

Cleavage of Vicinal Diols by Iodine Triacetate and Iodine(I) Acetate

By Richard C. Cambie,* David Chambers, Peter S. Rutledge, and Paul D. Woodgate,* Department of Chemistry, University of Auckland, Auckland, New Zealand

Oxidative cleavage of *vic*-diols is achieved rapidly and in high yield with iodine triacetate or iodine(I) acetate. Acetic acid and a macrocyclic peroxide have been isolated from the reaction of *cis*-cyclohexane-1,2-diol with iodine(I) acetate in dichloromethane, suggesting that the cleavage occurs by a radical process.

THE oxidative cleavage of *vic*-diols by reagents such as (diacetoxyiodo)benzene which contain iodine in one of its higher valency states, has been examined by a number of workers.¹⁻⁵ Recently, we reported⁶ the preparation of iodine triacetate from iodine trichloride and silver(I) acetate and its regio- and stereo-specific addition to alkenes. We now report on its role and that of iodine(I) acetate as oxidants of *vic*-diols.

The products from the action (stirring for 2 min at 20 °C) of iodine triacetate (1 mol. equiv.) in acetic acid on a series of *vic*-diols are given in the Table together with their isolated yields. New compounds were identified from their spectral parameters and where possible, by microanalyses of the parent or of a suitable derivative (see Experimental section). Iodine trichloride alone in acetic acid did not cause oxidative cleavage and its action on *cis*-cyclohexane-1,2-diol (1), for example, resulted in acetylation to give the corresponding diacetate (3).⁷ Oxidative cleavage of the *vic*-diols also

silver(I) acetate but the diol was unaffected after treatment with iodine(I) chloride and thallium(I) acetate¹³ at 20 °C for 5 days. The reactions of either *trans*-cyclohexane-1,2-diol (2) or of 5 α -androstane-2 β ,3 α -diol (10) with the iodine-silver(I) acetate (1 : 1) reagent gave both starting material and the respective dialdehydes in a *ca.* 1 : 1 ratio, and it was necessary to use *ca.* two mol. equiv. of the reagent in order to achieve quantitative cleavage.

Comparative t.l.c. examination of the reaction of *cis*-cyclohexane-1,2-diol with iodine(I) acetate (1 mol. equiv.) indicated the formation of hexane-1,6-dial (16) and another compound which was converted completely into the dialdehyde (16) on treatment of the mixture with additional iodine(I) acetate (1.5 mol. equiv.). This intermediate, together with acetic acid, was isolated from a reaction carried out in dichloromethane. From spectroscopic and microanalytical data the intermediate was identified tentatively as the perhydrotribenzotetraoxecin (25), a stable¹⁴ crystalline peroxide (*cf.* ref. 15). Formation of this macrocycle was not detected during analogous reactions with the *trans*-diol (2).

Criegee¹ has postulated a cyclic mechanism for the oxidative cleavage of *vic*-diols with (diacetoxyiodo)benzene but presumably this is not the case with iodine triacetate since the *trans*-diaxial diol (10) was cleaved readily to the dialdehyde (19). The isolation of acetic acid from the reaction of *cis*-cyclohexane-1,2 diol with iodine(I) acetate in dichloromethane is consistent with cleavage *via* a radical pathway involving a hypiodite.¹⁶

As indicated above, we showed earlier⁶ that treatment of cyclohexene with iodine triacetate [prepared from iodine trichloride and silver(I) acetate] gave a mixture of the *trans*-iodo-acetate (4) (45%) and *trans*-iodohydrin (5) (10%). During the present work, treatment of cyclohexene with iodine trichloride (1 mol. equiv.) and the cheaper and more soluble (in acetic acid) thallium(I)

Cleavage of diols with iodine triacetate

Diol	Product	Yield (%)
(1) ⁷	(16) ¹²	63
(2) ⁷	(16) ¹²	78
(7) ⁵	(17)	94
(8) ⁸	(18)	92
(9) ⁹	(19)	93
(10) ⁹	(19)	93
(11) ¹⁰	(20)	86
(12) ¹⁰	(21)	85
(13) ³	(22) ³	100 ^a
(14) ^{3,11}	(23) ^{3,11}	93
(15) ¹¹	(24) ¹¹	95

^a Isolated as the 2,4-dinitrophenylhydrazone, m.p. and mixed m.p. 128°.

occurred at a similar rate if iodine(I) acetate, prepared from equimolar quantities of iodine and silver(I) acetate, was used instead of iodine triacetate. Oxidative cleavage of *cis*-cyclohexane-1,2-diol also occurred if the iodine(I) acetate was prepared from iodine(I) chloride and

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² P. S. Raman, *Proc. Indian Acad. Sci.*, 1956, **44A**, 321 (*Chem. Abs.*, 1957, **51**, 8010).

³ A. Goosen and H. A. H. Laue, *J. Chem. Soc. (C)*, 1969, 383.

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⁶ R. C. Cambie, D. Chambers, P. S. Rutledge, and P. D. Woodgate, *J.C.S. Perkin I*, 1977, 2231.

⁷ S. Winstein and R. E. Buckles, *J. Amer. Chem. Soc.*, 1942, **64**, 2780.

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⁹ R. C. Cambie, G. J. Potter, P. S. Rutledge, and P. D. Woodgate, *J.C.S. Perkin I*, 1977, 530.

¹⁰ B. F. Bowden, R. C. Cambie, and J. C. Parnell, *Austral. J. Chem.*, 1975, **28**, 91.

¹¹ A. McKillop, R. A. Raphael, and E. C. Taylor, *J. Org. Chem.*, 1972, **37**, 4204.

¹² P. M. Hardy, A. C. Nicholls, and H. N. Rydon, *J.C.S. Perkin II*, 1972, 2270.

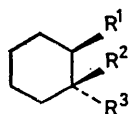
¹³ R. C. Cambie, W. I. Noall, G. J. Potter, P. S. Rutledge, and P. D. Woodgate, *J.C.S. Perkin I*, 1977, 226.

¹⁴ D. Swern, 'Organic Peroxides,' Wiley-Interscience, New York, 1971, vol. II, p. 583.

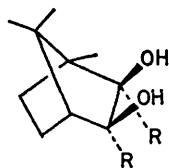
¹⁵ P. R. Story, B. Lee, C. E. Bishop, D. D. Denson, and P. Busch, *J. Org. Chem.*, 1970, **35**, 3059.

¹⁶ T. R. Beebe, B. A. Barnes, K. A. Bender, A. D. Halbert, R. D. Miller, M. L. Ramsay, and M. W. Ridenour, *J. Org. Chem.*, 1975, **40**, 1992.

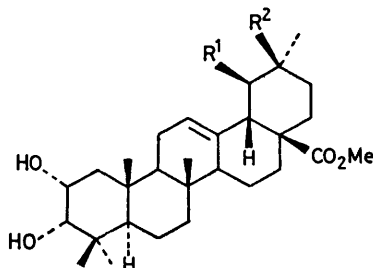
acetate (3 mol. equiv.) gave the *trans*-iodo-acetate (4) in 79% yield. However no cleavage of *cis*-cyclohexane-1,2-diol occurred with this reagent after 24 h at 20 °C



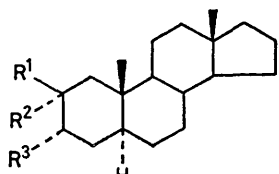
- (1) $R^1 = R^2 = \text{OH}, R^3 = \text{H}$
 (2) $R^1 = R^3 = \text{OH}, R^2 = \text{H}$
 (3) $R^1 = R^2 = \text{OAc}, R^3 = \text{H}$
 (4) $R^1 = \text{OAc}, R^2 = \text{H}, R^3 = \text{I}$
 (5) $R^1 = \text{OH}, R^2 = \text{H}, R^3 = \text{I}$
 (6) $R^1 = \text{Cl}, R^2 = \text{H}, R^3 = \text{I}$



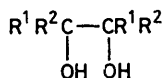
- (7) $R = \text{H}$
 (8) $R = \text{CH}_3$



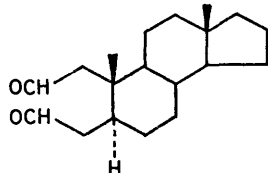
- (11) $R^1 = \text{H}, R^2 = \text{CH}_3$
 (12) $R^1 = \text{CH}_3, R^2 = \text{H}$



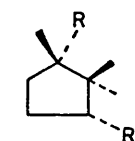
- (9) $R^1 = \text{H}, R^2 = \text{OH}$
 (10) $R^1 = \text{OH}, R^2 = \text{H}$



- (13) $R^1 = R^2 = \text{CH}_3$
 (14) $R^1 = \text{H}, R^2 = \text{Ph}$
 (15) $R^1 = R^2 = \text{Ph}$



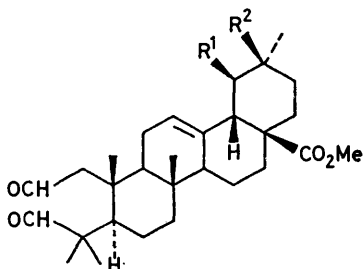
(19)



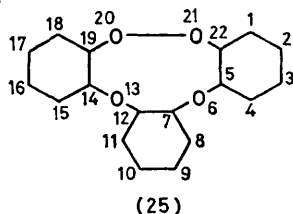
- (17) $R = \text{CHO}$
 (18) $R = \text{COCH}_3$



- (22) $R^1 = R^2 = \text{CH}_3$
 (23) $R^1 = \text{Ph}, R^2 = \text{H}$
 (24) $R^1 = R^2 = \text{Ph}$



- (20) $R^1 = \text{H}, R^2 = \text{CH}_3$
 (21) $R^1 = \text{CH}_3, R^2 = \text{H}$



(25)

(cf. ref. 11). Treatment of cyclohexene with thallium(I) acetate and iodine trichloride in a 1 : 1 molar ratio also

gave the *trans*-iodo-acetate (4) (42%) but in addition formed the *trans*-iodo-chloride (6) ¹³ (42%).

EXPERIMENTAL

General experimental details are given in ref. 17.

General Procedure for Oxidative Cleavage of vic-Diols.—(a) *With iodine triacetate.* Iodine trichloride (1.78 g, 7.6 mmol) was added rapidly to dried acetic acid (25 ml) under nitrogen and the mixture was stirred at 20 °C until all solid had dissolved. Dried silver(I) acetate (7.6 g, 45 mmol) was added and the yellow suspension was stirred for 10 min, centrifuged, and the clear liquid decanted under nitrogen. The molarity of the solution (equivalent to an 84% concentration of I^{III}) was determined by addition of an excess of potassium iodide to a portion and titration with standardised sodium thiosulphate solution under nitrogen.

A portion (5 ml \equiv 1.01 mmol) of the iodine triacetate solution was added rapidly under nitrogen to the diol (ca. 1.0 mmol) and the mixture was stirred at 20 °C for 2 min. The red solution was poured into ice-water, extracted with ether, and the extract was washed successively with water, saturated aqueous sodium hydrogencarbonate, water, saturated aqueous sodium disulphite, and brine. Solvent was removed from the dried solution under reduced pressure to give the crude product which was purified by p.l.c.

(b) *With iodine(I) acetate.* Freshly ground iodine (0.19 g, 0.75 mmol) was added over 20 min at 20 °C to a stirred solution of silver(I) acetate (0.125 g, 0.75 mmol) in dried acetic acid (5 ml) under nitrogen. The mixture was stirred for 10 min and the diol (0.3 mmol) was then added. The reaction was quenched after 2 min and worked up as in (a).

Hexane-1,6-dial (16).—This had ν_{max} 1 725 cm^{-1} (CO), λ_{max} 277 nm, δ (cf. ref. 12) 1.48—1.77 (m, 2 \times CH₂), 2.26—2.63 (m, 2 \times CH₂), and 9.71 (distorted t, 2 \times CHO), m/e 96 ($M^+ - \text{H}_2\text{O}$).

(Z)-1,2,2-Trimethylcyclopentane-1,3-carbaldehyde (17).—This was an oil, b.p. 80° at 0.75 mmHg, ν_{max} (CCl₄) 1 725 cm^{-1} (CO), δ (CCl₄) 0.90—2.95 (m, 2 \times CH₂, CH), 1.00 (s, 2-CH₃), 1.12 (s, 2-CH₃), 1.29 (s, 1-CH₃), 9.66 (s, 1-CHO), and 9.75 (d, J 2 Hz, 3-CHO); *bis*-2,4-dinitrophenylhydrazone, m.p. 273—274° (Found: C, 49.5; H, 4.6; N, 20.7. C₂₂H₂₉N₈O₈ requires C, 50.0; H, 4.6; N, 21.2%), m/e 528 (M^+) and 332 ($M^+ - \text{C}_6\text{H}_4\text{N}_4\text{O}_4$).

(Z)-1,3-Diacetyl-1,2,2-trimethylcyclopentane (18).—This was an oil, b.p. 80° at 0.75 mmHg, ν_{max} 1 700 cm^{-1} (CO), δ 0.62—3.00 (m, CH₂, CH), 0.70 (s, 2-CH₃), 1.13 (s, 2-CH₃), 1.30 (s, 1-CH₃), and 2.08 (s, 2 \times MeCO), m/e 196 (M^+), 153 ($M^+ - \text{CH}_3\text{CO}$), and 110 ($M^+ - 2\text{CH}_3\text{CO}$); *bis*-semicarbazone, m.p. 197—198.5°, m/e 251 ($M^+ - \text{NHCONH}_2$) and 236 ($M^+ - \text{NHNHCONH}_2$); *bis*-2,4-dinitrophenylhydrazone, m.p. 153—154°. A satisfactory analysis was not obtained.

2,3-seco-5 α -Androstane-2,3-dial (19).—This was a viscous oil (Found: C, 78.8; H, 10.55. C₁₉H₃₀O₂ requires C, 78.6; H, 10.4%), ν_{max} 1 724 cm^{-1} (CO), δ 0.71 (s, 18-H₃), 0.84 (s, 19-H₃), and 9.58—9.86 (m, 2 \times CHO), m/e 290 (M^+), and 246 ($M^+ - \text{CH}_2\text{CHOH}$).

Methyl 2,3-Dioxo-2,3-seco-olean-12-en-28-oate (20).—This was an unstable oil, b.p. 180—190° at 1 mmHg, δ 3.55 (s, OMe), 5.25 (m, $W_{1/2}$ 9 Hz, 12-H), 9.53 (s, 3-CHO), and 9.76 (distorted t, 2-CHO), m/e 484 (M^+), 466 ($M^+ - \text{H}_2\text{O}$), and 424 ($M^+ - \text{HOAc}$).

Methyl 2,3-Dioxo-2,3-seco-urs-12-en-28-oate (21).—This

¹⁷ 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; R. C. Cambie, R. C. Hayward, J. L. Roberts, and P. S. Rutledge, *ibid.*, 1974, 1858.

was an unstable oil, δ 3.65 (s, OMe), 5.25 (distorted t, 12-H), 9.64 (s, 3-CHO), and 9.88 (distorted t, 2-CHO), *m/e* 484 (M^{++}), 466 ($M^{++} - H_2O$), and 424 ($M^{++} - HOAc$).

Reaction of cis-Cyclohexane-1,2-diol with Iodine Trichloride.—The *cis*-diol (1) (92 mg, 0.8 mmol) was added to a solution of iodine trichloride (0.21 g, 0.89 mmol) in acetic acid (5 ml) and the mixture was stirred at 20 °C for 24 h. Work-up and p.l.c. (hexane-ether, 3 : 2) gave *cis*-cyclohexane-1,2-diyl diacetate (3)¹⁷ (88 mg, 55%), δ 1.16–2.34 (m, CH₂), 2.01 (s, 2 × OAc), and 4.95 (m, $W_{1/2}$ 11 Hz, 2 × CHOAc).

Reaction of cis-Cyclohexane-1,2-diol with Iodine(I) Acetate in Dichloromethane.—The *cis*-diol (1) (1.22 g, 10.5 mmol) was added to a solution of iodine (2.76 g, 10.5 mmol) and silver(I) acetate (1.74 g, 10.5 mmol) in dichloromethane (40 ml) and the mixture was stirred at 20 °C for 10 min. Work-up yielded an oil (1.21 g) which was separated by p.l.c. (ether-hexane, 7 : 3) into starting material, acetic acid, and *perhydrotribenzo[b,e,h]tetraoxecin* (25) (0.46 g) which crystallized from ethanol-ether as plates, m.p. 86–87° (Found: C, 69.9; H, 10.1. C₁₈H₃₀O₄ requires C, 69.6; H, 9.7%), ν_{max} 1 130 cm⁻¹ (—O—), δ 1.02–1.95 (m, CH₂), 3.95 (m, $W_{1/2}$ 9 Hz, 5-,7-,12-,14-H), and 4.95 (distorted t, 19-,22-H), *m/e* 310.213 4 (M^{++}), 309.206 0 ($M^{++} - H$), 213.148 0

($M^{++} - C_6H_8O$), 211.132 8 ($M^{++} - C_6H_{11}O$), 196.145 8 ($M^{++} - C_6H_{10}O_2$), and 98.073 1 ($M^{++} - C_{12}H_{20}O_3$), δ_C 21.2 (C-2,-13,-16,-17), 24.9 (C-9,-10), 28.9 (C-1,-4,-15,-18), 35.8 (C-8,-11), 74.8 (C-5,-7,-12,-14), and 104.5 p.p.m. (C-19,-22).

Reaction of Cyclohexene with Iodine Trichloride and Thallium(I) Acetate.—(a) *Using a 1 : 3 ratio.* Thallium(I) acetate (5.0 g, 18.9 mmol) in dried acetic acid (10 ml) was added dropwise under nitrogen to a solution of iodine trichloride (1.42 g, 6.1 mmol) in dried acetic acid (15 ml) and the mixture was stirred at 20 °C for 30 min. The resulting suspension was centrifuged and a portion (5 ml) of the clear solution was stirred with cyclohexene (99 mg, 1.2 mmol) at 20 °C for 10 s. Work-up gave *trans*-2-iodocyclohexyl acetate (4) (0.26 g, 79%) (correct ¹H n.m.r. spectrum).⁶

(b) *Using a 1 : 1 ratio.* Cyclohexene was treated as in (a) with a solution prepared from thallium(I) acetate (2.0 g, 7.6 mmol) and iodine trichloride (1.77 g, 7.7 mmol). Work-up and p.l.c. of the crude product gave *trans*-2-iodocyclohexyl acetate (4) (0.29 g, 42%) and *trans*-1-chloro-2-iodocyclohexane (6) (0.26 g, 42%) (correct ¹H n.m.r. spectrum).⁶

[8/105 Received, 23rd January, 1978]