2.03 (s, 3 H, CH_3CO), 1.96–2.08 (m, 2 H, H-9A,11), 1.69 (d, d, d, 1 H, $J_{9B,8}$ = 8.6 Hz, $J_{9B,9A}$ = 14.1 Hz, $J_{9B,10}$ = 5.1 Hz, H-9B), 1.49, 1.49 (t, 2 H, $J_{17A,18}$ = 9.5 Hz, t, 1 H, $J_{17B,18}$ = 7.3 Hz, H-17A,17B), 1,24 (t, q, 2 H, $J_{19,18}$ = 7.0 Hz, $J_{19,20}$ = 7.0 Hz, H-19), 1.089 (s, 3 H, H-21), 1.085 (s, 3 H, H-22), 1.17–1.03 (m, 2 H, H-18), 0.86 (d, 3 H, $J_{23,11}$ = 6.7 Hz, H-23), 0.84 (t, 3 H, $J_{20,19}$ = 7.0 Hz, H-20). Trans isomer: ^{1}H NMR (400 MH_2; prostaglandin numbering) δ 6.82 (d, d, 1 H, $J_{13,14}$ = 15.0 Hz, $J_{13,12}$ = 8.8 Hz, H-13), 6.40 (d, 1 H, $J_{14,13}$ = 15.2 Hz, H-14), 5.17 m, 1 H, C-10), 3.61 (s, 3 H, OMe), 2.43 (m, 3 H, H-8,11,12), 2.36, 2.24 (d, AB q, 2 H, $J_{7A,7B}$ = 15.0 Hz, $J_{7A,8}$ = 5.3 Hz, $J_{7B,8}$ = 8.2 Hz, H-7A,7B), 2.11–2.03 (m, 1 H, H-9A), 2.04 (s, 3 H, CH_3CO), 1.67 (d, d, d, 1 H, $J_{9B,8}$ = 8.2 Hz, $J_{9B,9A}$ = 14.5 Hz, $J_{9B,10}$ = 6.3 Hz, H-9B), 1.493 (t, 1 H, $J_{17A,18}$ = 7.4 Hz, H-17A), 1.493 (t, 1 H, $J_{17B,18}$ = 9.4 Hz, H-17B), 1.24 (t, q, 2 H, $J_{19,18}$ = 7.4 Hz, $J_{19,20}$ = 7.0 Hz, H-19), 1.15–1. 05 (m, 2 H, H-18), 1.092, s, 3 H, H-21), 1.085 (s, 3 H, H-22), 0.84 (t, 3 H, $J_{20,19}$ = 7.2 Hz, H-20), 0.81 (d, 3 H, $J_{23,11}$ = 6.3 Hz, H-23).

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Preparation of Hexacyclo[6.6.0.0^{2,6}.0^{3,13}.0^{4,11}.0^{5,9}]tetradecane-10,14-dione and Derivatives

Tahsin J. Chow*[1a] and Tung-Kung Wu[1b]

Institute of Chemistry, Academia Sinica, Nankang, Taipei, Taiwan, Republic of China, and Department of Chemistry, National Taiwan University, Taipei, Taiwan, Republic of China

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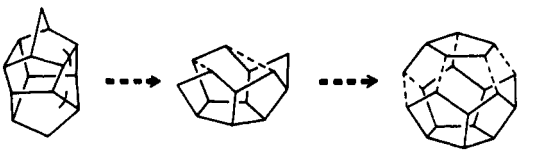
The highly symmetrical structure of heptacyclo-[6.6.0.0^{2,6}.0^{3,13}.0^{4,11}.0^{5,9}.0^{10,14}]tetradecane (1) has attracted wide interest since its discovery in 1961.[2,3] The synthesis of 1 can be completed in one step by coupling two units of norbornadiene through the mediation of certain transition metals. This reaction has provided an efficient method for the synthesis of a highly compact molecule which otherwise would be difficult to prepare.[4] The cage geometry of these molecules makes them attractive to both organic and theoretical chemists.[5] For a particular example, selective cleavage of two C–C bonds would produce a polyquinane with a folded geometry (*cisoid* fused) which might be used for a more efficient synthesis of dodecahedrane (Scheme I).[6] In this report we describe the preparation of hexaquinanedione 2 and its derivatives by cutting open the cage of 1.

Compound 1 was oxidized smoothly by lead tetraacetate in the presence of trifluoroacetic acid to form two major alcohols, 3 and 4, in 20% and 70% yields, respectively[7] (corrected for unreacted starting materials). The structure of 3 was confirmed by comparison with an authentic sample, while the structure of 4 was determined by analysis of its spectroscopic data. The presence of a hydroxy group in 4 is evident in both its ^{1}H NMR (signal disappears upon D_2O) and IR spectra (3605 cm^{-1}). The mass spectrum shows a strong parent peak at m/z 200 (base peak). The appearance of 14 separate signals in the ^{13}C NMR spectrum rules out the more symmetrical structure with the hydroxy group located on the bridgehead (i.e. C(6) of 1). A DEPT experiment indicates the presence of 2 secondary, 11 tertiary, and 1 quaternary carbons. Most of its ^{1}H NMR absorptions seriously overlapped each other, but they can be resolved clearly on a two-dimensional ^{1}H–^{13}C correlation spectrum.

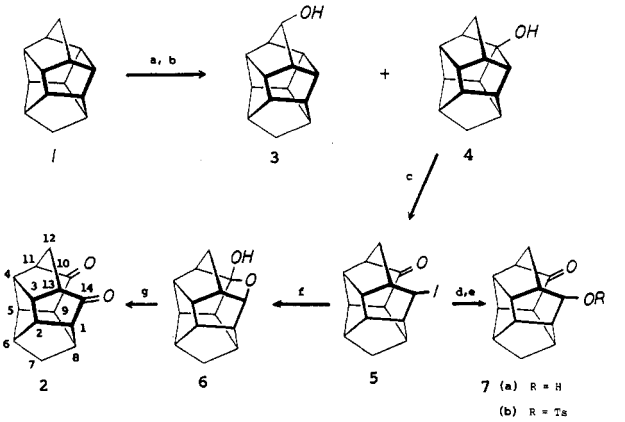
Selective ring-opening of 4 was carried out by a reagent combining I_2 and $Pb(OAc)_4$.[8] Bond cleavage happened mainly between C(1) and C(2) to produce 5 in 63% yield. The structure was proved indirectly by conversion to the more symmetrical diketone 2 (Scheme II). In the ^{13}C NMR spectrum of 5, the upfield signal at δ 31.8 indicates the presence of an iodo carbon. The iodide 5 can be hydrolyzed either in base or in acid. Basic hydrolysis produced the hemiketal 6, while acidic hydrolysis produced the hydroxide 7a. The iodide 5 was also converted to the *p*-toluensulfonate 7b by reaction with silver *p*-toluenesulfonate in acetonitrile.

Both the keto alcohol 7a and the hemiketal 6 were easily oxidized to the diketone 2 by Jones reagent. The ^{13} NMR spectrum of 2 contains only 9 peaks, demonstrating the presence of a plane of symmetry.

Scheme I



Scheme II[a]



[a] (a) $Pb(OAc)_4$, CF_3COOH, LiCl, CH_2Cl_2; (b) 5% NaOH; (c) $Pb(OAc)_4$, I_2; (d) CF_3COOH; (e) AgOTs, CH_3CN; (f) 10% NaOH; (g) Jones.

Experimental Section

^{1}H and ^{13}C NMR spectra were obtained on a Brucker MSL-200 FT spectrometer. Chemical shifts are reported as parts per million (ppm) downfield from tetramethylsilane (δ scale). Infrared spectra were recorded on a Perkin-Elmer 297 infrared spectrophotometer. Melting points were determined on a Yamato Model MP-21

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melting point apparatus and are uncorrected. Elemental analyses were obtained on a Perkin-Elmer 240 EA instrument. Mass spectra were carried out on a JEOL JMS-D300 mass spectrometer.

Oxidation of 1. To a solution of trifluoroacetic acid (25 mL) containing 0.1 M lithium chloride was added 1 (1.90 g, 10.0 mmol), lead tetraacetate (7.76 g, 17.5 mmol), and methylene chloride (25 mL). The solution was stirred for 24 h in the dark at room temperature and then quenched with 5% NaOH. The reaction mixture was extracted with three portions of 40 mL of ether, and the organic extracts were combined, washed with saturated aqueous sodium carbonate (3 × 40 mL) and brine (3 × 40 mL), dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure left a mixture of trifluoroacetate adducts which were hydrolyzed by refluxing with 10% aqueous sodium hydroxide for 16 h. The crude mixture was extracted with ether (3 × 40 mL). The ether extracts were combined, washed with brine, and dried over anhydrous magnesium sulfate. Evaporation of solvent produced white solids identified as a mixture of 1, 3, and 4. Separation was completed on a silica gel chromatographic column for the yields of 1 (1.48 g), 3 (80 mg, 0.37 mmol), and 4 (320 mg, 1.60 mmol, 70% yield corrected for recollected starting material). Physical data of 4: mp 208–208.5 °C; ^{1}H NMR ($CDCl_3$) 1.75–1.80 (3 H, m), 1.93 (1 H, s, OH), 2.05 (1 H, dd, J = 1.5 and 12 Hz), 2.20 (1 H, t, J = 5 Hz), 2.3–2.6 (9 H, m), 2.73 (1 H, m); ^{13}C NMR ($CDCl_3$) 40.74 (t), 42.59 (t), 48.79 (d), 49.49 (d), 50.45 (d), 50.88 (d), 51.54 (d), 51.76 (d), 52.76 (d), 53.38 (d), 55.11 (d), 57.82 (d), 63.41 (d), 98.50 (d); MS, m/z (relative intensity) 200 (M^+, 100), 172 (2.5), 159 (3.4), 143 (2.6), 133 (8.6); IR ($CDCl_3$) 3605, 3450 (OH), 2958, and 2867 cm^{-1}. Anal. Calcd for $C_{14}H_{16}O$: C, 83.96, H, 8.05. Found: C, 83.95; H, 8.17.

14-Iodohexacyclo[6.6.0.0^{2,6}.0^{3,13}.0^{4,11}.0^{5,9}]tetradecan-10-one (5). To dry benzene (200 mL, freshly distilled over sodium) were added 4 (1.00 g, 5.00 mmol), lead tetraacetate (4.44 g, 10.0 mmol), and iodine (2.54 g, 10.0 mmol) under nitrogen. The solution was heated to reflux for 20 min and then stirred at 70–75 °C for 1.5 h. It was cooled and filtered, and the precipitates were washed with ether. The liquid portions were combined and shaken with saturated sodium thiosulfate (100 mL) until the color of the solution faded. The organic layer was separated, washed with water (2 × 50 mL) and saturated sodium bicarbonate (2 × 50 mL), and dried over anhydrous magnesium sulfate. Evaporation of the solvent at reduced pressure yielded a light yellow oil which was purified by column chromatograph. Compound 5 was collected in 60% yield (1.03 g, 3.15 mmol): mp 77–78 °C; ^{1}H NMR ($CDCl_3$) 1.74 (2 H, s), 1.90 (1 H, dt, J = 7 and 13 Hz), 2.49 (1 H, d, J = 13 Hz), 2.59–2.66 (3 H, m), 2.8–3.1 (3 H, m), 3.16 (3 H, m), 3.41 (1 H, m), 4.03 (1 H, d, J = 2 Hz, CHI); ^{13}C NMR ($CDCl_3$) 31.80 (d, CHI) 43.90 (t), 45.85 (t), 46.24 (d), 47.56 (d), 51.70 (d), 51.98 (d), 53.34 (d), 55.55 (d), 56.16 (d), 57.21 (d), 64.54 (d), 65.21 (d), 227.20 (s, C=O); MS, m/z (relative intensity) 326 (M^+, 0.4), 199 (M^+ – I, 100), 171 (45), 129 (26), 105 (42), 91 (26); IR ($CDCl_3$) 1738 cm^{-1} (C=O). Anal. Calcd for $C_{14}H_{15}IO$: C, 51.55; H, 4.64. Found C, 51.55; H, 4.61.

Hydrolysis of 5. The iodide 5 (1.03 g, 3.15 mmol) was hydrolyzed by refluxing in 10% NaOH for 16 h to yield the hemiketal 6 (640 mg, 3.0 mmol) in 94%: mp 261–262 °C dec; ^{1}H NMR ($CDCl_3$) 1.53 (1 H, dt, J = 3.5 and 11 Hz), 1.70 (2 H, s), 2.07 (1 H, d, J = 11 Hz), 2.20 (1 H, m), 2.30–2.65 (6 H, m), 2.67–2.72 (2 H, m), 2.75–2.80 (1 H, m), 3.87 (1 H, d, J =6 Hz, OH), 4.40 (1 H, t, J = 9.5 Hz); ^{13}C NMR ($CDCl_3$) 33.00 (t), 37.41 (d), 42.84 (t), 47.05 (d), 49.15 (d), 49.77 (d), 51.37 (d), 53.95 (d), 54.12 (d), 54.40 (d), 54.56 (d), 57.35 (d), 77.69 (d), 106.12 (s); MS, m/z (relative intensity) 216 (M^+, 100), 198 (9), 188 (11), 175 (12), 171 (24), 170 (24); IR ($CDCl_3$) 3581, 3370 (OH), 2958, and 2871 cm^{-1}. Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.74; H, 7.45. Found C, 77.48; H, 7.44. The iodide 5 (33 mg, 0.10 mmol) was also hydrolyzed in trifluoroacetic acid/methylene chloride (v/v 1/1) by stirring for 24 h at room temperature to produce 7a (23 mg) in nearly quantitative yield: mp 291–292 °C dec; ^{1}H NMR ($CDCl_3$) 1.70 (2 H, s), 2.06 (1 H, m), 2.25 (1 H, br s, OH), 2.4–2.7 (5 H, m), 2.87 (2 H, m), 2.9–3.2 (4 H, m), 3.77 (1 H, s, CHOH); ^{13}C NMR ($CDCl_3$) 42.69 (t), 43.27 (d), 46.28 (t), 47.91 (d), 51.58 (d), 52.10 (d), 53.96 (d), 56.44 (d), 57.20 (2 C, d), 59.82 (d), 60.31 (d), 81.23 (CHOH, d), 228.45 (C=O, s); MS, m/z (relative intensity) 216 (M^+, 100), 198 (M^+ – 18, 33), 170 (34), 129 (60), 121 (52); IR ($CDCl_3$) 3610 (OH) and 1722 (CO) cm^{-1}.

11-Oxohexacyclo[6.6.0.0^{3,7}.0^{4,14}.0^{5,12}.0^{6,10}]tetradecanyl *p*-Toluenesulfonate (7b). In a round-bottom flask a solution of 5 (180 mg, 0.55 mmol) and silver *p*-toluenesulfonate (155 mg, 0.56 mmol) in acetonitrile (13 mL) was stirred at 0 °C for 2 h. The solution was allowed to warm up to room temperature and stirred for another 18 h. It was quenched with water and was extracted with ether. The organic layers were combined, washed, dried, and evaporated as usual. The white solids collected were purified by column chromatography to yield 7b (147 mg, 0.40 mmol, 72%) and 6 (8.4 mg, 0.04 mmol, 7%). Compound 7b: mp 141–142 °C; ^{1}H NMR ($CDCl_3$) 1.68 (2 H, m), 1.95 (1 H, dt, J = 7 and 13 Hz), 2.20 (1 H, d, J = 13 Hz), 2.37 (1 H, m), 2.44 (3 H, s), 2.55–2.61 (3 H, m), 2.75–2.90 (3 H, m), 2.90–3.05 (1 H, m), 3.05–3.20 (2 H, m), 4.28 (1 H, d, J = 2 Hz), 7.34 (2 H, d, J = 8 Hz), 7.74 (2 H, d, J = 8 Hz); ^{13}C NMR ($CDCl_3$) 21.56, 42.22, 42.73, 46.21, 47.76, 51.51, 52.09, 53.92, 56.17, 56.76, 57.07, 57.26, 65.73, 90.79, 127.80, 129.74, 133.4, 144.54, 226.83; MS, m/z (relative intensity) 370 (M^+, 1.0), 215 (2.8), 198 (100), 170 (30), 155 (10); IR ($CDCl_3$) 1722 (CO), 1601, and 1361 cm^{-1}.

Hexacyclo[6.6.0.0^{2,6}.0^{3,13}.0^{4,11}.0^{5,9}]tetradecane-10,14-dione (2). The oxidation was completed by mildly heating at 55 °C a solution of 6 (500 mg, 2.32 mmol) with potassium dichromate (1.36 g, 4.63 mmol) in 1.0% sulfuric acid (50 mL). The reaction mixture was neutralized with 5% NaOH, followed by extractions with ether. The diketone 2 was purified by column chromatograph, yield 78% (385 mg, 1.80 mmol): mp 293.5–294.5 °C dec; IR (CCl_4) 1760 cm^{-1} (CO); ^{1}H NMR ($CDCl_3$) 1.85 (2 H, t, J = 1.2 Hz), 2.15 (1 H, dt, J = 8 and 12 Hz), 2.63–2.80 (6 H, m), 2.9–3.1 (3 H, m), 3.38 (2 H, m); ^{13}C NMR ($CDCl_3$) 42.55, 43.20, 46.99, 47.65, 52.31, 54.08, 56.14, 57.35, 223.42 (CO); MS, m/z (relative intensity) 214 (M^+, 100), 196 (2.2), 186 (15), 168 (3.5), 158 (5.5), 148 (13). Anal. Calcd for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.40; H, 6.57.

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Registry No. 1, 17872-39-8; 2, 112533-27-4; 3, 112533-28-5; 4, 112533-29-6; 5, 112533-30-9; 6, 112533-31-0; 7a, 112533-33-2; 7b, 112533-32-1.

Supplementary Material Available: 2D ^{1}H–^{13}C NMR COSY spectrum of 4 (1 page). Ordering information is given on any current masthead page.

Optimization of a Simple System for the Oxidation of Octan-2-ol with Sodium Bromate, Mediated by Ruthenium Tetraoxide Generated in Situ

Susan Giddings and Andrew Mills*

Department of Chemistry, University College of Swansea, Singleton Park, Swansea SA2 8PP, Great Britain

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1. Introduction

Ruthenium tetraoxide has, for many years, been recognized as a powerful oxidizing agent for the conversion of secondary alcohols to ketones.[1] Initially it was used in stoichiometric amounts[2-4] as an alternative to the more toxic and expensive compound, osmium tetraoxide, since,

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