Tetrahedron Vol. 37, pp. 143 to 150
Pergamon Press Ltd., 1981. Printed in Great Britain

0040-4020/81/0101-0143/$02.00/0

PROPELLANES—LIII

THE -ENE REACTION OF OLEFINIC PROPELLANES WITH SINGLET OXYGEN[a]

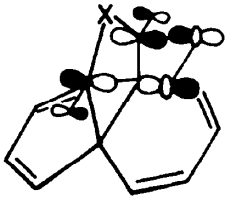
IMAN LANDHEER and DAVID GINSBURG*

Department of Chemistry, Israel Institute of Technology, Haifa, Israel

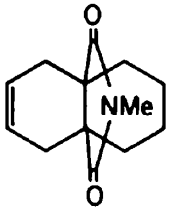
(*Received in U.K. 5 November* 1979)

Abstract—The -ene reactions of propellanes containing an anhydride ring or a methylimide ring undergo secondary orbital control. In attack by $^1O_2$ only the *syn*-products are obtained. In the corresponding lactone or ether steric hindrance plays a more important role in the direction of attack.

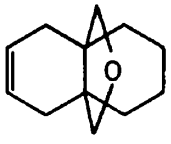
We have reported on reactions of singlet oxygen with (conjugated) dienic and tetraenic propellanes.[a] We think that here too secondary orbital interactions between the HOMO of $^1O_2$ and the π^* LUMO of the C=O groups in the heterocyclic ring, when these are present, are responsible for stabilizing the transition state for *syn*-attack (with respect to the hetero-rings. It was of interest to see whether such control of regio-specificity may occur also in the -ene reaction of olefinic propellanes and $^1O_2$. We have found preference for *syn* as compared to *anti*-attack using **1** as



a substrate for epoxidation of the double bond as compared to the substrate **2** where CO groups are absent in the hetero-ring and the ratio of *syn*- to *anti* epoxides is 1:1.[1] Similar preference for *syn*-attack of **1**



1



2

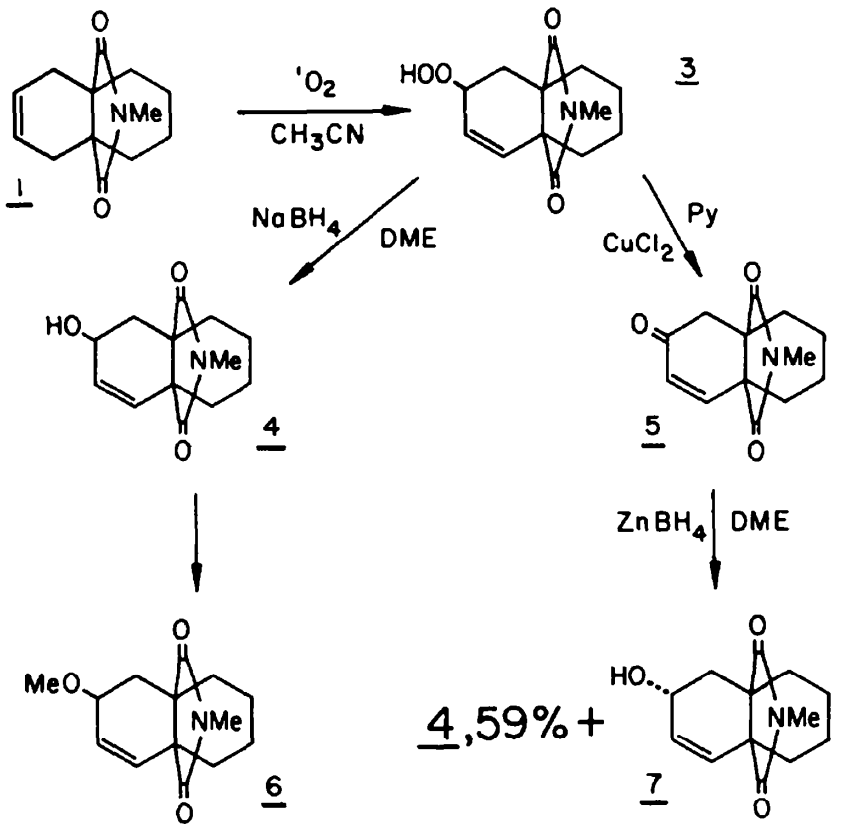
by singlet oxygen was shown by reduction of the hydroperoxide **3**, prepared in CH_3CN solution, without its characterization, to the *syn*-alcohol **4** (Scheme 1). Treatment of **3** with cupric chloride in pyridine,[2] gave the α,β-unsaturated ketone **5** which with $ZnBH_4$ afforded a mixture of *syn* (59%) and *anti* (23%) alcohols. Since we had **7** in hand we feel certain that the ene reaction of **1** could not have given more than, say 1-2% of the *anti*-hydroperoxide, for we could not show that **7** accompanies **4** when the hydroperoxide mixture, if it is indeed a mixture, apparently containing **3** alone was reduced with $NaBH_4$. The NMR spectra of the two epimeric alcohols **4** and **7** differ significantly in the olefinic region so that it would have been easy to detect **7** if it had been formed from its corresponding hydroperoxide precursor. The OMe group did not alter the pattern of the olefinic signals as compared to the *syn*-alcohol. This observation was also confirmed for the analogous anhydride derivatives and is therefore important for assigning the initial direction of attack by $^1O_2$.

That the *syn* face of the anhydride **8** was preferred by singlet oxygen was proved as shown in Scheme 2. Here too the hydroperoxide **9** was converted either into the *syn*-alcohol **10** or the enone **11** and methylation of the hydroxyl of **10** was accomplished by CH_2N_2 in the presence of $AlCl_3$.[3] Methanolysis of the anhydride ring of **10** followed by acid treatment gave mixture of two products, the lactone-ester **13** and the dienic anhydride **14**. Alternatively, if after methanolysis of **10**, iodine was added, the iodo-lactone **15** was obtained, again proving the *syn* configuration of the hydroxyl group in **10**. Dehydroiodination[4] of **15** again afforded the unsaturated lactone-ester **13**, identical with the product derived directly from **10**.

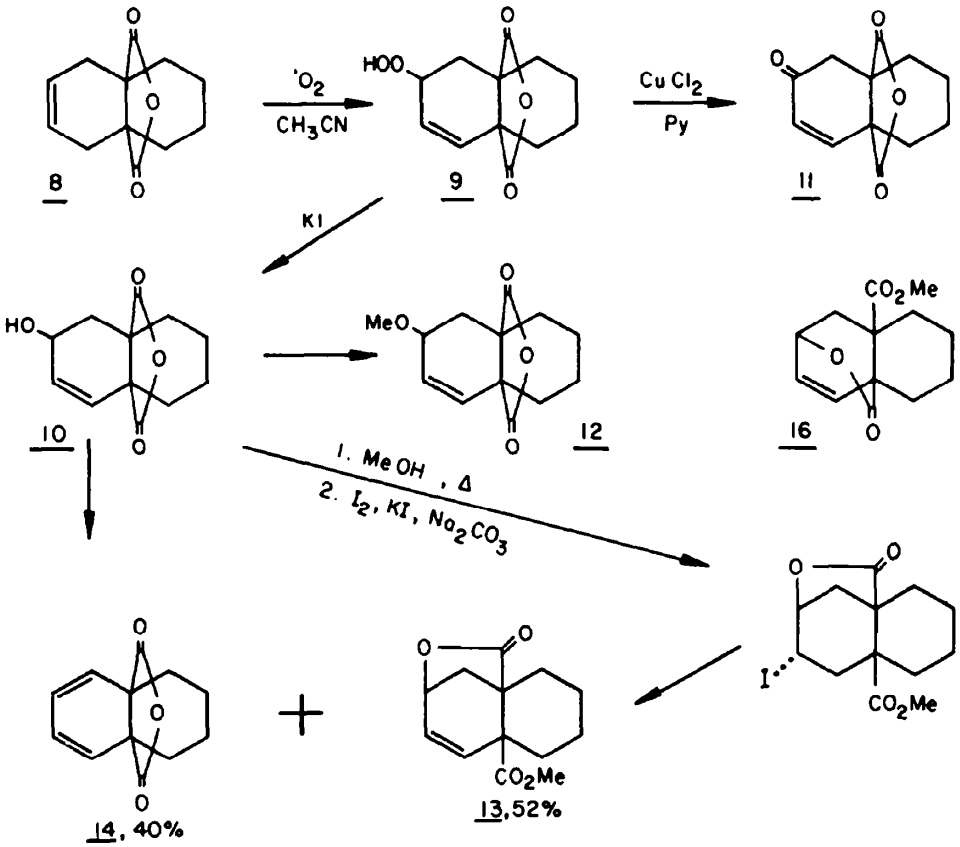
It should be noted that the use of unfiltered light in the photo-oxidation gave a small amount (8-10%) of 5,6,7,8-tetrahydro-2-naphthol (Experimental). The infrared C=O bands for both **13** and **15**, 1790; 1741 and 1783; 1740 cm^{-1}, respectively, support their formulation as γ- rather than δ-lactones. Had a δ-lactone, e.g. **16**, formed one would expect it to undergo potential retro-Diels-Alder reaction leading to a dienic-ester, with loss of CO_2 upon heating. The lactone **13**, however, was stable when heated in an evacuated nmr tube at 220° for 105 min with no significant change in its nmr spectrum. Heating **13** at 240° for 30 min led to **14** and a minor unidentified product.[5]

Scheme 3 shows the preparation from **9** of propellene lactone and ether derivatives which permitted the construction of a frame of reference for configurational correlation with compounds described in Schemes 4 and 5.

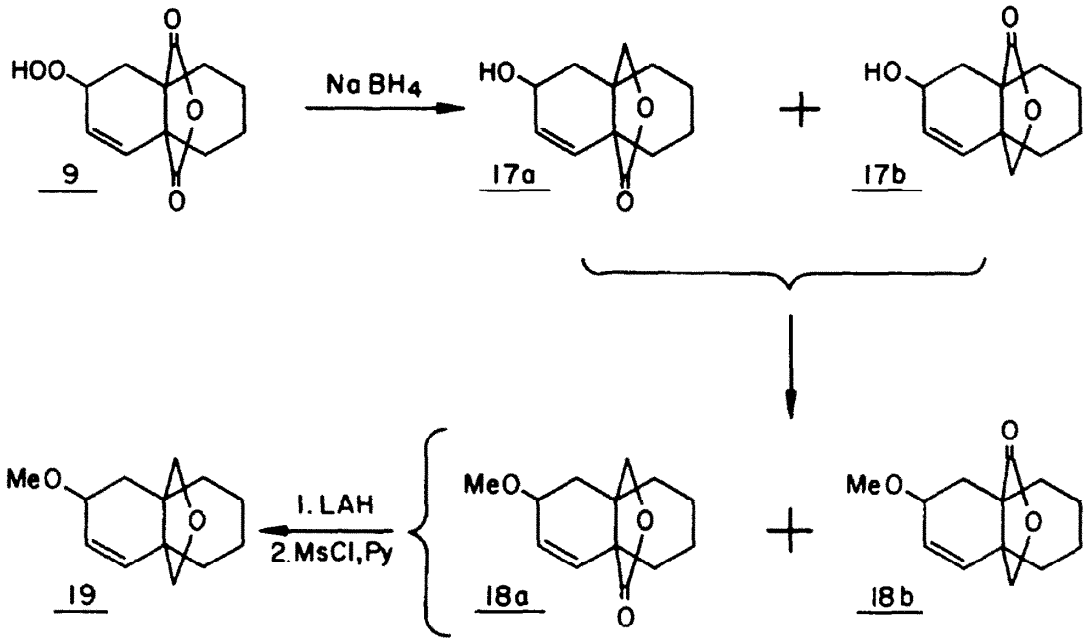
[a]Part LII. I. Landheer and D. Ginsburg, *Tetrahedron* preceding paper.



Scheme 1.



Scheme 2.

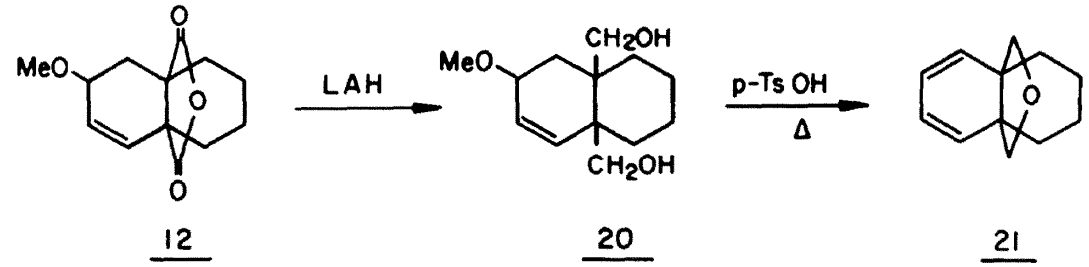


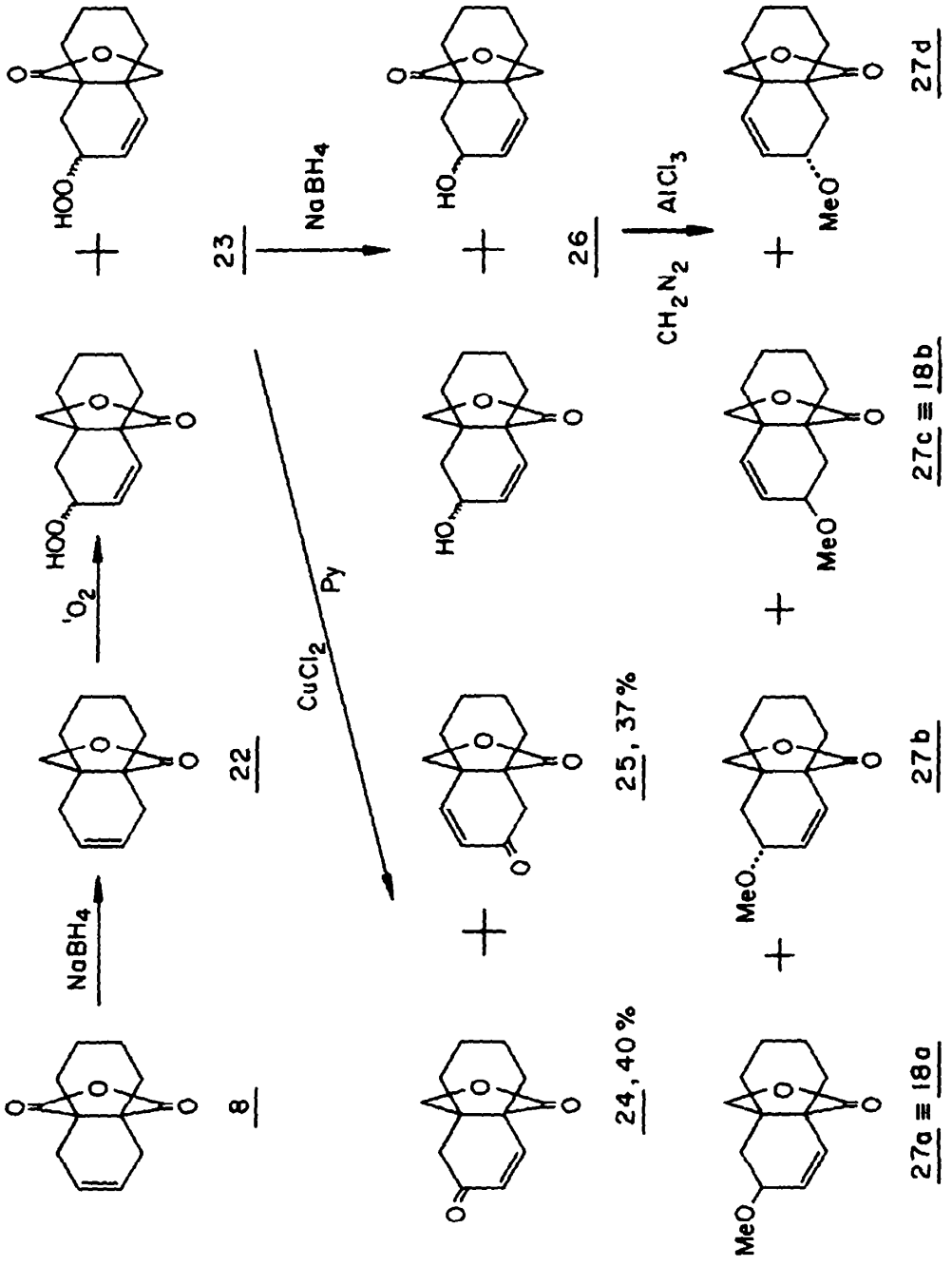
Scheme 3.

Thus reduction of **9** afforded a mixture of two isomeric lactones **17(a, b)** which was methylated go the corresponding mixture of methyl ethers **18(a, b)** still at the lactone oxidation state. Of course, when the lactone carbonyl was reduced with LAH the product was a single one, the methoxyl compound at the ether oxidation state, **19**. This ether could not be prepared from the anhydride **12**. Reduction of the latter with LAH gave the diol **20**. However, the usual cyclization to a 5-membered ether ring[6] failed in this case due to elimination of methanol and formation of **21**. A useful alternative was found (Scheme 5).

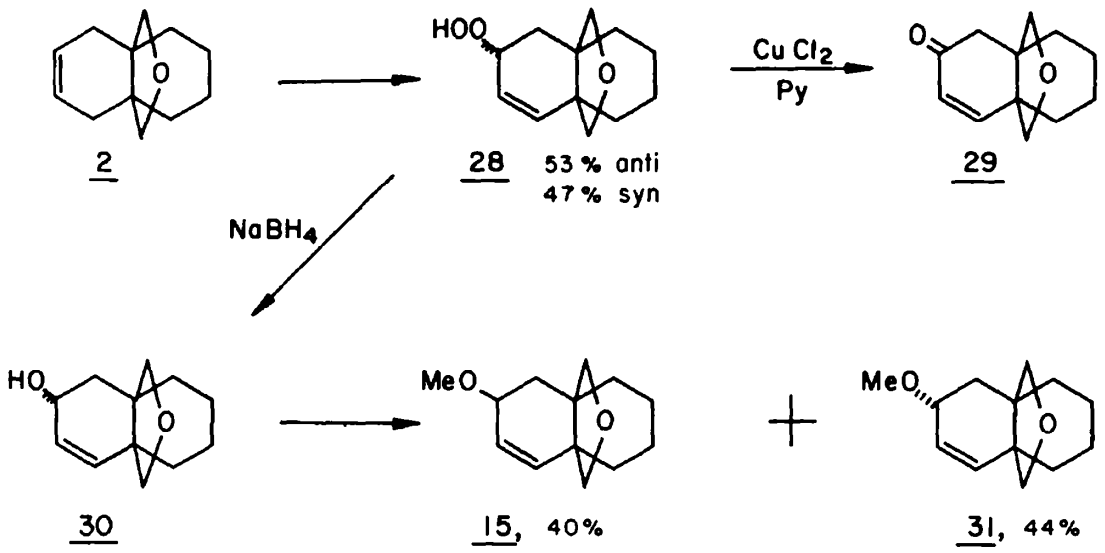
In the lactone series due to the absence of a plane of symmetry the reaction with singlet oxygen gives a mixture of isomers already at the hydroperoxide stage. Thus **22** gives **23**. Treatment of the latter with cupric chloride in pyridine therefore gives two enones **24** and **25** whilst reaction of **23** gives a mixture of lactone-alcohols **26** and methylation of the OH function gives a mixture of lactone-methyl ethers **27** (Scheme 4). It should be noted however, that if our expectation of lower regiospecificity in attack by singlet oxygen is fulfilled then **23**, **26** and **27** could consist of a mixture of 4 stereoisomers as shown explicitly in the scheme by all 4 structures of **27(a–d)**.

Indeed in this case both faces of the cyclohexene were attacked by singlet oxygen and we interpret this in the context of a less efficient secondary orbital interaction with $^1O_2$ since there are no longer two C=O groups to interact with in the substrate; there is only one and the other is replaced by two H atoms which superimpose steric repulsion upon the attractive secondary orbital interaction capable of expressing itself fully in the methylimide or in the anhydride. The *syn-anti* ratio in **23**, *ca* 1:1 was determined from the NMR spectrum. However, this may be determined also from inspection of the more complex spectra of, e.g. **26** and **27** as well as of **30** (see below). In **26** and **27** all four isomers are present, giving a complex pattern in the olefinic region. But the position of the olefinic proton α- to the alcohol in **26** varies with respect to whether we are dealing with a *syn* or an *anti*-ol. The carbonyl of the lactone does not appear to influence this proton. So for the anhydride **10**, the signals for this proton are two doublets (A part of ABX) whilst for the isomer mixtures in **26** and **30**, these signals consist of 2 symmetrical triplets (2 superimposed doublets). The NMR spectrum of **27** revealed in addition, 3 signals for the OMe-Me group in a ratio of 2:1:1 again exhibiting an overall *syn-anti*-ratio of 1:1. It should also be noted




NaBH4
8
22
1O2
HOO
CuCl2
Py
23
NaBH4
HO
26
CH2N2
AlCl3
MeO
24, 40%
25, 37%
27a ≡ 18a
27b
27c ≡ 18b
27d

Scheme 4.



Scheme 5.

in this connection that the two enones **24** and **25** are formed in a 1:1 ratio. Assignment of their structure was based on the comparison of their NMR spectra with those of the methylimide-enone **5**, the anhydride-enone **11** and the ether-enone **29**.

Finally, the olefinic ether **2** was treated with $^1O_2$ in the expectation that here too, perhaps even more than in the case of the corresponding lactone **22**, there would be more *anti*- than *syn* attack. In the event, on the basis of interpretation of the NMR spectra of the products described in Scheme 5, it was clear that the *syn-anti* ratio is 1:1. The configuration of the *syn*-isomer could be assigned due to similarities as compared to the NMR spectrum of **12**, whose configuration was proven (see above). The enone **29** was prepared in order to aid in the structural assignments of **24** and **25** obtained in the lactone series.

EXPERIMENTAL

IR spectra were recorded on a Perkin-Elmer 237 spectrometer, NMR spectra on a Varian T-60 or a Bruker WP-60 instrument and mass spectra on a Varian MAT-711 spectrometer. Mp's and bp's are uncorrected.

Singlet oxygen was generated photochemically using methylene blue (MB) or rose bengal (RB) as sensitizer, by means of a water-cooled tungsten-halogen lamp, Osram-64663, 400 w, 36 v or an ordinary halogen projection lamp, 150 w, 24 v. The light was filtered by a sodium bichromate soln (20 g/l). The reaction mixture was vigorously stirred magnetically in a reaction vessel cooled by an ice bath. Oxygen uptake was measured volumetrically. After completion, checking by tlc on silica, MB or RB was removed by stirring the reaction mixture with carbon black followed by filtration. Evaporation of solvent afforded crude product.

Alox-n = grade I, neutral alumina.

Alox$^-$ = grade I, basic alumina.

Reaction of **1** *with* $^1O_2$

A soln of **1** (2.01 g) and MB (20 mg) in dry acetonitrile (35 ml) was irradiated with the halogen lamp for 2 hr. The usual workup gave crude product **3** (2.75 g) which was not characterized but subjected to the following reactions.

(a) Half of the crude product **3** (1.375 g) was dissolved in dry dimethoxyethane (DME) and added to a stirred suspension of $NaBH_4$ (1.0 g) in dry DME (40 ml). Stirring was continued for 1 hr at room temp. Careful hydrolysis with HCl (6N, 10 ml) was effected and the solvents removed at the water pump. The residue was partitioned between ice-water (60 ml) and ether (25 ml) and extracted with ether (2 × 20 ml), the aqueous phase saturated with salt and the extraction repeated (2 × 20 ml). The combined ether extracts were washed with a brine soln and dried (Na_2SO_4). Removal of ether at the water pump and passing an EtOAc soln of the residue on Alox-n gave the *syn*-alcohol **4** (915 mg; 85%), m.p. 110° (ether). (Found: C, 66.26; H, 7.27; N, 5.83; M.W. 235.1272. $C_{13}H_{17}NO_3$ requires: C, 66.36; H, 7.28; N, 5.95%, M.W. 235.1208). IR ($CHCl_3$): 3575, 3420, 2925, 2840, 1775, 1698, 1427, 1378, 1307, 1090, 1062, 1039, 1013, 962 cm^{-1}. NMR ($CDCl_3$): δ 5.85–5.38 (ABX, 2H, J = 10, 2, 1 Hz); 4.28 (m, 1H); 2.90 (s, 3H); 2.60–2.16 (m, 3H); 1.83–1.20 (m, 8H). MS: M$^+$, 235 (96); 192 (27); 179 (11); 166 (100); 150 (38); 149 (24); 148 (21); 133 (22); 132 (45); 131 (11); 123 (12); 122 (15); 117 (14).

(b) The second half of the crude product **3** (1.375 g) was dissolved in dry pyridine (15 ml) to which $CuCl_2$ (20 mg) had been added and the whole was stirred overnight at room temp. Removal of solvent and passing an EtOAc solution of the product on Alox-n gave **5** (960 mg; 90%), m.p. 82–83° (ether). (Found: C, 66.86; H, 6.39; N, 5.95; M.W. 233.1030. $C_{13}H_{15}NO_3$ requires: C, 66.93; H, 6.48; N, 6.01%; M.W. 233.1052). IR (KBr): 2925, 2840, 1776, 1709, 1682, 1618, 1446, 1424, 1378, 1346, 1301, 1260, 1090, 1060, 1037, 986, 960, 947, 885, 860, 836, 783, 734 cm^{-1}. NMR ($CDCl_3$): δ 6.63–5.91 (AB, 2H, J = 10 Hz); 2.94 (s, 3H); 3.05–2.30 (AB, 2H; J = 17 Hz); 1.82–1.28 (br s, 8H). MS: M$^+$, 233 (18); 147 (6); 133 (10); 121 (16); 120 (100).

In neither the NMR spectrum of the hydroperoxide nor the alcohol **4** could any signals be observed corresponding to the presence of an *anti*-isomer.

Methylation of **4**

To a suspension of sodium hydride (90 mg; 60% in oil washed with 3 × 2 ml pentane) in dry THF (10 ml) under argon was added **4** (100 mg). The whole was warmed to reflux and allowed to cool down to room temp. By this time gas evolution had ceased. MeI (1.5 ml) was added and the whole stirred overnight at room temp. Filtration of solid and evaporation of solvent gave crude **6** (95 mg). Tlc on prep silica plates using EtOAc(2): hexane (8) gave pure **6** (87 mg; 82%) as an oil, distilled bulb to bulb, b.p. 110°/10^{-2} mm. (Found: C, 67.03; H, 7.58; N, 5.65; M.W. 249.1375. $C_{14}H_{19}NO_3$ requires: C, 67.44; H, 7.68; N, 5.62%; M.W. 249.1365). IR

($CHCl_3$): 2950, 2910, 2840, 1775, 1700, 1598, 1427, 1376, 1345, 1097, 1035, 1021, 956 cm^{-1}. NMR ($CDCl_3$): δ 5.81–5.28 (ABX, 2 H, J = 10, 2, 1 Hz); 3.70 (m, 1 H); 3.32 (s, 3 H); 2.85 (s, 3 H); 2.56–2.25 (m, 2 H); 1.81–1.13 (m, 8 H). MS: M^+, 249 (100); 234 (51); 164 (30); 163 (33); 149 (34); 132 (20); 121 (19).

Reduction of **5**

A mixture of $NaBH_4$ (550 mg) suspended in dry DME (filtered through Alox$^-$; 50 ml) and $ZnCl_2$ (450 mg) was stirred 15 min at room temp. A soln of **5** (532 mg) in dry DME (10 ml) was added and stirring thus continued for 2 hr more. The mixture was hydrolyzed with HCl (6 H, 5 ml) and the solvents evaporated. Ether extraction as described above for **3** followed by tlc on silica (3 plates) and run twice with benzene (1): ether (1), gave in ascending order of polarity: **5** (11 mg); **4**, identical with that described above (305 mg; 59%) and the isomeric *anti*-alcohol, **7** (122 mg; 23%), b.p. 120°/10^{-2} mm, m.p. 93–95°.

Compound **7**. (Found: C, 66.16; H, 7.33; N, 5.81; M.W. 235.1217. $C_{13}H_{17}NO_3$ requires C, 66.36; H, 7.28; N, 5.95%; M.W. 235.1208). IR ($CHCl_3$): 3560, 2920, 2840, 1778, 1701, 1433, 1381, 1094, 1080, 1024, 970 cm^{-1}. NMR ($CDCl_3$): δ 6.09–5.53 (ABX, 2 H, J = 10, 4, 0.5 Hz); 4.28 (m, 1 H); 3.4 (br s, 1 H); 2.92 (s, 3 H); 1.99–1.23 (m, 10 H). MS: M^+, 235 (38); 219 (18); 192 (30); 180 (20); 178 (21); 166 (100); 134 (32); 133 (70); 132 (28).

Reaction of **8** *with* $^1O_2$

A soln containing **8** (320 mg), RB (20 mg) and dry CH_3CN (35 ml) was irrad for 4.5 hr with the halogen lamp. Evaporation left crude **9** (407 mg) which was dissolved in pyridine (20 ml) containing $CuCl_2$ (20 mg) and the whole stirred overnight at room temp. After removal of solvent and the usual ether extractions (as above) the crude product (300 mg) was divided between 2 prep silica plates using EtOAc (4): hexane (6), giving recovered **8** (63 mg) and enone **11** (175 mg; 64%), m.p. 177–178° (MeOAc). (Found: C, 65.67; H, 5.93. $C_{12}H_{12}O_4$ requires: C, 65.44; H, 5.49%). IR ($CHCl_3$): 2910, 2835, 1853, 1792, 1692, 973, 925, 877 cm^{-1}. NMR ($CDCl_3$): δ 6.68–5.97 (AB, 2 H, J = 10 Hz); 3.05–2.32 (AB, 2 H, J = 17 Hz); 1.90–1.25 (br s, 8 H). MS: M^+-CO_2, 176.0846; $M^+-C_2O_3$, 148.0864 (base peak).

When unfiltered light was used in the photo-oxidation about 8% of 5,6,7,8-tetrahydro-2-naphthol was isolated by tlc on silica, EtOAc (2): hexane (8), identical to an authentic specimen obtained from Aldrich.

A similar run using **8** (600 mg), MB (20 mg) and dry CH_3CN (35 ml), affording **9** (720 mg) was followed by dissolving crude **9** in MeOH (20 ml) and acetone (20 ml), KI (600 mg) was added and the whole stirred 1 hr at room temp. Ether extraction as above including washing with aq thiosulfate afforded after the usual workup and column chromatography on silica using benzene as eluant, **8** (276 mg). MeOAc eluted the alcohol **10** (161 mg, 46%), m.p. 126–128° (ether). (Found: C, 64.66; H, 6.21. $C_{12}H_{14}O_4$ requires: C, 64.85; H, 6.35%). IR ($CHCl_3$): 3550, 3350, 2920, 2840, 1841, 1785, 1085, 1031, 982, 925 cm^{-1}. NMR ($CDCl_3$): δ 6.03–5.41 (ABX, 2 H, J = 10, 2, 1 Hz); 4.44 (br t, 1 H); 2.80 (br s, 1 H); 2.49–2.17 (dd, 2 H); 1.77–1.20 (m, 8 H). MS: M^+-CO, 194.0942 (26); 150 (68); 149 (100).

Methylation of **10**

To a soln of **10** (50 mg) in diethyl ether (5 ml) was added a catalytic amount of $AlCl_3$ (*ca* 5 mg) and ethereal diazomethane until polymeric ppt began to appear. Filtration and evaporation gave crude **12** which on tlc on prep silica plates using ether (1): benzene (9) afforded with MeOAc, **12** (36 mg; 68%), distilled bulb to bulb, b.p. 120°/10^{-2} mm as an oil. (Found: C, 65.93; H, 6.91; M.W. 236.1049. $C_{13}H_{16}O_4$ requires: C, 66.08; H, 6.83%; M.W. 236.1048). IR (CCl_4): 3005, 2950, 2910, 2840, 2800, 1846, 1790, 1445, 1378, 1343, 1170, 1098, 978, 920, 661 cm^{-1}. NMR ($CDCl_3$): δ 6.05–5.40 (ABX, 2 H, J = 10, 2, 1 Hz); 3.94 (m, 1 H); 3.39 (s, 3 H); 2.54–2.19 (m, 2 H); 1.74–1.21 (m, 8 H). MS: M^+, 236 (1); 208 (80); 149 (14); 136 (27); 135 (24); 133 (41); 132 (28); 131 (22 121 (100).

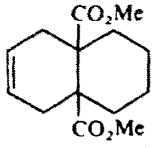
Proof of syn-*structure of* **10**

A degassed ampoule containing **10** (60 mg) and MeOI (3 ml) was sealed under vacuum and heated at 95–100° fo 19 hr. The ampoule was opened and the solvent removed. Th half-ester was taken up in xylene (5 ml), *p*-TsOH (5 mg) adde and the whole heated under reflux for 15 min. The solvent wa removed at the water pump and the residue subjected to pre tlc on silica using ether (2): benzene (8) affording (MeOAc) i ascending order of polarity **14** (10 mg; 40%) identical to a authentic specimen; **13** (15 mg; 52%) and **10** (33 mg). Th lactone **13** had m.p. 115–119° (ether). (Found: C, 65.87; H 6.79; M.W. 236.1044. $C_{13}H_{16}O_4$ requires: C, 66.08; H 6.83%; M.W. 236.1049). IR (CCl_4): 3015, 2965, 2915, 284(1790, 1741, 1641, 1445, 1437, 1329, 1315, 1282, 1221, 1185 1162, 1140, 1096, 1070, 1055, 990, 946, 925 cm^{-1}. NMI ($CDCl_3$): δ 6.32–5.68 (ABX, 2 H, J = 10, 5, 0.5 Hz); 4.71 (ps 1 H, J = 5 Hz); 3.63 (s, 3 H); 2.60–1.24 (m, 10 H). MS: M^+ 236 (6); 192 (5); 191 (9); 177 (7); 135 (4); 134 (17); 133 (100) 132 (34); 131 (18); 119 (5).

Alternative preparation of **13**

(a) The half-ester was made as above from **10** (1.0 g) an MeOH (15 ml). It was taken up in satd aq $KHCO_3$ (30 ml) Part which remained insoluble was extracted with ether an afforded after drying (Na_2SO_4), **10** (207 mg). To the alkalin aq soln was added iodine (1.3 g) and KI (5 g) in water (15 ml and the whole was stirred in the dark at room temp for 20 hr After extraction (4 × 30 ml $CHCl_3$) the combined extract were washed with 10% $K_2S_2O_3$ aq, 5% NaHCO aq and sat NaCl aq and dried (Na_2SO_4). Removal of solvent afforde crystalline iodo-lactone **15** (1.02 g; 72%), m.p. 166–167 (ether). (Found: C, 42.76; H, 4.67; I, 34.71; M.W. 364.0159 $C_{13}H_{17}IO_4$ requires: C, 42.87; H, 4.71; I, 34.85%; M.W 364.0169). IR (CCl_4): 2925, 2845, 1783, 1740, 1463, 1447 1430, 1354, 1292, 1273, 1227, 1199, 1130, 1105, 1090, 1055 1004 cm^{-1}. NMR ($CDCl_3$): δ 4.64–4.14 (2m, 2 H); 3.67 (s 3 H); 2.94–2.58 (dd, 2 H); 2.44–1.14 (2m, 10 H). MS: M^+, 36 (14); 237 (39); 192 (14); 191 (35); 177 (21); 134 (16); 133 (100) 131 (24); 94 (23); 93 (13).

The aq layer was acidified with conc HCl and extracte with ether (5 × 20 ml). Evaporation gave the by-produc monoacid-monoester which was characterized afte



methylation with CH_2N_2 as b.p. 160°/10^{-2} mm. (Found: 66.84; H, 7.97. $C_{14}H_{20}O_4$ requires: C, 66.64; H, 7.99%). I (CCl_4): 3005, 2925, 2840, 1736, 1461, 1449, 1428, 1284, 122 1190, 1169, 1157, 1133, 1062, 1033, 1007 cm^{-1}. NM ($CDCl_3$): δ 5.52 (br s, 2 H); 3.60 (s, 6 H); 2.37 (br s, 4 H 2.06–1.23 (m incl br s at 1.47, 8 H).

(b) To a soln of **15** (860 mg) in dry THF (20 ml) under N was added DBN (5 ml) and the soln was stirred overnight room temp. Removal of solvent and ether extraction as abo gave pure **13** (500 mg; 89%), m.p. 115–119° (ether) identic with that described above.

Preparation of lactone derivatives

(a) *From anhydride starting material.* A soln of **8** (900 m and RB (50 mg) in dry CH_3CN (30 ml) was irrad with t halogen lamp for 8 hr. After the usual workup crude **9** w dissolved in MeOH (50 ml) and treated with NaBI (900 mg). After the usual workup methylation of the hydrox lactone mixture **17a** and **17b** was effected as described abo with CH_2N_2–$AlCl_3$. Preparative tlc on silica usi chloroform permitted isolation of **22** (120 mg; see below) a a fraction distilled bulb to bulb of pure methoxy-lactc mixture of isomers **18a** + **18b**, b.p. 95°/10^{-2} mm as an

(Found: C, 70.01; H, 8.29; M.W. 222.1242. $C_{13}H_{18}O_3$ requires: C, 70.24; H, 8.16%; M.W. 222.1256). IR (CCl_4): 3000, 2955, 2910, 2835, 2795, 1784, 1447, 1201, 1189, 1090, 1000 cm^{-1}. NMR ($CDCl_3$): δ 5.82–5.23 (m, 2H); 4.25–3.58 (m, 3H); 3.26 (s, 3H; expanded scale shows 2 singlets); 2.23–1.19 (m, with br s at 1.51). MS: M^+, 222 (28); 192 (17); 190 (19); 178 (21); 177 (84); 166 (20); 163 (100); 162 (18); 151 (56); 149 (35); 148 (18); 145 (25); 136 (23); 135 (34); 133 (76); 121 (90).

(b) *From lactone starting material.* The lactone **22** was prepared from a soln of **8** (4.72 g) in dry DME (30 ml) which was added during 10 min to an ice-cooled suspension of $NaBH_4$ (3.0 g; 3.4 eq) in dry DME (150 ml).[7] The ice bath was removed and stirring continued for 2 hr. After the usual workup and ether extraction as above the crude residue was taken up in benzene and passed over Alox-n affording **22** (3.52 g; 80%) of pure crystalline lactone, m.p. 56–58°. (Found: C, 74.89; H, 8.46; M.W. 192.1166. $C_{12}H_{16}O_2$ requires: C, 74.97; H, 8.39%; M.W. 192.1150). IR (KBr): 3010, 2915, 2890, 2840, 1766, 1480, 1446, 1435, 1422, 1361, 1286, 1212, 1182, 1160, 1140, 1092, 990, 978, 753 cm^{-1}. NMR: $CDCl_3$: δ 5.65 (br s, 2H); 4.08–3.77 (AB, 2H); 2.30–1.25 (m with br s at 1.46, 12H). MS: M^+, 192 (100); 147 (84).

Reaction of **22** *with* $^1O_2$

A soln of **22** (150 mg) and RB (10 mg) in dry CH_3CN (30 ml) was irrad for 17 hr with the halogen lamp. The NMR spectrum of the crude mixture exhibited a 1:1 *syn-anti* mixture.

(a) The crude residue after workup was dissolved in pyridine (5 ml) containing $CuCl_2$ (10 mg) and stirred overnight at room temp. After removal of solvent and ether extraction as above the crude product (170 mg) was subjected to prep tlc on silica using ether (15): benzene (85), giving (MeOAc) in ascending order of polarity: the enone **25** (60 mg; 37%) and the enone **24** (64 mg; 40%).

Compound **24**: M.p. 165–167° (ether). (Found: C, 69.86; H, 6.90; M.W. 206.0963. $C_{12}H_{14}O_3$ requires C, 69.88; H, 6.84%; M.W. 206.0943). IR (CCl_4): 2950, 2915, 2875, 2840, 1791, 1694, 1445, 1384, 1102, 1018 cm^{-1}. NMR ($CDCl_3$): δ 6.66–5.96 (AB, 2H, J = 10 Hz); 4.43–4.00 (AB, 2H); 2.92–2.28 (AB, 2H); 1.61 (br s, 8H). MS: M^+, 206 (27); 149 (13); 148 (100); 120 (38).

Compound **25**: M.p. 103° (ether). (Found: C, 70.04; H, 6,.89; M.W. 206.0953). IR (CCl_4): 2950, 2915, 2875, 2840, 1789, 1694, 1447, 1365, 1179, 1088, 1010 cm^{-1}. NMR ($CDCl_3$): δ 6.55–6.01 (AB, 2H, J = 10 Hz); 3.92 (s, 2H); 2.84–2.15 (AB, 2H); 1.56 (br s, 8H). MS: M^+, 206 (26); 162 (86); 147 (26); 134 (100); 133 (35); 120 (36); 119 (73).

Assignment of structure was based on comparison of NMR spectra with those of corresponding enones at the anhydride and the ether oxidation level.

(b) The crude mixture of **23** (*ca* 1:1-*syn*: *anti*) obtained from **22** (1.0 g) and RB (50 mg) in dry CH_3CN (30 ml) after irrad for 18 hr with halogen lamp was dissolved in MeOH (50 ml) and treated with $NaBH_4$ (1.0 g) during 30 min. After 30 min additional stirring and workup as above, including treatment of unisolated mixture **26** with $CH_2N_2/AlCl_3$ as above gave after prep tlc on silica (2 × chloroform) with MeOAc, recovered **22** (144 mg) and an oil (720 mg). Distillation of the latter, b.p. 95°/10^{-2} mm, afforded oily mixture of methoxy-lactones **27** (*syn-anti* ratio still *ca* 1:1 by NMR; 642 mg; 65% overall). Since **27** is a more complex mixture of isomers than **18** we record the overall spectral results: IR (CCl_4) identical to **18a** + **18b**. NMR ($CDCl_3$): δ 6.02–5.25 (m, 2H); 4.37–3.63 (m, 3H); 3.27 (s, 3H, expanded scale shows 3 singlets); 2.14–1.23 (m with br s at 1.54). MS: M^+, 222.1245 (27); 192(22); 178 (30); 177 (100); 164 (40); 163 (33); 162 (20); 151 (29); 150 (23); 146 (26); 145 (26); 135 (50); 133 (83); 131 (38); 122 (51).

Reaction of **2** *with* $^1O_2$

A soln of **2** (500 mg) and RB (20 mg) in dry CH_3CN (30 ml) was irrad for 18 hr with the halogen lamp. The NMR spectrum of the crude mixture showed presence of *ca* 10% of **2** and an epimeric mixture of hydroperoxides **28** in the ratio of *ca* 1:1.

(a) The product after workup as above was dissolved in MeOH and treated with sodium borohydride (800 mg) during 90 min. Stirring was continued for another 30 min. After the usual workup crude **30** (570 mg) was obtained. Column chromatography on silica gave with hexane **2** (24 mg; low recovery due to its high vapor pressure). MeOAc afforded the alcohols **30** (450 mg; 90%) distilled bulb to bulb, b.p. 110°/10^{-2} mm as an oil. (Found: C, 73.56; H, 9.44; M.W. 194.1316. $C_{12}H_{18}O_2$ requires: C, 74.19; H, 9.34%, M.W. 194.1306). IR (CCl_4): 3570, 3390, 2990, 2950, 2910, 2845, 1780, 1481, 1448, 1392, 1110, 1050, 1019, 941, 911 cm^{-1}. NMR ($CDCl_3$): δ 5.82–5.25 (m, 2H); 4.48–4.12 (m, 1H); 3.98–3.44 (m, 4H); 2.89 (br s, 1H); 1.77 (d, 2H, J = 7 Hz); 1.48 (br s, 8H). MS: M^+, 194 (3); 176 (29); 163 (20); 149 (30); 148 (21); 145 (30); 134 (31); 133 (100); 132 (46); 131 (65); 121 (22).

(b) The crude product obtained similarly by 8 hr irrad (halogen lamp) of **2** (330 mg), RB (20 mg) in dry acetonitrile (30 ml) was taken up in pyridine (5 ml) containing $CuCl_2$ (30 mg) and the soln stirred overnight at room temp. After usual workup the crude product (354 mg) was chromatographed on a column of Alox-n. Some **2** (63 mg) was eluted with hexane, the enone **29** (170 mg) with ether. Prep tlc on silica, using EtOAc (2): hexane (8) gave (MeOAc) pure enone **29** (158 mg; 89%) distilled bulb to bulb, m.p. 120°/10^{-2} mm, as an oil. (Found: C, 74.86; H, 8.32; M.W. 192.1142. $C_{12}H_{16}O_2$ requires: C, 74.97; H, 8.39%; M.W. 192.1150). IR (CCl_4): 2995, 2950, 2910, 2845, 1683, 1443, 1382, 1054, 1042, 1031, 921, 904 cm^{-1}. NMR ($CDCl_3$): δ 6.49–5.71 (AB, 2H, J = 10 Hz); 3.98–3.66 (AB, 2H); 3.79–3.44 (AB, 2H); 2.35 (s, 2H); 1.48 (br s, 8H). MS: M^+, 192 (45); 163 (78); 162 (69); 147 (86); 134 (100); 133 (39); 132 (39); 121 (39); 119 (76).

Methylation of **30**

A soln of **30** (240 mg) in dry DME (5 ml) was added under argon to a slurry of sodium hydride (500 mg) in dry DME (2 ml) and the whole heated under reflux until gas evolution ceased (*ca* 20 min), then cooled. MeI (4 ml) was added and the soln stirred overnight. Filtration and removal of solvent followed by prep tlc on silica using ether (1): benzene (9) gave (MeOAc) in ascending order of polarity: *syn*-methyl ether **19** (102 mg; 40%) identical with product obtained from **8** as starting material (see below); *anti*-methyl ether **31** (114 mg; 44%), both distilled bulb to bulb, b.p. 85°/10^{-2} mm, forming oils.

Compound **19**. (Found: C, 74.60; H, 9.47; M.W. 208.1463. $C_{13}H_{20}O_2$ requires: C, 74.96; H, 9.68%, M.W. 208.1463). IR (CCl_4): 3000, 2955, 2905, 2845, 2800, 1781, 1481, 1448, 1392, 1343, 1324, 1183, 1088, 1052, 1032, 948, 910 cm^{-1}. NMR ($CDCl_3$): δ 5.83–5.34 (ABX, 2H, J = 10, 2.5, 1 Hz); 3.93–3.45 (m, 5H); 3.31 (s, 3H); 1.78 (d, 2H, J = 7 Hz); 1.47 (br s, 8H). MS: M^+, 208 (9); 192 (25); 177 (28); 176 (12); 163 (82); 162 (46); 161 (20); 148 (25); 146 (17); 145 (18); 137 (10); 132 (37); 131 (43); 123 (100); 122 (25); 121 (63); 119 (57); 117 (51); 109 (21); 108 (28); 107 (36); 106 (20); 105 (68).

Compound **31**. (Found: C, 74.80; H, 9.50; M.W. 208.1491). IR (CCl_4): 3000, 2955, 2910, 2850, 2800, 1786, 1481, 1448, 1393, 1340, 1323, 1186, 1096, 1049, 950, 911 cm^{-1}. NMR ($CDCl_3$): δ 5.84–5.24 (ABX, 2H, J = 10, 2, 1 Hz); 3.90–3.46 (m, 5H); 3.27 (s, 3H); 1.74 (d, 2H, J = 7 Hz); 1.42 (br s, 8H). MS: M^+, 208 (5); 176 (33); 164 (93); 163 (78); 150 (34); 149 (100); 147 (57); 145 (30); 136 (44); 135 (42); 134 (37); 133 (66); 132 (47); 131 (94); 123 (44); 121 (83).

Preparation of **19** *from* **18a** + **18b**

A soln of the mixture **18** (100 mg) in dry THF (5 ml) was added to a suspension of LAH (120 mg) in dry THF (30 ml), under argon and heated under reflux overnight. The usual workup gave diol (100 mg) which was dissolved in pyridine (5 ml) and heated with MsCl (50 μl). Stirring at room temp for 2 hr followed by the usual workup gave crude **19**. Prep tlc

using ether (15): benzene (85) gave pure **19** (60 mg; 58 %), b.p. 85°/10^{-2} mm, identical with the product described above.

REFERENCES

[1]W. J. W. Mayer, I. Oren and D. Ginsburg, *Tetrahedron* **32**, 1005 (1976).
[2]G. O. Schenck, O. A. Neumuller and W. Eisfeld, *Ann.* **618**, 202 (1958); *Idem.* Angew. Chem. **70**, 595 (1958).
[3]E. Müller, R. Heischkeil and M. Bauer, *Ann.* **677**, 55 (1964).
[4]*Cf.* B. M. Trost, J. M. Timko and J. L. Stanton, *J. Chem. Soc.* Chem. Commun., 436 (1978).
[5]*Cf.* W. J. Bailey and C. N. Bird, *J. Org. Chem.* **42**, 3895 (1977).
[6]*Cf.* J. Altman, E. Babad, J. Itzchaki and D. Ginsburg, *Tetrahedron* suppl. **8**, Part I. 279 (1966).
[7]For similar reductions *cf.* D. M. Bailey and R. E. Johnson, *J. Org. Chem.* **35**, 3574 (1970).