (see later) and 3-*t*-butylcyclohexene.

*r*-1,2-Epoxy-*t*-3-*t*-butylcyclohexane (15).—A suspension of potassium carbonate (49 mg, 0.35 mmol) in 50% aqueous methanol (10 ml) containing the iodo-acetate (2) (57 mg, 0.18 mmol) was stirred at 20 °C for 10 h. The mixture was poured into water and extracted with ether. Work-up gave a product (19 mg, 72%) containing starting material (17%; <sup>1</sup>H n.m.r. analysis) and *r*-1,2-epoxy-*t*-3-*t*-butylcyclohexane,  $\delta$  1.00 (s,  $CM_e_3$ ) and 2.92 (m,  $W_{\frac{1}{2}}$  7 Hz, 1- and 2-H),  $m/e$  154.1355 ( $M^{+}$ ,  $C_{10}H_{18}O$ ).

*Solvolysis of the Iodo-acetates (2) and (9) in Benzene*.—A 3:1 mixture of the iodo-acetates (2) and (9) (1.53 g, 4.7 mmol) and silver(I) acetate (0.94 g, 5.63 mmol) were heated under reflux in benzene (20 ml) for 9 h. Work-up gave an oily mixture (1.28 g). Multiple p.l.c. (hexane-ether, 3:1) gave (i) the iodo-acetate (9) (0.15 g); (ii) *c*-2-hydroxy-*c*-6-*t*-butylcyclohexan-*r*-1-yl acetate (19) (0.11 g), plates (from pentane-ether), m.p. 79–80° (Found: C, 67.5; H, 10.3.  $C_{12}H_{22}O_3$  requires C, 67.3; H, 10.3%),  $\nu_{max}$  ( $CCl_4$ ) 3 480 (OH), 1 740 (OAc), 1 370 ( $CM_e_3$ ), and 1 240  $cm^{-1}$  (CO and  $CM_e_3$ ),  $\delta$  0.90 (s,  $CM_e_3$ ), 2.07 (s, OAc), 3.53 (m,  $W_{\frac{1}{2}}$  18 Hz, 2-H), and 5.43 (d,  $J_{obs}$  2 Hz, 1-H),  $m/e$  214 ( $M^{+}$ , <1%), 172 ( $M - COCH_2$ , 2%), 157 ( $M - CM_e_3$ , 8%), 98 (69%), 97 (100%), 83 (20%), and 57 ( $CM_e_3^{+}$ , 49%); and (iii) a mixture (72 mg) of *c*-2-hydroxy-*t*-6-*t*-butylcyclohexan-*r*-1-yl acetate (17),  $\nu_{max}$  ( $CCl_4$ ) 3 480 (OH), 1 720 (OAc), 1 370 ( $CM_e_3$ ), and 1 240  $cm^{-1}$  (CO and  $CM_e_3$ ),  $\delta$  0.92 (s,  $CM_e_3$ ), 2.05 (s, OAc), 3.97 (d,  $J_{obs}$  2 Hz, 2-H), and 4.68 (dd,  $J_{1,2}$  2,  $J_{1,6}$  10 Hz, 1-H), and *c*-2-hydroxy-*t*-3-*t*-butylcyclohexan-*r*-1-yl acetate (16),  $\nu_{max}$  ( $CCl_4$ ) 3 480 (OH), 1 720 (OAc), 1 370 ( $CM_e_3$ ), and 1 240  $cm^{-1}$  (CO and  $CM_e_3$ ),  $\delta$  0.98 (s,  $CM_e_3$ ), 2.10 (s, OAc), 3.50 (dd,  $J_{1,2}$  3,  $J_{2,3}$  10 Hz, 2-H), and 5.02 (d,  $J_{obs}$  3 Hz, 1-H).

*Solvolysis of t-2-Iodo-t-3-t-butylcyclohexan-r-1-yl Acetate*.—A mixture of the iodo-acetate (2) (0.19 g, 0.6 mmol) and silver(I) acetate (0.11 g, 0.68 mmol) in acetic acid (20 ml) was stirred at 20 °C for 24 h. Work-up gave a product (0.13 g) containing (<sup>1</sup>H n.m.r. analysis) *c*-2-hydroxy-*t*-3-

*t*-butylcyclohexan-*r*-1-yl acetate (16) (23%), *c*-2-hydroxy-*t*-6-*t*-butylcyclohexan-*r*-1-yl acetate (17) (36%), *c*-2-hydroxy-*c*-6-*t*-butylcyclohexan-*r*-1-yl acetate (19) (36%), *c*-2-hydroxy-*c*-3-*t*-butylcyclohexan-*r*-1-yl acetate (21) (trace; see later), and unidentified material (5%).

*Reduction of c-2-Hydroxy-c-6-t-butylcyclohexan-r-1-yl Acetate*.—The hydroxy-acetate (19) (27 mg, 0.13 mmol) was reduced with lithium aluminium hydride (27 mg, 0.71 mmol) in dry ether (6 ml) at 20 °C for 4 h. Work-up and p.l.c. (hexane-ether, 4:1) gave *c*-3-*t*-butylcyclohexane-*r*-1,*c*-2-diol (20) (100%), m.p. 73–75° (lit.,<sup>13</sup> 78–79°),  $\nu_{max}$  ( $CCl_4$ ) 3 400 (OH) and 1 360  $cm^{-1}$  ( $CM_e_3$ ),  $\delta$  0.98 (s,  $CM_e_3$ ), 2.25 (s, OH, exchanged with  $D_2O$ ), 3.40 (m,  $W_{\frac{1}{2}}$  21 Hz, 1-H), and 4.00br (s,  $W_{\frac{1}{2}}$  6 Hz, 2-H),  $m/e$  172.1483 ( $M^{+}$ ,  $C_{10}H_{20}O_2$ , 18%), 157.1217 ( $M^{+} - CH_3$ , 21%), 154.1347 ( $M^{+} - H_2O$ , 3%), 139.1140 ( $M^{+} - H_2O - CH_3$ , 17%), 136.1273 ( $M^{+} - 2H_2O$ , 5%), 121.1025 ( $M^{+} - 2H_2O - CH_3$ , 11%), 98 (100%), 82 (28%), 70 (37%), and 57 (59%).

*Reduction of the Hydroxy-acetates (16), (17), and (19)*.—The foregoing mixture of hydroxy-acetates (16), (17), and (19) (58 mg, 0.27 mmol) was reduced with lithium aluminium hydride (99 mg, 2.6 mmol) in dry ether (13 ml) at 20 °C for 5 h. Work-up gave an oil (37 mg) which contained (<sup>1</sup>H n.m.r. analysis) a 2:1 mixture of the *cis*-diols (18) and (20). P.l.c. (hexane-ether, 2:3) gave (i) 3-*t*-butylcyclohex-2-enol (22) (10%),  $\delta$  1.08 (s,  $CM_e_3$ ), 4.37 (s,  $W_{\frac{1}{2}}$  8 Hz, 1-H), and 5.70 (s,  $J_{obs}$  3 Hz, 2-H); and (ii) a 3:1 mixture of *t*-3-*t*-butylcyclohexane-*r*-1,*c*-2-diol (18),<sup>14</sup>  $\delta$  1.05 (s,  $CM_e_3$ ), 2.05br (s, OH, exchanged with  $D_2O$ ), 3.53 (dd,  $J_{2,3}$  10,  $J_{1,2}$  3 Hz, 2-H), and 3.97br (s,  $W_{\frac{1}{2}}$  6 Hz, 1-H), and *c*-3-*t*-butylcyclohexane-*r*-1,*c*-2-diol (20).

*Solvolysis of t-2-Iodo-c-3-t-butylcyclohexan-r-1-yl Acetate*.—A mixture of the iodo-acetate (9) (0.14 g, 0.43 mmol) and silver(I) acetate (80 mg, 0.48 mmol) was stirred in acetic acid as for (2). Work-up gave a product containing (<sup>1</sup>H n.m.r. analysis) starting material (21%), *c*-2-hydroxy-*c*-6-*t*-butylcyclohexan-*r*-1-yl acetate (19) (58%), and *c*-2-hydroxy-*c*-3-*t*-butylcyclohexan-*r*-1-yl acetate (21) (21%),  $\delta$  1.07 (s,  $CM_e_3$ ), 2.08 (s, OAc), 4.65 (s,  $W_{\frac{1}{2}}$  2.5 Hz, 2-H), and 5.23br (s,  $W_{\frac{1}{2}}$  9 Hz, 1-H).

*Reduction of the Hydroxy-acetates (19) and (21)*.—The foregoing mixture of hydroxy-acetates (19) and (21) (61 mg, 0.29 mmol) was reduced with lithium aluminium hydride (55 mg, 1.45 mmol) in dry ether at 20 °C for 18 h. Work-up gave an oil which contained (<sup>1</sup>H n.m.r. analysis) starting materials, *c*-3-*t*-butylcyclohexane-*r*-1,*c*-2-diol (20), and traces of two minor compounds.

*Reduction of Iodoacetoxylated Products with Tri-n-butyltin Hydride*.—The cooled 3:1 mixture of iodo-acetates (2) and (9) (65 mg, 0.20 mmol) and freshly distilled tri-*n*-butyltin chloride (13 mg, 0.04 mmol) in dry ethanol (3 ml) were treated with a suspension of sodium borohydride (10 mg, 0.26 mmol) in ethanol (4 ml). The mixture was irradiated with a 100 W mercury lamp for 35 min and then treated with oxalic acid (2 mg). After 5 min, dichloromethane (20 ml) was added and the mixture worked up to give an oil. <sup>1</sup>H N.m.r. analysis showed that the major product was *t*-3-*t*-butylcyclohexan-*r*-yl acetate,  $\nu_{max}$  ( $CCl_4$ ) 1 750 (OAc) and 1 365  $cm^{-1}$  ( $CM_e_3$ ),  $\delta$  0.88 (s,  $CM_e_3$ ), 2.01 (s, OAc), and 5.03br (s,  $W_{\frac{1}{2}}$  7 Hz, 1-H).

*3-t-Butylcyclohexanols*.—The crude product (50 mg, 0.25 mmol) from the preceding experiment was reduced with lithium aluminium hydride (57 mg, 1.5 mmol) in dry ether at 20 °C for 22 h. Work-up gave an oil (27 mg) which contained (in order of increasing retention time on g.l.c.)

*c*-2-*t*-butylcyclohexan-*r*-1-ol (5), *t*-2-*t*-butylcyclohexan-*r*-1-ol (11), *t*-3-*t*-butylcyclohexan-*r*-1-ol (4), and *c*-3-*t*-butylcyclohexan-*r*-1-ol (12). The first three compounds were identified by co-injection with authentic samples. The average ratios of products from a series of reductions were 2 : 4 : 72 ± 3 : 22 ± 2, respectively, partial overlap of some peaks occurring under the g.l.c. conditions. Authentic samples of the alcohols (5) and (11) were obtained by p.l.c. separation of a commercial mixture of the stereoisomers.

*Reduction of the Epoxides (15) and (25) with Redal.*—A 94 : 6 mixture of *trans*- and *cis*-1,2-epoxy-3-*t*-butylcyclohexane (80 mg, 5.2 mmol) in benzene (5 ml) was reduced with a 70% solution of sodium bis-(2-methoxyethoxy)-aluminium hydride in benzene (1 ml, 0.36 mmol) at 20 °C for 6 h and then under reflux for 13 h. Work-up gave an oil (58 mg, 72%) which contained the alcohols (5), (11), (4), and (12) (identified as above) in the ratio 5 : 33 : 34 : 27.

*Reaction of the Epoxides (15) and (25) with Sodium Iodide–Sodium Acetate.*—A 94 : 6 mixture of *trans*- and *cis*-1,2-epoxy-3-*t*-butylcyclohexane (0.50 g, 3.3 mmol) was added to a suspension of sodium iodide (0.71 g, 4.7 mmol) and sodium acetate (67 mg, 0.82 mmol) in glacial acetic acid (5 ml) and ethyl acetate (8 ml) at –14 °C. The mixture was stirred for 10 min and then kept at 0 °C for 24 h.

Ether and brine were added and the mixture was worked up to give an oil (0.51 g) which contained four compounds. P.l.c. (hexane–ether, 95 : 5) gave (i) unidentified material (trace); (ii) *t*-2-iodo-*t*-6-*t*-butylcyclohexan-*r*-1-ol (14) (0.20 g),  $\nu_{\max}$  (CCl<sub>4</sub>) 3 550 (OH) and 1 360 cm<sup>-1</sup> (CMe<sub>3</sub>),  $\delta$  0.99 (s, CMe<sub>3</sub>), 2.22 (d,  $J_{1\beta\text{H},\text{OH}}$  2.5 Hz, OH, exchanged with D<sub>2</sub>O), 3.46 (6 lines,  $J_{1\beta\text{H},\text{OH}}$  2.5,  $J_{1\beta,6\alpha} + J_{1\beta,2\alpha}$  18.8 Hz, 1-H), and 4.17 (ABXYC system,  $\Delta\nu_{1\beta,2\alpha}$  42.5 Hz,  $J_{2\alpha,3\alpha} + J_{2\alpha,3\beta}$  16.9,  $J_{2\alpha,3\beta} + J_{2\alpha,3\alpha} + J_{1\beta,2\alpha}$  26.8 Hz, 2-H), *m/e* 282 (*M*<sup>+</sup>, <1%), 267 (1%), 265.0386 (*M*<sup>+</sup> – OH), 249.0152 (*M*<sup>+</sup> – H<sub>2</sub>O – CH<sub>3</sub>, 3%), 155.1472 (*M*<sup>+</sup> – I, 18%), 137 (72%), and 57 (100%); (iii) *t*-2-iodo-*c*-6-*t*-butylcyclohexan-*r*-1-ol (8) (83 mg),  $\nu_{\max}$  (CCl<sub>4</sub>) 3 610 and 3 410 (OH), and 1 360 cm<sup>-1</sup> (CMe<sub>3</sub>),  $\delta$  0.97 (s, CMe<sub>3</sub>), 1.62 (s, OH, exchanged with D<sub>2</sub>O), 4.25 (m,  $W_{\frac{1}{2}}$  7 Hz, 1-H), and 4.38 (3 lines,  $J_{\text{obs}}$  2.8 Hz, 2-H), *m/e* 282 (*M*<sup>+</sup>, <1%), 267 (1%), 249 (2%), 155 (17%), 137 (76%), and 57 (100%); (iv) *t*-2-iodo-*t*-3-*t*-butylcyclohexan-*r*-1-ol (7) (62 mg),  $\nu_{\max}$  (CCl<sub>4</sub>) 3 620, 3 430, 955 (OH), and 1 360 cm<sup>-1</sup> (CMe<sub>3</sub>),  $\delta$  0.95 (s, CMe<sub>3</sub>), 2.20 (s, OH, exchanged with D<sub>2</sub>O), 4.22 (3 lines,  $J_{\text{obs}}$  2.8 Hz, 1-H), and 4.32 (m,  $W_{\frac{1}{2}}$  7 Hz, 2-H), *m/e* 282 (*M*<sup>+</sup>, <1%), 265 (<1%), 249 (<1%), 155.1427 (*M*<sup>+</sup> – I, 20%), 137 (100%), and 57 (82%).

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