

Reactions of 1-Methyl-4-t-butylcyclohexene and 1-Methylcyclohexene with Thallium(I) Acetate-Iodine

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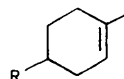
Treatment of 1-methyl-4-t-butylcyclohexene (2) with thallium(I) acetate-iodine in wet acetic acid at 90 °C gives a complex mixture of products, which differs from that obtained from a Woodward reaction with silver(I) acetate followed by hydrolysis and which includes the unexpected hydroxy-iodoacetate (25). At 20 °C the thallium(I)-mediated reaction gives a mixture of regioisomeric iodo-acetates. A re-investigation of the reaction of thallium(I) acetate-iodine with 1-methylcyclohexene (1) at 20 °C has shown that this is not highly regioselective as reported earlier.

The actions of KOAc-I₂-18-crown-6 and of iodine(III) triacetate in acetic acid on the alkenes (1) and (2), and of I₂-H₂O in tetramethylene sulphone-chloroform on the alkene (2) are reported.

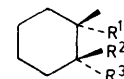
THE Prévost reaction¹ and its Woodward modification² are important methods for the formation of *vic*-diols. Each reaction involves the treatment of an alkene with iodine and at least 2 equiv. of a silver(I) carboxylate. Both reactions are considered to proceed *via* a *trans-vic*-iodo-carboxylate which, by interaction of the neighbouring acyloxy-group and displacement of iodide, gives an intermediate 1,3-dioxolan-2-ylum ion. Use of an anhydrous solvent in the Prévost reaction then results in an S_N2 displacement by carboxylate to give a diester of a *trans*-diol while the use of moist acetic acid in the Woodward reaction results in solvolysis with fission of a C-2 oxygen bond to give the monoacetate (or monoacetates) of a *cis*-diol. The Woodward reaction is particularly useful in cases where diastereoisomeric *cis*-diols are possible since, in contrast to osmium tetroxide and aqueous potassium permanganate, it leads to the isomer in which the hydroxy-groups are introduced on the more hindered side of the molecule.³ However, with trisubstituted double bonds the Woodward reaction affords only low yields of *cis*-diols and gives, instead, allylic alcohols and ketones,⁴⁻⁶ and even *trans*-diols.⁷

During our investigation⁸ of the use of thallium(II) carboxylates in the Prévost and Woodward reactions it was found that reaction of thallium(I) acetate and iodine with 1-methylcyclohexene (1) in dried acetic acid at 20 °C gave a 90% yield of the *trans-vic*-iodo-acetate (3), and that when the reaction was carried out in wet acetic acid⁹ at *ca.* 90 °C the *cis*-hydroxy-acetate (4) was obtained in quantitative yield. Since Mangoni and his co-workers⁶ have shown that the Woodward reaction with 1-methylcyclohexene, followed by hydrolysis, gives a mixture of four products, *viz.* (5) (48%), (9) (10%), (14) (2.5%), and (19) (1.5%), it appeared that the use of thallium(I) acetate in place of silver(I) acetate might decrease the variety of products usually obtained from substrates which contain trisubstituted double bonds. Accordingly, reactions of thallium(I) acetate and iodine with 1-methyl-4-t-butylcyclohexene (2), a conformationally biased compound which has been reported⁶ to afford six compounds, *viz.* (10) (16%), (1) (8%), (20) (6%), (21) (43%), (22) (<1%), and (29) (8%) after hydrolysis of the Woodward reaction products, have been investigated.

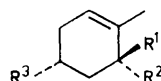
Products from the Woodward reaction of the alkene (2) prior to hydrolysis have been examined by g.c.-m.s. and re-examination of the reactions of thallium(I) acetate and



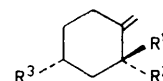
- (1) R = H
(2) R = Bu^t



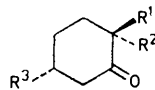
- | | R ¹ | R ² | R ³ |
|-----|----------------|----------------|----------------|
| (3) | OAc | I | H |
| (4) | OH | H | OAc |
| (5) | OH | H | OH |
| (6) | I | OAc | H |
| (7) | OAc | H | OH |
| (8) | OH | I | H |



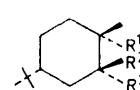
- | | R ¹ | R ² | R ³ |
|------|----------------|----------------|-----------------|
| (9) | OH | H | H |
| (10) | OH | H | Bu ^t |
| (11) | H | OH | Bu ^t |
| (12) | OAc | H | Bu ^t |
| (13) | H | OAc | Bu ^t |



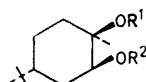
- | | R ¹ | R ² | R ³ |
|------|----------------|----------------|-----------------|
| (14) | OH | H | H |
| (15) | OAc | H | Bu ^t |
| (16) | H | OAc | Bu ^t |
| (17) | OH | H | Bu ^t |
| (18) | H | OH | Bu ^t |



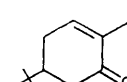
- | | R ¹ | R ² | R ³ |
|------|----------------|----------------|-----------------|
| (19) | Me | H | H |
| (20) | Me | H | Bu ^t |



- | | R ¹ | R ² | R ³ |
|------|----------------|----------------|----------------------|
| (21) | OH | H | OH |
| (22) | OH | OH | H |
| (23) | OH | H | OAc |
| (24) | OAc | H | OAc |
| (25) | OH | H | OCOCH ₂ I |
| (26) | OAc | I | H |
| (27) | I | OAc | H |
| (28) | OH | I | H |



- | | R ¹ | R ² |
|------|----------------|----------------|
| (29) | H | H |
| (30) | H | Ac |



(31)

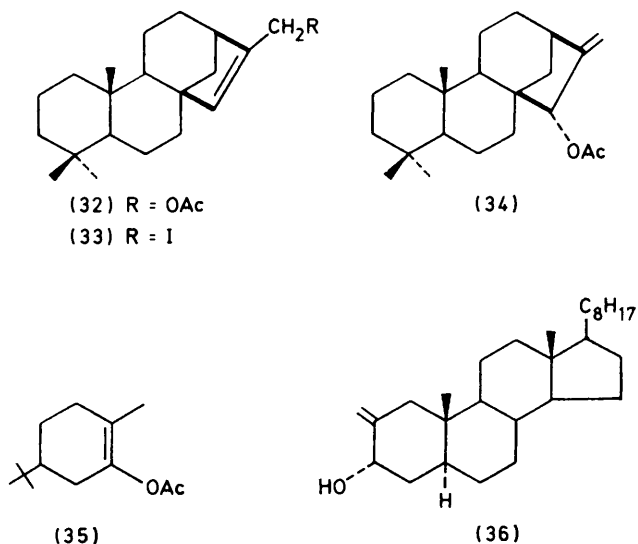
iodine⁸ and of thallium(I) acetate-iodine(I) chloride¹⁰ with 1-methylcyclohexene are also reported.

Treatment of the cyclohexene (2) with iodine (1.1 equiv.) and thallium(I) acetate (2.3 equiv.) in wet acetic acid at 90 °C gave a complex mixture which was separated by preparative t.l.c. into a mixture (5.5 : 1) of the *cis*-hydroxy-acetates (23) and (30) (35%), the $\alpha\beta$ -unsaturated ketone (31)¹¹ (10%), the *cis*-diacetate (24) (1%), the hydroxy-iodoacetate (25) (12%), and a fraction (34%) which was shown by g.l.c. to contain five components. Analysis of the latter fraction by g.c.-m.s. indicated that the five compounds were the ketone (20) (9%), the unsaturated acetates (12) (12%) and (13) (7%), and the unsaturated acetates (15) or (16) (3%) and (16) or (15) (4%). Structures of the products were assigned from a consideration of their spectral parameters (see Experimental section)* and by analogy with the products formed from the Woodward reaction on the same substrate followed by hydrolysis.⁶ The presence of two components in the mixture of the *cis*-hydroxy-acetates (23) and (30) was revealed by the single-frequency off-resonance decoupled (SFORD) ¹³C n.m.r. spectrum which exhibited double peaks for the *t*-butyl carbons (δ_C 31.9 and 32.3 p.p.m.), the C-2 carbons (δ_C 69.4 and 70.0 p.p.m.), and the carbonyl carbons (δ_C 170.1 and 170.2 p.p.m.). Reduction of the mixed hydroxy-acetates with lithium aluminium hydride gave a mixture (ca. 4.5 : 1) of the corresponding diols (21) and (29).

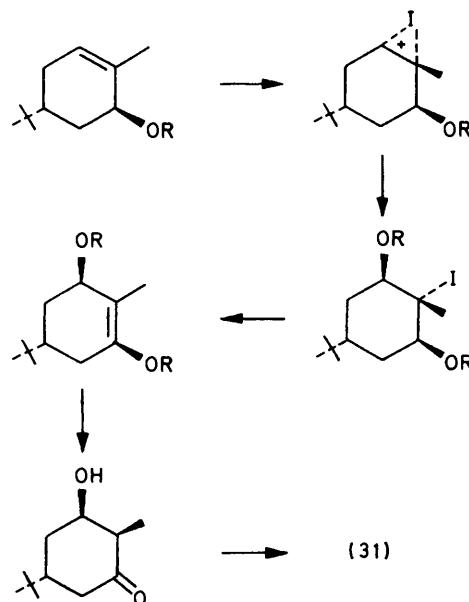
As expected, the *cis*-hydroxy-acetate (23) was the major product of the reaction, which arose in the normal manner by attack of water at C-2 of the intermediate 1,3-dioxolan-2-ylum ion formed from the Markownikov iodo-acetate (26). The isomeric hydroxy-acetate (30) would arise, in a similar manner, from the anti-Markownikov iodo-acetate (27). However, although thallium(I) ions clearly operate as a scavenger of iodide ions, it is not clear whether or not they play a direct role analogous to that of silver(I) ions in the solvolysis of the initially formed iodo-acetate. The *cis*-diacetate (24) may arise by reaction of the hydroxy-acetate (23) with the solvent,¹³ but an S_N2 pathway from the intermediate *trans*-iodo-acetate (26) is considered to be more likely since treatment of the hydroxy-acetate (23) under more vigorous conditions (acetic anhydride-pyridine under reflux for 2 h) gave only a low yield (16%) of the *cis*-diacetate (24). However, in the light of recent work¹⁴ the *cis*-diacetate (24) may arise by attack of acetate ion or of solvent at C-2 of an intermediate 1,3-dioxolan-2-ylum ion. The saturated ketone (20) is identical with that obtained from the Woodward reaction with the cyclohexene (2)⁶ and represents the first example of the isolation of a ketone

* An attempt was made to develop independent syntheses of the allylic acetates (12), (13), (15), and (16) by formation of the corresponding allylic iodides followed by solvolysis with silver(I) acetate, as for the preparation of the allylic acetates (32) and (34) (ref. 12). However, analysis (i.r. and ¹H n.m.r. spectroscopy) of the products from treatment of the alkene (2) with thallium(I) tosylate (Th¹OTs) and iodine indicated that while addition of the elements of IOTs had occurred, no allylic iodides had been formed.

from a reaction of this type involving thallium(I). The ketone (20) is probably formed from an enol acetate (35) which, in turn, arises from an anti-Markownikov iodo-acetate (27) by loss of HI (cf. ref. 15). The $\alpha\beta$ -unsaturated ketone (31) is identical with that isolated by Man-



goni and his co-workers¹¹ from a Prévost reaction of the cyclohexene (2) with silver(I) benzoate rather than from the Woodward reaction. In the case of the Prévost reaction, it was suggested¹¹ that the enone arose by the pathway given in Scheme 1 (R = Bz). However, in

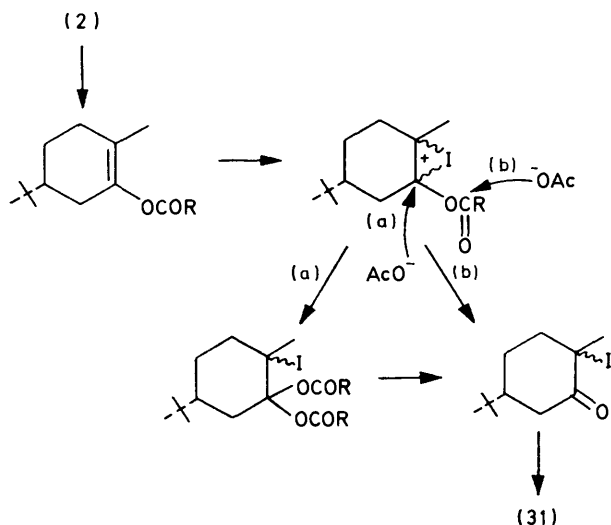


SCHEME 1

accord with our own work on the action of thallium(I) acetate-iodine with enol acetates,¹⁶ it is more likely that compound (31) arises *via* an enol ester as indicated in Scheme 2 (R = Me or Ph).

The acetates (12), (13), (23), and (24) are all esters of

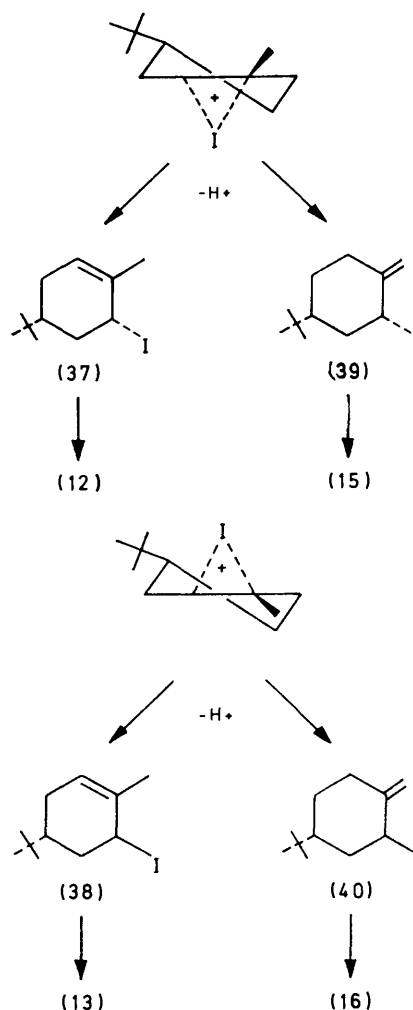
alcohols or diols obtained by Mangoni after hydrolysis of the products of the Woodward reaction on the cyclohexene (2).⁶ The exocyclic allylic alcohols (17) and (18) which correspond to the exocyclic allylic acetates (15) and (16) were not obtained from the latter sequence, although the allylic alcohols (14) and (36) were isolated after hydrolysis of the Woodward reaction products from



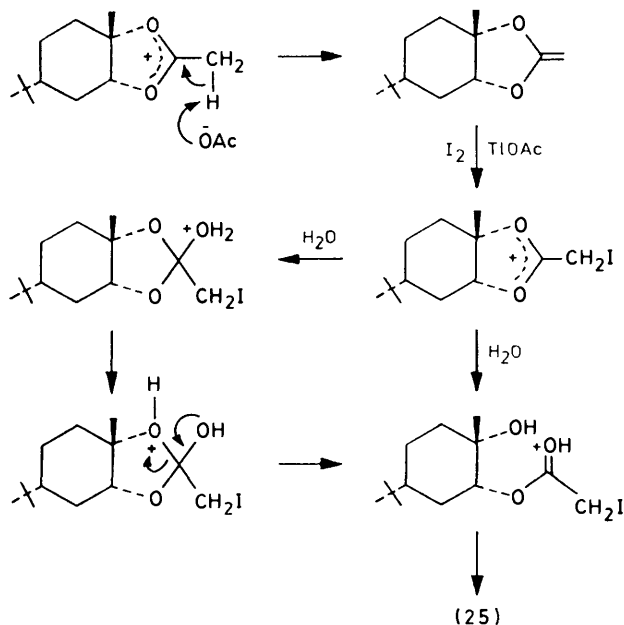
SCHEME 2

1-methylcyclohexene (1)⁶ and from 2-methyl-5 α -cholest-2-ene,¹⁷ respectively. Mangoni suggested that the endo-allylic alcohols (10) and (11) were formed *via* the allylic iodides (37) and (38). In view of our previous results with the diterpenoid allylic iodide (33),¹² a similar pathway for the reaction involving thallium(I) acetate-iodine can be proposed (Scheme 3) for the formation of the allylic acetates (12) and (13) *via* the allylic iodides (37) and (38), and for the formation of the acetates (15) and (16) *via* the allylic iodides (39) and (40).

Formation of the iodoacetate (25) was unexpected and is without precedent. Elemental analysis and the high resolution mass spectrum of the compound gave a molecular formula of C₁₃H₂₃IO₃. The mass spectrum also included ions attributable to M⁺ - I, M⁺ - I - H₂O, and M⁺ - C(O)CH₂I, which suggests that the compound was a hydroxy-iodoacetate. This was supported by the i.r. spectrum which showed hydroxy-group (3 590 cm⁻¹) and acetate (1 720 and 1 270 cm⁻¹) peaks, and by the ¹H n.m.r. spectrum which included a broad D₂O-exchangeable hydroxy-proton signal at δ_H 1.65, a two-proton doublet of doublets at δ_H 3.61 attributable to methylene protons flanked both by an iodine atom and a carbonyl group, and a doublet of doublets ($J_{1,6eq}$ 5.0, $J_{1,6ax}$ 10.0 Hz) centred at δ_H 4.65 due to an axial proton geminal to an ester group. The SFORD ¹³C n.m.r. spectrum included a high field triplet at δ_C - 5.3 p.p.m. consistent with the presence of an iodomethylene carbon.¹⁸ The hydroxy-iodoacetate (25) probably arises from the 1,3-dioxolan-2-ylum cation (41) *via* a ketal acetal as indicated in Scheme 4. Such a pathway



SCHEME 3



SCHEME 4

finds support from the known preparation of keten acetals from trialkyl orthocarboxylates *via* 1,3-dioxolan-2-ylum intermediates¹⁹ and from the addition of iodine to 1,1-diethoxypropene²⁰ (see also ref. 21). Reduction of the hydroxy-iodoacetate (25) with lithium aluminium hydride gave the *cis*-diol (21).⁵

The above results indicate that the thallium(I)-mediated iodoacetoxylation of the cyclohexene (2) is not highly regioselective and this was confirmed by a series of reactions carried out for 48 h under varied conditions at the lower temperature of 20 °C (Table). In all cases

TABLE

Iodoacetoxylations of 1-methyl-4-*t*-butylcyclohexene (2)

(2): I ₂ : TlOAc	Solvent	(26)%	(27)%
1: 1: 2	CH ₂ Cl ₂	24	24
1: 1: 4	CH ₂ Cl ₂	12	11 ^a
1: 1: 2	HOAc ^b	19	9 ^c
1: 1: 2	HOAc	30	10 ^d
1: 1 ^e : 2	HOAc	50	21 ^d
1: 2 ^e : 2	HOAc	34	17 ^f

^a Contained starting material (27%). ^b Wet acetic acid. ^c Solvolysis products included (12), (13), (15), (16), (23), and (24). ^d Solvolysis products included (12), (13), (15), (16), and (24) (25%). ^e ICl used instead of I₂ [*cf.* ref. 10; a u.v. study has confirmed our earlier conclusion (ref. 10) that, unlike the TlOAc-I₂ mixture (λ_{\max} 450 nm), acetyl hypoiodite (ref. 22) can be pre-formed from a mixture of TlOAc-ICl, (λ_{\max} 267 nm; *cf.* AgOAc-I₂, λ_{\max} 276.5 nm and I₂, λ_{\max} 475 nm) (ref. 23)]. ^f Also contained other unidentified products (*ca.* 49%).

mixtures of the Markownikov and anti-Markownikov iodo-acetates (26) and (27)²⁴ were obtained and in those reactions where acetic acid was the solvent, solvolysis products were also formed. An increased ratio (3:1) for compounds (26): (27) was obtained when the reaction was carried out with thallium(I) acetate (2 equiv.) in dried acetic acid at 20 °C for 48 h. A higher overall yield of compounds (26) and (27) was obtained when iodine(I) chloride was used instead of iodine in the latter reaction, but the ratio of compounds (26): (27) was then lower. The identity of the solvolysis products was confirmed when treatment of a mixture of the iodo-acetates (26) and (27) with silver(I) acetate in wet acetic acid afforded the compounds (12), (20), (23), (24), and (31) in the ratio 15:1:75:6:2, together with several minor, unidentified compounds.

In view of the above results the primary products from the Woodward reaction of the cyclohexene (2) were also examined. Treatment of the alkene (2) with silver(I) acetate and iodine in wet acetic acid at room temperature gave a complex mixture which was shown by g.c.-m.s. to be composed of the compounds (10) (2%), (11) (2%), (12) (1.5%), (13) (2%), (17) or (18) (2%), (20) (6%), (23) (54%), (24) (<1%), (30) (21%), and (31) (1.5%). A feature of the reaction was that there was no evidence for formation of the hydroxy-iodoacetate (25), obtained from the corresponding thallium(I)-mediated reaction. Either compound (25) is not formed in the Woodward reaction or, more likely, loss of the iodo-substituent is facilitated by silver(I), which leads eventually to the diol (21).

The moderate regioselectivity in the above reactions

prompted a re-investigation of the reaction of thallium(I) acetate and iodine with 1-methylcyclohexene.⁸ Treatment of the latter in wet acetic acid at 20 °C for 2 h consistently afforded a mixture of the iodo-acetates (3)^{8,24} (75%) and (6)²⁴ (19%). Thus, contrary to our earlier report, this reaction is not highly regioselective. The present work also indicates that some solvolysis might have occurred in our previously reported reaction of thallium(I) acetate-iodine(I) chloride with 1-methylcyclohexene in acetic acid¹⁰ where the products were the *trans*-iodo-acetates (3) (50%) and (6) (10%), and the *cis*-hydroxy-acetates (4) (10%) and (7) (30%). Indeed, repetition of this latter reaction using rigorously dry conditions gave only the iodo-acetates (3) and (6) in yields (79% and 21%, respectively) similar to those obtained from the thallium(I) acetate-iodine reaction. Thus, although the thallium(I) acetate-iodine(I) chloride system differs from the thallium(I) acetate-iodine system in allowing preformation of a solution of iodine(I) acetate in acetic acid,¹⁰ it now appears that with 1-methylcyclohexene it leads to a similar ratio of the same products.

In an attempt to find a highly regioselective iodoacetoxylation of trisubstituted alkenes, the reactions of potassium acetate-iodine-18-crown-6 with the cyclohexene (2) and 1-methylcyclohexene (1) were also investigated. A moderate yield (37%) of a mixture of the regioisomers (3) and (6) was obtained from the alkene (1), along with a trace of the *trans*-iodohydrin (8).¹⁰ In the case of the alkene (2), the reaction was even less successful and gave a large amount of starting material as well as both the regioisomeric iodo-acetates (26) and (27). Complex mixtures were also obtained from both compounds (1) and (2) when they were treated with iodine-(III) triacetate.²⁵

In an earlier study we showed that treatment of simple alkenes with iodine and water in tetramethylene sulphone gave high yields of *trans-vic*-iodohydrins.¹⁰ Application of this reaction to the cyclohexene (2) gave a mixture of 1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1-*t*-2-diol (22)⁵ (24%) and 2-iodo-1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1-ol (28)²⁴ (18%) which indicates that this reaction is regioselective.

EXPERIMENTAL

General experimental details are given in ref. 3. 1-Methyl-4-*t*-butylcyclohexene (2) was prepared from a mixture of *cis*- and *trans*-1-methyl-4-*t*-butylcyclohexanols by the method of Cross and Whitham.²⁶ The product had b.p. 83–84 °C at 20 mmHg, n_D^{24} 1.4598 (lit.,²⁶ 84–86 °C at 20 mmHg, n_D^{25} 1.4578) and contained (by ¹H n.m.r. spectroscopy) 1-methyl-4-*t*-butylcyclohexene (94%) and 1-methyl-ene-4-*t*-butylcyclohexane (6%).

*Reaction of 1-Methyl-4-*t*-butylcyclohexene (2) with Thallium(I) Acetate and Iodine.*—(a) *In wet acetic acid at 90 °C.* A solution of iodine (0.90 g, 3.55 mmol) in glacial acetic acid (65 ml) was added as drops to a stirred solution of thallium(I) acetate (1.91 g, 7.25 mmol) and 1-methyl-4-*t*-butylcyclohexene (2) (0.50 g, 33 mmol) in wet ⁹ acetic acid (15.5 ml) and the mixture was then heated at 90 °C for 8 h. The

precipitate was filtered off from the cooled mixture and washed with diethyl ether. Solvent was removed from the combined filtrates to give a pale yellow oil (0.82 g) which was separated by preparative layer chromatography (p.l.c.) (hexane-diethyl ether, 7:1) into (i) a mixture (5.5:1) of *c*-2-hydroxy-*t*-2-methyl-*c*-5-*t*-butylcyclohexan-*r*-1-yl acetate (23) and *c*-2-hydroxy-*t*-2-methyl-*t*-5-*t*-butylcyclohexan-*r*-1-yl acetate (30) (0.26 g, 35%), b.p. 107–108 °C at 0.25 mmHg; n_D^{23} 1.4654 (Found: C, 67.8; H, 10.8. $C_{13}H_{24}O_3$ requires C, 68.4; H, 10.6%); ν_{\max} 3 600 (OH), 1 720 (CO), and 1 240 cm^{-1} (CO); δ_H 0.90 (s, CM_e_3), 1.20 (s, Me), 1.2–1.8 (m, 3,4,5, and 6-H), 1.80 br (s, OH, exchanged with D_2O), 2.14 (s, OAc), and 4.70 [dd, $J_{1,6eq}$ 5.0, $J_{1,6ax}$ 10.0 Hz, 1-H of (23)]; δ_C 21.1 (COMe), 21.7 (C-4 of (23)), 21.3 [C-4 of (30)], 27.2 (Me), 27.5 [Me_3C], 28.2 (C-6), 31.9 [Me_3C of (30)], 32.3 [Me_3C of (23)], 34.8 [C-3 of (30)], 37.6 [C-3 of (23)], 40.7 [C-5 of (30)], 46.4 [C-5 of (23)], 69.4 [C-2 of (30)], 70.0 [C-2 of (23)], 75.9 [C-1 of (30)], 78.5 [C-1 of (23)], 170.1 [CO of (30)], and 170.2 p.p.m. [CO of (23)]; m/z 228.1739 (M^{++} requires 228.1726), 213 ($M^{++} - Me$), 210 ($M^{++} - H_2O$), 186 ($M^{++} - CH_2CO$) and 168 ($M^{++} - HOAc$); (ii) 2-methyl-5-*t*-butylcyclohex-2-enone (31) (52 mg, 10%); ν_{\max} (CCl_4) 3 020 (C=CH) and 1 670 cm^{-1} (conj. CO); λ_{\max} (EtOH) 237 nm (lit.¹¹ 237 nm); δ_H (CCl_4) 0.90 (s, CM_e_3), 1.70 (s, Me), and 6.62br (m, 3-H); m/z 166 (M^{++}) and 151 ($M^{++} - Me$); (iii) *t*-1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1-*c*-2-diyl diacetate (24) (10 mg, 1%); ν_{\max} (CCl_4) 1 740 (OAc) and 1 240 cm^{-1} (CO); δ_H (CCl_4) 0.90 (s, CM_e_3), 1.35 (s, Me), 2.00 (s, 2 × OAc), and 4.51 (m, $J_{1,6eq}$ 5.0, $J_{1,6ax}$ 11 Hz, 2-H); m/z 270 (M^{++}), 228 ($M^{++} - CH_2CO$), 210 ($M^{++} - HOAc$), and 168 ($M^{++} - HOAc - CH_2CO$); and (iv)–(viii) a mixture (0.23 g, 34%) which could not be separated by t.l.c. This mixture had ν_{\max} (CCl_4) 3 070 (C=CH₂), 3 010 (CH=CH₂), 1 730 (CO), 1 720 (CO), 1 650 (C=CH₂), 1 230 (CO), 905 (C=CH₂), and 840–800 cm^{-1} (C=CH); δ_H (CCl_4) 0.90 (s, CM_e_3), 2.0–2.1 (OAc), and 4.2–5.8 (m, 1, vinyl protons). G.c.-m.s. indicated five components which were eluted in the following order: (iv) 2-methyl-5-*t*-butylcyclohexanone (20)⁶ (9%); m/z 168 (M^{++}), 153 ($M^{++} - Me$), 150 ($M^{++} - H_2O$), 135 ($M^{++} - Me - H_2O$), 111 ($M^{++} - C_4H_9$), and 69 ($M^{++} - C_7H_{15}$); (v) 2-methyl-*t*-5-*t*-butylcyclohex-2-en-*r*-1-yl acetate (12) (12%); R_t 17.5 min;⁶ m/z 210 (M^{++}), 168 ($M^{++} - CH_2CO$), 153 ($M^{++} - CH_2CO - Me$), 150 ($M^{++} - CH_2CO - H_2O$ or $M^{++} - HOAc$), and 135 ($M^{++} - HOAc - Me$); (vi) 2-methyl-*c*-5-*t*-butylcyclohex-2-en-*r*-1-yl acetate (13) (7%); m/z 210 (M^{++}), 168 ($M^{++} - CH_2CO$), 150 ($M^{++} - CH_2CO - H_2O$ or $M^{++} - HOAc$), and 135 ($M^{++} - HOAc - Me$); (vii) 2-methylene-*tr*-*c*-5-*t*-butylcyclohexyl acetate (15) or (16)* (4%); m/z 210 (M^{++}), 168 ($M^{++} - CH_2CO$), 150 ($M^{++} - CH_2CO - H_2O$ or $M^{++} - HOAc$), and 135 ($M^{++} - HOAc - Me$); and (viii) 2-methylene-*c*-*or*-*t*-5-*t*-butylcyclohexyl acetate (16 or 15) (3%); m/z 210 (M^{++}), 168 ($M^{++} - CH_2CO$), 150 ($M^{++} - CH_2CO - H_2O$ or $M^{++} - HOAc$), and 135 ($M^{++} - HOAc - Me$).

A further fraction (0.13 g, 11%) obtained from p.l.c. crystallized from hexane to give *c*-2-hydroxy-*t*-2-methyl-*c*-5-*t*-butylcyclohexan-*r*-1-yl iodoacetate (25) as needles, m.p. 68.5–69.5 °C (Found: C, 44.4; H, 6.8; I, 36.0. $C_{13}H_{23}IO_3$ requires C, 44.1; H, 6.6; I, 35.8%); ν_{\max} ($CHCl_3$) 3 590 (OH), 1 720 (CO), and 1 270 cm^{-1} (CO); δ_H (CCl_4) 0.90 (s, CM_e_3), 0.86–2.20br (m, 3,4,5, and 6-H), 1.64br (s, OH ex-

changed with D_2O), 2.21 (s, Me), 3.60 and 3.80 (2 d, J 9.5 Hz, CH_2I), and 4.45–4.85br (m, $J_{1,6eq}$ 5, $J_{1,6ax}$ 10 Hz, 1-H); δ_C –5.3 (CH_2I), 21.6 (C-4), 27.2 (Me), 27.5 [Me_3C], 27.8 (C-6), 32.4 (Me_3C), 37.7 (C-3), 46.4 (C-5), 70.3 (C-2), 80.4 (C-1), and 167.9 p.p.m. (CO); m/z 354.0664 (M^{++} requires 354.0692), 339 ($M^{++} - Me$), 336 ($M^{++} - H_2O$), 297 ($M^{++} - C_4H_9$), 227.1654, ($C_{13}H_{23}O_3$), 209.1563 ($C_{13}H_{21}O_2$), and 185.1571 ($C_{11}H_{21}O_2$).

(b) *In dichloromethane at 20 °C.* A solution of iodine (0.17 g, 0.67 mmol) in dry dichloromethane (11 ml) was added as drops over 1 h to a stirred suspension of thallium(i) acetate (0.69 g, 2.62 mmol) and 1-methyl-4-*t*-butylcyclohexene (0.10 g, 0.66 mmol) in dry dichloromethane (5 ml). The mixture was stirred at 20 °C for 3 h, the precipitate was removed and washed with diethyl ether, and the solvent was removed from the filtrate and washings. The resulting oil was dissolved in diethyl ether and the solution was washed with aqueous sodium hydrogensulphite, dried, and concentrated to yield a pale yellow oil (0.12 g). Preparative t.l.c. (hexane-diethyl ether, 7:4) gave (i) starting material (27 mg, 27%); (ii) *t*-2-iodo-1-methyl-*c*-4-*t*-butylcyclohexan-*r*-1-yl acetate (26)²⁴ (26 mg, 12%); ν_{\max} 1 740 (CO) and 1 240 cm^{-1} (CO); δ_H (CCl_4) 0.90 (s, CM_e_3), 1.64 (s, Me), 1.95 (s, OAc), and 5.10br (s, $W_{\frac{1}{2}}$ 7 Hz, 2-H); m/z 338 (M^{++}), 278 ($M^{++} - HOAc$), 263 ($M^{++} - HOAc - Me$), 211 ($M^{++} - I$), and 151 ($M^{++} - HOAc - I$); and (iii) *t*-2-iodo-*c*-2-methyl-*t*-5-*t*-butylcyclohexan-*r*-1-yl acetate (27)²⁴ (24 mg, 11%); ν_{\max} 1 740 (CO) and 1 240 cm^{-1} (CO); δ_H (CCl_4) 0.90 (s, CM_e_3), 2.00 (s, OAc and Me), and 5.30br (s, $W_{\frac{1}{2}}$ 5 Hz, 1-H); m/z 278 ($M^{++} - HOAc$), 263 ($M^{++} - HOAc - Me$), 211 ($M^{++} - I$), 169 ($M^{++} - I - CH_2CO$), and 151 ($M^{++} - HOAc - I$).

For other reactions in dichloromethane see Table.

(c) *In wet acetic acid at 20 °C.* A solution of iodine (83 mg, 0.33 mmol) in glacial acetic acid (5 ml) was added as drops over 1 h to a stirred solution of thallium(i) acetate (0.17 g, 0.65 mmol) and 1-methyl-4-*t*-butylcyclohexene (50 mg, 0.43 mmol) in wet acetic acid (1.5 ml). The mixture was stirred at 20 °C for 48 h, filtered, and the filtrate was neutralised with saturated sodium hydrogencarbonate. The mixture was extracted with diethyl ether and the extract was worked up to give a pale yellow oil (68 mg) which was shown by i.r. and ¹H n.m.r. spectroscopic analysis to contain the iodo-acetates (26) (19%) and (27) (9%) and the solvolysis products (12), (13), (15), (16), (23), and (24).

For other reactions in dried acetic acid and with iodine(i) chloride instead of iodine see Table.

Reduction of c-2-Hydroxy-t-2-methyl-c-5-t-butylcyclohexan-r-1-yl Iodoacetate (25).—A solution of the iodoacetate (25) (13 mg, 0.37 mmol) in dry diethyl ether (1 ml) was added as drops to a stirred suspension of lithium aluminium hydride (36 mg, 0.95 mmol) in dry diethyl ether (1 ml) and the slurry was stirred at room temperature under nitrogen for 3.5 h. The mixture was worked up to give 1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1-*c*-2-diol (21)⁵ as an oil (7.5 mg) (i.r., ¹H n.m.r., and mass spectra identical with those reported below).

1-Methyl-c-4-t-butylcyclohexane-r-1,c-2-diol (21).—A solution of potassium permanganate (2.8 g, 17.7 mmol) in water (62 ml) was added as drops to a cooled (–20 °C), stirred solution of 1-methyl-4-*t*-butylcyclohexene (2) (1.0 g, 6.58 mmol) in 66% aqueous ethanol (72 ml) and 10% aqueous sodium hydroxide (0.2 ml). The mixture was warmed to room temperature over 1 h and stirred for a further 1 h. Sodium hydrogensulphite (10.0 g) in water (24 ml) was

* Although the starting alkene (2) contained 6% of the exocyclic isomer, 1-methylene-4-*t*-butylcyclohexane, the combined yield of compounds (15) and (16) must reflect their formation from the alkene (2) since their total yield is greater than 6%.

added and the resulting precipitate was worked up to give an oil (0.70 g) which contained starting material and the diol (21) in a ratio of 1 : 1.6 (¹H n.m.r. spectroscopic analysis). P.l.c. of a portion (0.11 g) on alumina (hexane-diethyl ether, 1 : 1) gave 1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1,*c*-2-diol (21) (44 mg) which crystallized from hexane as needles, m.p. 81–83 °C with sublimation from 75 °C (lit.,⁵ 82–84 °C); ν_{\max} (CHCl₃) 3 570 (OH), 2 940, 2 870 (CH), and 1 365 cm⁻¹; δ_{H} 0.86 (s, CMe₃), 0.86–2.20br (m, 3,4,5, and 6-H), 1.24 (s, Me), 1.73br (s, OH, exchanged with D₂O), and 3.30br (m, $W_{\frac{1}{2}}$ 17 Hz, 2-H); m/z 186 (M^{++}), 171 ($M^{++} - \text{Me}$) 168 ($M^{++} - \text{H}_2\text{O}$), 153 ($M^{++} - \text{H}_2\text{O} - \text{Me}$), and 135 ($M^{++} - 2\text{H}_2\text{O} - \text{Me}$).

Reduction of the Hydroxy-acetates (23) and (30).—A solution of the mixture of hydroxy-acetates (23) and (30) (99 mg, 0.43 mmol) in dry diethyl ether (2 ml) was added as drops to a stirred suspension of lithium aluminium hydride (20 mg, 0.53 mmol) in dry diethyl ether (1 ml) under nitrogen. The mixture was stirred at room temperature for 1 h, heated under reflux for 4.5 h, and again stirred at room temperature for 40 h with the addition of further portions of lithium aluminium hydride (20 mg and 40 mg) after 2.5 h and 26 h, respectively. Work-up gave an oil (87 mg) which, after p.l.c. on alumina (hexane-diethyl ether, 2 : 3), afforded a crystalline mixture (59 mg, 73%) of 1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1,*c*-2-diol (21) (82%) (correct ¹H n.m.r. spectrum) and 1-methyl-*t*-4-*t*-butylcyclohexane-*r*-1,*c*-2-diol (29)⁵ (18%); δ_{H} 0.90 (s, CMe₃), 0.80–2.20br (m, 3,4,5, and 6-H), 1.26 (s, Me), 1.75br (s, OH, exchanged with D₂O), 3.61br (s, $W_{\frac{1}{2}}$ 8 Hz, 2-H).

Acetylation of *c*-2-Hydroxy-*t*-2-methyl-*c*-5-*t*-butylcyclohexan-*r*-1-yl Acetate (23).—The hydroxy-acetate (23) (71 mg, 0.31 mmol) was heated under reflux with acetic anhydride (2.1 g, 19.6 mmol) and dried pyridine (1 ml) for 2 h. Work-up gave a yellow oil (44 mg) which consisted mainly of starting material (t.l.c. and g.l.c. analysis). Preparative t.l.c. (hexane-diethyl ether, 5 : 1) gave *t*-1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1,*c*-2-diyl diacetate (24) (13 mg, 15%) (identified by i.r., ¹H n.m.r., and mass spectra), and starting material (11 mg, 15%).

Reaction of 1-Methyl-4-*t*-butylcyclohexene with Silver(I) Acetate and Iodine.—A solution of iodine (0.48 g, 1.91 mmol) in glacial acetic acid (25 ml) was added as drops to a stirred mixture of silver(I) acetate (0.72 g, 4.34 mmol) and the alkene (2) (0.20 g, 1.32 mmol) in acetic acid (10 ml) under nitrogen. The mixture was stirred at room temperature for 30 min, water (0.24 g, 0.13 mmol) was added, and the stirring was continued for 15.5 h. Work-up gave a pale yellow oil (0.32 g), shown by g.c.–m.s. to contain (i) 2-methyl-*t*-5-*t*-butylcyclohex-2-en-1-yl acetate (12) (1.5%); R_{F} 17.5 min (correct mass spectrum); (ii) 2-methyl-5-*t*-butylcyclohex-2-enone (31) (1.5%); R_{t} 20 min; m/z 166 (M^{++}) and 151 ($M^{++} - \text{Me}$); (iii) *c*-2-hydroxy-*t*-2-methyl-*c*-5-*t*-butylcyclohexan-1-yl acetate (23) (54%); R_{t} 30 min; m/z 228 (M^{++}), 213 ($M^{++} - \text{Me}$), 210 ($M^{++} - \text{H}_2\text{O}$), 168 ($M^{++} - \text{HOAc}$), and 153 ($M^{++} - \text{HOAc} - \text{Me}$); (iv) 1-methyl-5-*t*-butylcyclohexanone (20) (6%); R_{t} 31.3 min (correct mass spectrum); (v) 2-methyl-*t*-5-*t*-butylcyclohex-2-enol (10) (2%); R_{t} 33.8 min; m/z 168 (M^{++}), 153 ($M^{++} - \text{Me}$), 150 ($M^{++} - \text{H}_2\text{O}$), and 135 ($M^{++} - \text{H}_2\text{O} - \text{Me}$); (vi) 2-methyl-*c*-5-*t*-butylcyclohex-2-enol (11) (2%); R_{t} 33.8 min; m/z 168 (M^{++}), 153 ($M^{++} - \text{Me}$), 150 ($M^{++} - \text{H}_2\text{O}$), and 135 ($M^{++} - \text{H}_2\text{O} - \text{Me}$); (vii) 2-methylene-*t*-*or*-*c*-5-*t*-butylcyclohexanol (17) or (18) (2%); R_{t} 33.8 min; m/z 168 (M^{++}) and 150 ($M^{++} - \text{H}_2\text{O}$); (viii) *c*-2-hydroxy-*t*-2-methyl-*t*-5-*t*-

butylcyclohexan-*r*-1-yl acetate (30) (21%); R_{t} 36.5 min; m/z 228 (M^{++}), 213 ($M^{++} - \text{Me}$), 210 ($M^{++} - \text{H}_2\text{O}$), 168 ($M^{++} - \text{HOAc}$), 153 ($M^{++} - \text{HOAc} - \text{Me}$), and 150 ($M^{++} - \text{HOAc} - \text{H}_2\text{O}$); (ix) 2-methyl-*c*-5-*t*-butylcyclohex-2-en-1-yl acetate (13) (2%); R_{t} 37.3 min (correct mass spectrum); (x) *t*-1-methyl-*c*-4-*t*-butylcyclohexane-*r*-1,*c*-2-diyl diacetate (24) (<1%); R_{t} 46.5 min (correct mass spectrum); and unidentified material (ca. 7%).

Solvolysis of the Iodo-acetates (26) and (27).—A suspension of the mixture of the products (26) and (27) (0.17 g, 0.50 mmol, based on iodo-acetate) from iodo-acetoxylation of the alkene (2), and silver(I) acetate (0.10 g, 0.60 mmol) in wet acetic acid was stirred at 20 °C for 12 h. Work-up in the usual manner gave an oil (0.12 g) which, by i.r. and ¹H n.m.r. spectroscopic and g.l.c. analysis contained the hydroxy-acetate (23), the $\alpha\beta$ -unsaturated ketone (31), the diacetate (24), the ketone (20), and the unsaturated acetate (12) in the ratio 75 : 2 : 6 : 1 : 15, and several unidentified minor compounds.

Iodoacetoxylation of 1-Methylcyclohexene.—(a) *With thallium(I) acetate and iodine.* A solution of iodine (0.26 g, 1.02 mmol) in glacial acetic acid (10 ml) was added as drops to a stirred solution of 1-methylcyclohexene (0.10 g, 1.04 mmol) and thallium(I) acetate (0.33 g, 1.25 mmol) in glacial acetic acid (2 ml). The mixture was stirred at 20 °C for 2 h and the precipitate was removed and washed with diethyl ether. The combined filtrate and washings were diluted with an equal volume of water and extracted with diethyl ether. The extract was worked up to give a pale yellow oil (0.24 g, 83%) which contained (¹H n.m.r. spectroscopy) (i) *t*-2-iodo-1-methylcyclohexan-*r*-1-yl acetate (3)^{10,24} (75%); ν_{\max} (CCl₄) 1 740 (CO) and 1 240 cm⁻¹ (CO); δ_{H} 1.60 (s, Me), 2.00 (s, OAc), and 4.90 (m, $W_{\frac{1}{2}}$ 14 Hz, 2-H); (ii) *t*-2-iodo-2-methylcyclohexan-*r*-1-yl acetate (6)²⁴ (19%); ν_{\max} (CCl₄) 1 740 (CO) and 1 240 cm⁻¹ (CO); δ_{H} 1.97 (s, Me), 2.02 (s, OAc), and 5.13 (m, $W_{\frac{1}{2}}$ 12 Hz, 1-H); and starting material (6%).

(b) *With thallium(I) acetate and iodine(I) chloride.* A solution of iodine(I) chloride (0.16 g, 1.0 mmol) in dried acetic acid (7 ml) was added as drops over 20 min to a stirred suspension of thallium(I) acetate (0.53 g, 2.0 mmol) in dried acetic acid (5 ml). After 30 min 1-methylcyclohexene (96 mg, 1.0 mmol) was added and the mixture was stirred at 20 °C for 2 h. The precipitate was removed and the filtrate was neutralised with saturated sodium hydrogen-carbonate, extracted with diethyl ether, and the extract was worked up to give a pale yellow oil (0.26 g) which, by i.r. and ¹H n.m.r. spectroscopic analysis, contained the iodo-acetates (3) (79%) and (6) (21%).

Iodoacetoxylation using Potassium Acetate, Iodine, and 18-Crown-6.—(a) *With 1-methylcyclohexene.* Iodine (0.63 g, 2.48 mmol) and 1-methylcyclohexene (0.10 g, 1.04 mmol) were added to a stirred solution of potassium acetate (0.61 g, 6.22 mmol) and 18-crown-6 (0.33 g, 1.25 mmol) in chloroform (10 ml). The mixture was stirred at 20 °C in the dark for 48 h and the precipitate was removed and washed with chloroform. The filtrate and washings were washed with saturated sodium hydrogensulphite, dried, and passed through a column of silica gel. Removal of the solvent gave a pale yellow oil (0.12 g) which, by t.l.c. (hexane-diethyl ether, 7 : 3) and ¹H n.m.r. spectroscopic analysis, contained (i) *t*-2-iodo-1-methylcyclohexan-*r*-1-yl acetate (3) (31%) (correct i.r. and ¹H n.m.r. spectra); (ii) *t*-2-iodo-2-methylcyclohexan-*r*-1-yl acetate (6) (6%) (correct i.r. and ¹H n.m.r. spectra); and (iii) the iodohydrin (8)¹⁰ (trace).

(b) *With 1-methyl-4-t-butylcyclohexene* (2). The cyclohexene (2) (0.10 g, 0.66 mmol) was treated with iodine (0.40 g, 1.58 mmol), potassium acetate (0.39 g, 3.98 mmol), and 18-crown-6 (0.21 g, 0.79 mmol) in chloroform as in (a). Work-up as above gave a pale yellow oil (0.12 g) which by t.l.c. and i.r. and ^1H n.m.r. spectroscopic analysis contained mainly starting material, smaller amounts of the iodoacetates (3) and (6), and an unidentified compound.

Reaction of 1-Methyl-4-t-butylcyclohexene with Iodine and Water in Tetramethylene Sulphone-Chloroform.—Iodine (0.40 g, 1.58 mmol) was added over 1 h to a stirred solution of water (35 mg, 1.94 mmol) in tetramethylene sulphone (10 ml) and chloroform (10 ml). 1-Methyl-4-t-butylcyclohexene (0.10 g, 0.66 mmol) was added to the cooled solution and the mixture was stirred at 20 °C for 24 h and then poured into water and extracted with diethyl ether. The extracts were washed repeatedly with water and then successively with saturated sodium hydrogencarbonate, water, saturated sodium hydrogensulphite, water, and brine. The solvent was removed from the dried solution to yield a pale yellow oil (0.15 g) which was separated by preparative t.l.c. (hexane-diethyl ether, 9 : 1) into 1-methyl-*c*-4-t-butylcyclohexane-*r*-1,*t*-2-diol (22)⁵ (24%); ν_{max} (CCl₄) 3 600 cm⁻¹ (OH); δ_{H} 0.90 (s, CMe₃), 1.20 (s, Me), 1.75br (s, OH, exchanged with D₂O), and 3.60br (s, $W_{\frac{1}{2}}$ 6.5 Hz, 2-H); and *t*-2-iodo-1-methyl-*c*-4-t-butylcyclohexane-*r*-1-ol (28)²⁴ (18%); ν_{max} (CCl₄) 3 600 cm⁻¹ (OH); δ_{H} (CCl₄) 0.90 (s, CMe₃), 1.44 (s, Me), 2.65br (s, OH, exchanged with D₂O), and 4.35br (m, 2-H).

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