# Stereospecific Synthesis and Acetolysis of *anti*-Tricyclo[4.4.1.1$^{2,5}$]dodecan-11-yl and Related Derivatives

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Stereospecific conversion of tricyclo[4.4.1.1$^{2,5}$]dodecan-11-one and of several related unsaturated and cyclopropanated ketones into *syn* or *anti* alcohols is described. Acetolysis of *anti*-tricyclo[4.4.1.1$^{2,5}$]dodecan-11-yl *p*-bromobenzenesulfonate, *anti*-tricyclo[4.4.1.1$^{2,5}$]dodec-3-en-11-yl *p*-bromobenzenesulfonate, and *anti*-tetracyclo[5.4.1.1$^{2,6}$.0$^{3,5}$]tridecan-12-yl *p*-bromobenzenesulfonate each proceeds at about the same rate as other equatorial cyclohexyl *p*-bromobenzenesulfonates to give complex mixtures of rearranged acetates and hydrocarbons. No evidence for neighboring group participation by the remote double bond or cyclopropane ring in these esters was found. The stereochemically interesting ketone reductions, the unambiguous structural proofs of the reduction products, and possible explanations of the solvolysis rates are discussed.

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On décrit la conversion stéréospécifique de la tricyclo[4.4.1.1$^{2,5}$]dodécanone-11 et de plusieurs cétones non-saturées et cyclopropaniques apparentées en alcools *syn* ou *anti*. Les vitesses d'acétolyse des *p*-bromobenzènesulfonates des tricyclo[4.4.1.1$^{2,5}$]dodécanol-11 *anti*, tricyclo[4.4.1.1$^{2,5}$]dodécène-3 ol-11 et tétracyclo[5.4.1.1$^{2,6}$.0$^{3,5}$]tridécanol-12 sont toutes semblables et d'un ordre de grandeur similaire à d'autres *p*-bromobenzènesulfonates de cyclohexanols équatoriaux et les produits sont toujours formés d'un mélange complexe d'hydrocarbures et d'acétates réarrangés. Les résultats n'indiquent pas qu'il y a participation de la double liaison ou du noyau cyclopropanique dans ces réactions. On discute des réductions stéréochimiquement intéressantes des cétones, des preuves non ambigues des structures des produits de réduction et des explications plausibles des vitesses de solvolyse.

[Traduit par le journal]

## Introduction

The use of rigid polycyclic molecules with reasonably well-known geometries has been instrumental to a better understanding of many aspects of organic chemistry including the study of neighboring group participation in carbonium ion and related reactions (1, 2). In an attempt to define better the geometrical requirements for interactions of double bonds and cyclopropane rings with remote electron deficient centers we have undertaken the synthesis and solvolytic study of several rigid polycyclic derivatives. It is our hope that the relative importance of the several geometrical factors of importance to neighboring group participation (2) can be understood once the behavior of a number of molecules with different geometries is known.

Towards this end we have developed stereospecific syntheses of alcohols with the tricyclo[4.4.1.1$^{2,5}$]dodecan-11-yl skeleton and have studied the acetolysis of suitable derivatives which we would like to report at this time.

## Results and Discussion

It has been known for some time that reduction of trienone **1** with $LiAlH_4$ in ether gives only **2**-OH (3, 4), the structure of which was based on the very small value observed for $J_{1,11}$ and on the acetolysis behavior of **2**-OTs. We expected that a similar steric course would be followed in the reduction of closely related ketones and were surprised, therefore, when **5** (5) was reduced under the same conditions to yield predominantly **6**-OH (Table 1) with C-11 inverted with respect to **2**-OH.[2] This stereochem-

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[2]This reduction has been reported in preliminary form by other workers (6) with no comment regarding its stereochemistry and, although different physical constants for **5** and **6**-OH were reported than those obtained by us, Dr. Itô has kindly informed us that the i.r. spectra of the independently prepared samples are virtually identical.

TABLE 1. Stereochemistry of reduction of several ketones

| Ketone | *syn*-Alcohol[a] (%) | Method of analysis |
|---|---|---|
| **1** | 100 | n.m.r., g.l.c. |
| **9** | 100 | n.m.r., g.l.c. |
| **4** | 88 | n.m.r. |
| **5** | 12 | n.m.r., g.l.c. |
| **11** | 0 | n.m.r., g.l.c. |

[a]Values considered accurate to ±4%; the remaining fraction is *anti* epimer.

ical assignment was tentatively made on the basis of the larger observed value (*ca.* 5 Hz) for $J_{1,11}$ compared to that for **2**-OH but we felt that this conclusion was ambiguous. Although the unsaturated C-7–C-10 bridge of **2**-OH is rigid giving relatively fixed dihedral angles at C-11 of *ca.* 85 and 35°,[3] the saturated bridge of **6**-OH is flexible with at least three different conformations. In the two eclipsed conformers, **12** and **13**, both dihedral angles at C-11 are *ca.* 60° but in the staggered conformer, **14**, angles of *ca.* 85 and 35° are found once more. Because we could not unequivocally determine which conformer is preferred or, whether or not **6**-OH is conformationally mobile at the temperature and time scale of our n.m.r. instrument, we were uncertain of the C-11 configuration of **6**-OH. Because it was obviously crucial for our solvolytic studies to correctly assign this structure, we sought a more rigorous structural proof.

Addition of small amounts of the n.m.r. shift reagent $Eu(fod)_3$ to a solution of **2**-OH in $CDCl_3$ caused a marked downfield shift of the H-3 (H-4) signal and a much smaller downfield shift for H-7–H-10 (Fig. 1). Similar treatment of **6**-OH did not shift the olefinic proton appreciably although the behavior of H-11 was similar to that in **2**-OH (Fig. 1). These differences are in full accord with the assigned structures of **2**-OH and **6**-OH.

Catalytic hydrogenation of **2**-OH and **6**-OH gave the two saturated alcohols **3**-OH and **7**-OH, respectively, which were shown to be epimeric by their oxidation to the single known ketone **4** (5, 7). These two compounds have almost identical melting points which are not depressed on mutual mixing and, in our hands proved to be inseparable by g.l.c., but they had distinctly different i.r. and n.m.r. spectra. In particular, the H-11 signal is a relatively sharp singlet in

[3]These are the dihedral angles between H-1 (H-6) and the *syn* and *anti* positions at C-11, respectively, as measured from Dreiding models.

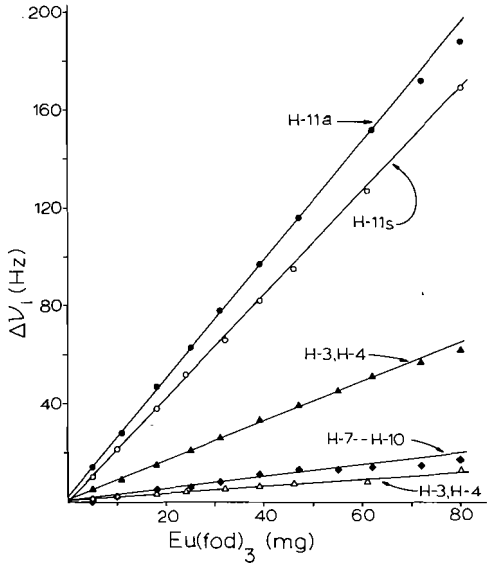


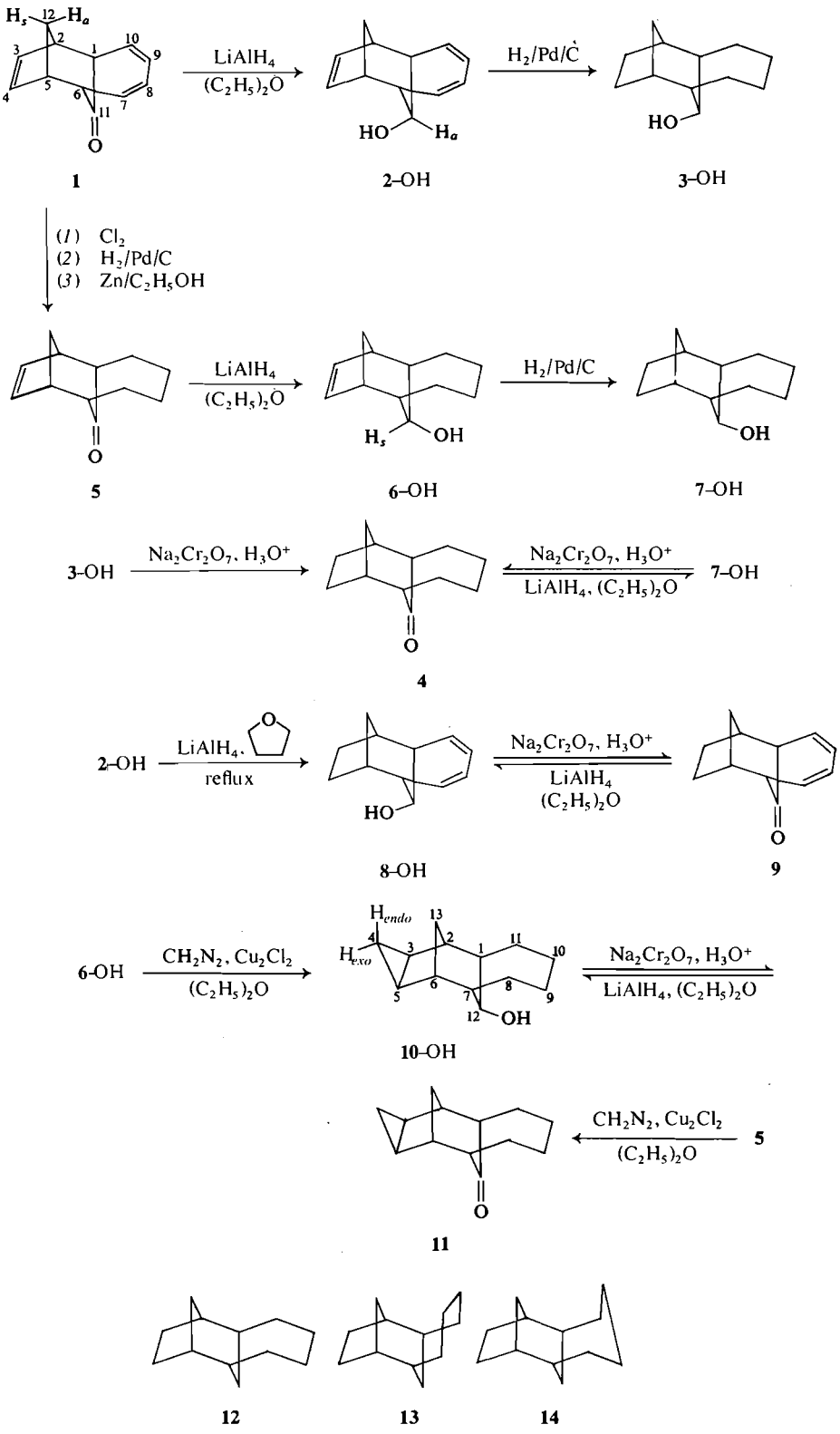

FIG. 1. A plot of chemical shift induced by shift reagent, $\Delta\nu_i$, *vs.* amount of added shift reagent for some protons of **2**-OH (solid points) and **6**-OH (open points).

**3**-OH ($w_{1/2}$ = 3.5 Hz) at slightly higher field (0.2 p.p.m.) than the broad singlet ($w_{1/2}$ = 11 Hz) of **7**-OH. These data are in accord with a predominance of conformer **14** for the tricyclo-[4.4.1.$1^{2,5}$]dodecane ring system. Unlike the distinct triplets observed for H-11 of the unsaturated **6**-OH and cyclopropanated **10**-OH (*vide infra*), no fine structure was observed in the broad peak of **7**-OH. The reason for this behavior is unclear.

Prolonged reduction of **1** with $LiAlH_4$ in refluxing tetrahydrofuran gave the dienol **8**-OH whose u.v. spectrum is typical of the conjugated diene chromophore (5). This reaction is similar to the well-known stereospecific reduction of the *syn* double bond of 7-oxygenated norbornadienes (8) and provides interesting support for the structure of **2**-OH. Oxidation gave the known ketone **9** (7); the sequence of reduction of **1** followed by oxidation to **9** provides an alternative route to the previously reported (7) selective hydrogenation of the isolated double bond of **1**.

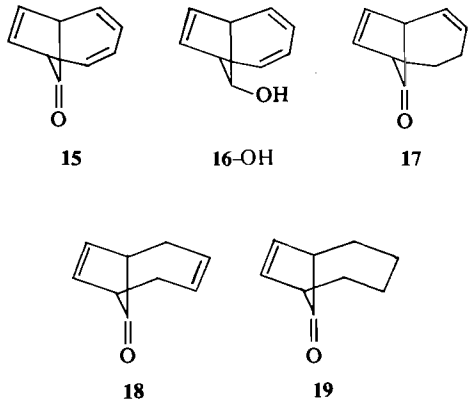
The spectroscopic and chemical evidence outlined above provides overwhelming proof of the structures of **2**-OH and **6**-OH and for the other alcohols prepared in this study.

Treatment of either **6**-OH or **5** with $CH_2N_2$ in the presence of $Cu_2Cl_2$ (9) led cleanly to **10**-OH and **11** respectively. The cyclopropane



ring was assigned the *exo* structure found in the related epoxide (5). The n.m.r. spectrum showed H-3 and H-5 to be coupled only very weakly to H-2 and H-6 as anticipated (5). H-$4_{exo}$ is found at relatively high field (*ca.* $\tau$ 9.8); this value is typical of *exo*-tricyclo[3.2.1.$0^{2,4}$]octanes (10) and demonstrates the previously noted (5) similarity of the tricyclo[4.4.1.$1^{2,5}$]dodecanyl and norbornyl ring systems.

The stereochemistry of reduction of **1**, **4**, **5**, **9**, and **11** has proven to be most interesting. Both **1** and **9**, in which the C-7–C-10 diene unit is present, reduce to give *syn* alcohols **2**-OH and **8**-OH exclusively (Table 1). In **4**, **5**, and **11**, however, the steric preference is reversed, *anti* alcohols **7**-OH, **6**-OH, and **10**-OH now being the predominant products. We are unaware of another example in which partial or total hydrogenation of remote unsaturation so dramatically changes the preferred direction of approach of reducing agents to a carbonyl group. In a related study (11) **15** was shown to reduce to only the *syn* alcohol **16**-OH. Partial or complete saturation of the diene unit (*i.e.* **17**, **18**, and **19**) resulted in an increase in attack from the *syn* side but the predominant products still had the *syn* stereochemistry. Despite a recent explanation of the stereochemistry of cyclohexanone reductions based on the induction of anisotropy in the electron density of the carbonyl group by the $\sigma$ bonds in the six-membered ring (12), and other possible electronic explanations, we prefer to interpret our results in simple steric terms. Examination of a Dreiding model of **1** and calculations of congestion (13) based on this model[4] reveal that the *anti* side of the molecule is much more open to attack than is the *syn* side. In **9** attack from the *syn* side is even more hindered. These two ketones thus give exclusively *syn* alcohol. In **4**, **5**, and **11** the situation is reversed. The two most likely conformers, **12** and **14**, have severe congestion on the *anti* side of the carbonyl group making the *syn* side much more




**15** **16**-OH **17**

**18** **19**

open to attack by nucleophiles and explaining the observed steric preference. The third conformer, **13**, does not have the *anti* side congestion of **12** and **14** but is probably not a major component because of a severe interaction between H-12*a* and the C-8—C-9 bond. We are not yet able to explain why reduction of **11** is more stereospecific than that of **4** or **5**.

The acetolysis of each ester (**6**-OBs, **7**-OBs, and **10**-OBs) is a clean first order process (Table 2) with no evidence in either the kinetic or product studies to indicate ion pair return. The three brosylates acetolyze at about the same rates as suitable model compounds (Table 3). Particularly striking is the similarity to molecules which also incorporate an equatorially substituted cyclohexane chair despite the improbability (Bredt's rule (*cf.* 14)) of direct hydrogen elimination leading to olefinic products. This is a major pathway in the acetolysis of cyclohexyl sulfonates (*cf.* 15). We conclude that neighboring group participation is a relatively inefficient process in the acetolysis of **6**-OBs and **10**-OBs. This conclusion is in accord with the assumed geometrical similarity of ketones **4**, **5**, and **11**, in $\nu_{CO}$ (**4**: 1707; **5**: 1710; **11**: 1706; cyclohexanone: 1716 (16)) and in $\lambda_{max}$ n $\rightarrow \pi^*$ (**4**: 297 ($\varepsilon$ 22); **5**: 294 ($\varepsilon$ 35); **11**: 294 ($\varepsilon$ 31); cyclohexanone: 283 ($\varepsilon$ 17)) both of which have been correlated with anchimeric assistance in other systems (16–18). Recent $^{13}$C n.m.r. data (19), however, do indicate a possible interaction between the double bond and carbonyl group of **5**.

The acetolyses of **6**-OBs, **7**-OBs, and **10**-OBs all result in the formation of very complex mixtures of as yet unidentified products (Table 2) which are >95% rearranged. The principal products in all cases are those of elimination. The

[4]Although we believe that these calculations are qualitatively meaningful, the angles in the C-7–C-10 bridge of the model are somewhat larger than 120° so that the six atoms C-1, C-6–C-10 may be incorporated in a coplanar arrangement. In the molecule itself it is possible that the conjugated diene unit is puckered to relieve the strain of angle distortion. The present lack of accurate structural data on **1** or any other member of this ring system makes quantitative discussion impossible. Such a puckering would alter the magnitude of the congestion factors but probably not their relative order. Models of **4**, **5**, and **11** appear to be relatively unstrained.

TABLE 2. Kinetic and product data for the acetolysis of *anti*-tricyclo[4.4.1.1$^{2,5}$]-dodecan-11-yl and related *p*-bromobenzenesulfonates[a]

| Compound | Temperature (°C) | $k \times 10^5$ ($s^{-1}$) | No. of hydrocarbon products | No. of acetate products | Hydrocarbon: acetate ratio |
|---|---|---|---|---|---|
| **7**-OBs[b] | 65.2 | 4.79 | | | |
| | 85.6 | 52.5 | 8 | 4 | 9:1 |
| | (75.0)[c] | 15.6 | | | |
| **6**-OBs[d] | 65.2 | 5.75 | | | |
| | 85.6 | 63.3 | 9 | 7 | 2:1 |
| | (75.0)[c] | 18.8 | | | |
| **10**-OBs[e] | 75.5 | 3.65 | | | |
| | 95.9 | 40.7 | 6 | 9 | 2:1 |
| | (75.0)[c] | 3.45 | | | |

[a]See Experimental for conditions.
[b]$\Delta H^* = 27.6$ kcal/mol, $\Delta S^* = 3.0$ e.u. (75 °C).
[c]Interpolated or extrapolated.
[d]$\Delta H^* = 27.7$ kcal/mol, $\Delta S^* = 3.7$ e.u. (75 °C).
[e]$\Delta H^* = 29.4$ kcal/mol, $\Delta S^* = 9.8$ e.u. (75 °C).

TABLE 3. Relative buffered acetolysis rates of several brosylates at 75 °C

| Brosylate | $k_{rel}$ | $k/k_{sat}$ | Notes |
|---|---|---|---|
| Cyclopentyl | 13 | | *a,b* |
| Cyclohexyl | 1 | | *a,b* |
| Cycloheptyl | 23 | 1 | *a,b* |
| 4-Cyclohepten-1-yl | 0.9 | 0.04 | *c* |
| *cis,cis*-Bicyclo[5.1.0]oct-4-yl | 3.2 | 0.14 | *c* |
| *exo*-Bicyclo[3.2.1]oct-3-yl | 3.9 | 1 | *b,d,e* |
| *exo*-Bicyclo[3.2.1]oct-6-en-3-yl | 2.7 | 0.7 | *e,f* |
| **7**-OBs | 1.1 | 1 | |
| **6**-OBs | 1.3 | 1.2 | |
| **10**-OBs | 0.25 | 0.22 | |

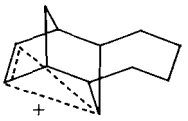
[a]Extrapolated or interpolated from data given in ref. 28.
[b]Unbuffered acetic acid.
[c]Interpolated from data given in ref. 29.
[d]Interpolated from data given in ref. 30.
[e]Calculated from data reported for the corresponding tosylate.
[f]Interpolated from data given in ref. 21.

presence of major peaks at $\tau > 9.5$ in the n.m.r. spectrum of the crude product from **10**-OBs indicates retention of the cyclopropane ring. The complex nature of the product mixtures, although not unprecedented in systems exhibiting large anchimeric assistance (20), is corroborative evidence for the absence of neighboring group participation.

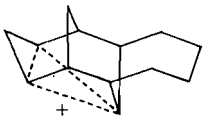
Our failure to observe even a portion of the tremendous anchimeric acceleration found in other systems, notably in those related to 7-norbornyl (1*a*, 2), is at first surprising in view of the apparent similarity in geometry between **6**-OBs, **10**-OBs, and the more reactive molecules. Closer examination reveals a number of rationalizations based on geometrical and electronic factors that could be advanced to explain the apparent discrepancy; we are not yet in a position to choose between them. The distance between the potential neighboring group and the reaction center in **6**-OBs and **10**-OBs is 2.6–2.8 Å (Dreiding models), somewhat longer than that in *anti*-7-norbornenyl and related esters (2.3–2.4 Å). This distance was cited previously (21) to explain the absence of participation by the double bond in the acetolysis of *exo*-bicyclo[3.2.1]oct-6-en-3-yl tosylate. Molecular models also predict that the developing p orbitals of **6**-OBs and **10**-OBs lie almost parallel to, but displaced from, the planes of the potential neighboring groups. The effective overlap predicted (18*b*, 22) for the transition states for the ionization of *anti*-7-norbornenyl and related esters is therefore much less likely for the ionization of **6**-OBs and **10**-OBs. Also

pertinent is the expectation that a molecular distortion analogous to that predicted (18*b*) to increase overlap, and hence stability, in the delocalized 7-norbornenyl cation, should decrease overlap in **20** and **21**. The differences in *I* strain (*cf.* 23) between the tricyclo[4.4.1.$1^{2,5}$]dodecan-11-yl and 7-norbornyl systems might also be used to explain our kinetic results.

Finally, it has been predicted recently by Goldman (24) that the homoaromatic stabilization expected for ions such as **20** and **21** (*cf.* 25) should be overcome by the antisymmetric alignment of the flanking σ bonds, *i.e.* C-1—C-2 and C-5—C-6, possibly resulting in a rate retardation by the potential neighboring group. Experimental verification of this proposal is not yet available in compounds without geometrical ambiguities so that its applicability to the present study is uncertain.



**20**



**21**

We are continuing our efforts to analyze the complex products from **6**-OBs, **7**-OBs, and **10**-OBs and also to synthesize and study the ionization of other geometrically interesting molecules.

## Experimental

Melting points were determined on a Thomas–Hoover apparatus and are uncorrected. The n.m.r. spectra were obtained on a Varian A60 A spectrometer in $CDCl_3$ solution. Peak positions are given in units of τ relative to internal tetramethylsilane at τ 10.00 or $CHCl_3$ at τ 2.75; in all cases the relative peak areas are consistent with the assigned structure. Infrared spectra were recorded on Nujol mulls, neat liquids, and solutions in $CCl_4$ using a Unicam SP 200, a Beckman IR 10, or a Perkin-Elmer 710 spectrophotometer; the peak positions are given in wave numbers. Ultraviolet spectra were recorded in 95% ethanol solution on a Unicam SP 800 recording spectrophotometer; peak positions are given in nm. Gas–liquid chromatographic analyses were carried out on Varian Aerograph A90 P3 or an F and M 700 chromatograph employing copper or stainless steel columns packed with Carbowax 20M unless otherwise stated. Combustion microanalyses were obtained from Galbraith Laboratories, Inc., Knoxville, Tenn. 37921.

*General Procedure for $LiAlH_4$ Reductions*

About 50 mg of pure ketone was added to a stirred slurry of *ca.* 100 mg of $LiAlH_4$ in 15 ml $(C_2H_5)_2O$ at room temperature under an atmosphere of $N_2$. The mixture was refluxed for *ca.* 0.5 h, cooled to 0 °C and the excess $LiAlH_4$ destroyed by the cautious addition of $H_2O$. The precipitated aluminum salts were dissolved by adding 10% aqueous $H_2SO_4$ and the aqueous solution extracted with 3 × 50 ml $(C_2H_5)_2O$. The ether was washed with 10% aqueous $Na_2CO_3$ solution and dried ($MgSO_4$), and the solvent removed to give crude product which was analyzed directly by g.l.c. or n.m.r.

*syn-Tricyclo[4.4.1.$1^{2,5}$]dodeca-3,7,9-trien-11-ol, 2-OH*

Treatment of **1** as described above gave a yellow oil which crystallized on standing. A pure sample of **2**-OH was prepared by g.l.c., m.p. 29.5–31.5 °C (lit. (3) m.p. 32.5–34.5 °C); n.m.r.: 3.62 (singlet, H-3, H-4), 4.03 (multiplet, H-1, H-2, H-5, H-6, OH), 7.73 (doublet, $J$ = 10.5 Hz, H-12*a*), 8.3–8.8 (multiplet, H-12*s*); n.m.r. and g.l.c. revealed that only one alcohol was present.

*syn-Tricyclo[4.4.1.$1^{2,5}$]dodecan-11-ol, 3-OH*

Crude **2**-OH (50 mg) was dissolved in 5 ml of 95% $C_2H_5OH$ and stirred under $H_2$ at *ca.* 1.1 atm at room temperature in the presence of 35 mg of 10% Pd-on-charcoal. After the $H_2$ uptake had ceased, the mixture was filtered and the solvent removed to give 50 mg (95% yield overall from **1**) of white crystals of **3**-OH which could be purified by g.l.c. or by vacuum sublimation (105 °C, 15 Torr), m.p. 75–76.5 °C. A mixed sample with **7**-OH had m.p. 74–76 °C; i.r.: 3375, 1075, 1040, 1035, 1025; n.m.r.: 6.12 (singlet, $w_{1/2}$ = 3 Hz, H-11*a*), 7.8–9.2 (multiplet, all other protons).

Anal. Calcd. for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.02; H, 11.29.

*Oxidation of 3-OH*

The oxidation was carried out according to the published procedure (26). A solution of 30 mg **3**-OH in *ca.* 110 μl of $(C_2H_5)_2O$ was treated at 0 °C for 10 min with 220 μl of a solution containing 100 g $Na_2Cr_2O_7$ and 136 g 97% $H_2SO_4$ and diluted with $H_2O$ to a total volume of 500 ml. The reaction mixture was diluted with *ca.* 50 ml $(C_2H_5)_2O$ and 20 ml $H_2O$, the layers separated, and the aqueous one extracted with 50 ml $(C_2H_5)_2O$. The combined $(C_2H_5)_2O$ solutions were washed with 10% aqueous $Na_2CO_3$ solution, dried ($MgSO_4$), filtered, and the solvent evaporated to give 19 mg (64%) of a colorless oil; g.l.c. showed that only one component was present; i.r. showed it to be identical to a previously prepared sample of **4** (5); i.r.: 1707; u.v.: $\lambda_{max}$ 297, ε 22.

*anti-Tricyclo[4.4.1.$1^{2,5}$]dodec-3-en-11-ol, 6-OH*

Treatment of 60 mg of the previously prepared **5** (5) (i.r.: 1710; u.v.: $\lambda_{max}$ 294, ε 35) with $LiAlH_4$ as described in the general procedure above gave 60 mg (99%) of yellowish crystals. The g.l.c. and n.m.r. analyses of the crude product showed the presence of two alcohols in the ratio of 88:12. The major component was identified as **6**-OH, the minor one was assumed to be its C-11 epimer on the basis of the shape of the H-11 n.m.r. signal (see text) but this product was not further characterized. A sample of **6**-OH was purified by g.l.c., m.p. 82–83.5 °C (lit. (6) volatile liquid[2]); i.r.: 3400, 3075, 1580; n.m.r.: 3.78 (singlet, H-3, H-4), 5.69 (triplet, $J$ = 5.5 Hz, H-11*a*), 7.2–9.2 (complex multiplet, all other protons).

*Nuclear Magnetic Resonance Shift Experiments*

Solutions of **2**-OH and **6**-OH of *ca.* 1.2 *M* were prepared in a total volume of *ca.* 450 μl $CDCl_3$ and a total

of 80 mg of the shift reagent europium(III)-tris-1,1,-1,2,2,3,3-heptafluoro-7,7-dimethyl-4,5-octanedione (Eu-(fod)$_3$) (Norell Chemical Co., Landisville, New Jersey 08326) added to each sample in increments of *ca.* 8 mg. The n.m.r. spectrum was recorded after each addition, the chemical shift change of each peak measured (assuming no change in internal tetramethylsilane) and the results plotted. Each peak in the spectrum of **2**-OH could be analyzed but only the olefinic peaks and H-11*s* could be analyzed for **6**-OH because of unresolved peak overlap. The plots for the most pertinent signals are shown in Fig. 1 and clearly show that the assigned configurations of **2**-OH and **6**-OH are correct.

*anti-Tricyclo[4.4.1.1$^{2,5}$]dodecan-11-ol, 7-OH*

A 50 mg sample of purified **6**-OH was dissolved in 5 ml of 95% $C_2H_5OH$, 40 mg of 10% Pd-on-charcoal added and the mixture stirred under $H_2$ at *ca.* 1.1 atm at room temperature. After the gas uptake had ceased, the mixture was filtered and the solvent evaporated to give 48 mg (95%) of white crystalline **7**-OH, a sample of which was purified by g.l.c., m.p. 72–73.5 °C. A mixed sample with **3**-OH had m.p. 74–76 °C; i.r.: 3350, 1070, 1020; n.m.r.: 5.93 (broad singlet, $w_{1/2}$ = 11 Hz, H-11*s*), 7.7–9.3 (complex multiplet, all other protons).

Anal. Calcd. for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 79.76; H, 11.00.

Similar hydrogenation of a crude sample of **6**-OH gave a solid whose n.m.r. spectrum clearly showed the presence of both **7**-OH and **3**-OH in the ratio of 88:12.

*Oxidation of 7-OH*

A sample of **7**-OH (35 mg) was oxidized as described above for **3**-OH to give 32 mg (92%) of a single ketone shown by i.r. to be **4** (5).

*Reduction of 4*

A freshly prepared sample of **4** (from hydrogenation of **1** (5)) was reduced with $LiAlH_4$ according to the general procedure described above giving a quantitative yield of crystalline alcohol. The n.m.r. analysis showed that it contained **7**-OH and **3**-OH in the ratio 92:8. These two alcohols proved to be unseparable by g.l.c. on columns of Carbowax 20M, LAC 728, SE 30, UCW 98, Apiezon L, and TCEP.[5]

*syn-Tricyclo[4.4.1.1$^{2,5}$]dodeca-7,9-dien-11-ol, 8-OH*

Solid **1** (310 mg) was added to a stirred slurry of *ca.* 1 g $LiAlH_4$ in 35 ml of freshly distilled tetrahydrofuran and the mixture refluxed for 50 h. The solution was cooled to 0 °C and $H_2O$ slowly added to destroy the excess $LiAlH_4$. The precipitated aluminum salts were dissolved by adding 10% aqueous $H_2SO_4$ and the solution extracted with 3 × 100 ml of $(C_2H_5)_2O$. The combined $(C_2H_5)_2O$ layers were washed with 100 ml $H_2O$, 10% aqueous $Na_2CO_3$ solution, dried ($MgSO_4$), and filtered. Evaporation of the solvent gave 285 mg of a yellowish oil which was shown by g.l.c. to contain at least five components. The major one (*ca.* 70%) was purified by g.l.c. and vacuum sublimation (115 °C, 12 Torr) and shown to be **8**-OH, m.p. 75–76 °C; i.r.: 3320, 3020, 1595; u.v.: $\lambda_{max}$ 275, ε 2990; 264, ε 5400; 254, ε 5240; 249, sh; 245, sh; n.m.r.: 4.41 (multiplet, H-7–H-10), 5.62 (singlet, $w_{1/2}$ = 4 Hz, H-11*a*), 7.1–9.2 (complex multiplet, all other protons).

Anal. Calcd. for $C_{12}H_{16}O$: C, 81.77; H, 9.15. Found: C, 81.47; H, 9.22.

*Tricyclo[4.4.1.1$^{2,5}$]dodeca-7,9-dien-11-one, 9*

Crude **8**-OH (155 mg) was oxidized as described above for **3**-OH to give 110 mg of a yellowish oil from which 40 mg of pure **9**, m.p. 96.5–98.5 °C (lit. (7) m.p. 92 °C) was obtained by g.l.c.; n.m.r.: 3.8–4.5 (complex multiplet H-1, H-6), 7.1–9.2 (complex multiplet, all other protons).

*Reduction of 9*

A sample of **9** was treated with $LiAlH_4$ according to the general procedure described above. Both n.m.r. and g.l.c. analyses of the crude product showed the presence of only one alcohol confirmed by i.r. to be **8**-OH. Other unidentified products were formed in this reaction but they contained neither carbonyl nor hydroxyl groups.

*anti-Tetracyclo[5.4.1.1$^{2,6}$.0$^{3,5}$]tridecan-12-ol, 10-OH*

Diazomethane was prepared by treatment of *N*-methyl-*N*-nitrosourea with 50% aqueous KOH solution and carried in a stream of $N_2$ into a stirred solution of 917 mg **6**-OH in 25 ml anhydrous $(C_2H_5)_2O$ containing 500 mg suspended $Cu_2Cl_2$ according to the convenient procedure of Pincock and Wells (9). The cyclopropanation was monitored by g.l.c. After several hours when the reaction was near completion it was terminated, the solution filtered, and the solvent removed to give 1.04 g of a green oil which was eluted with $(C_2H_5)_2O$ through a short column of alumina to remove the residual copper compounds. A small sample of the resulting colorless crystals (1.0 g, 100%) was purified by g.l.c., m.p. 67–68 °C; i.r.: 3380, 3070, 3010; n.m.r.: 5.38 (triplet, $J$ = 5.5 Hz, H-12*s*), 7.2–8.9 (complex multiplet, H-1, H-2, H-6–H-11, H-13, OH), 9.08 (doublet of doublets, $J$ = 3.6, 8 Hz, H-3, H-5), 9.34–9.95 (multiplet, H-4).

Anal. Calcd. for $C_{13}H_{20}0$: C, 81.20; H, 10.48. Found: C, 81.01; H, 10.54.

*Tetracyclo[5.4.1.1$^{2,6}$.0$^{3,5}$]tridecan-12-one, 11*

A 50 mg sample of **10**-OH was treated as described above for the oxidation of **3**-OH to give 32 mg (65%) of liquid **11** which was purified by g.l.c.; i.r.: 3100, 3050, 1706; u.v.: $\lambda_{max}$ 294, ε 31; n.m.r.: 7.35 (multiplet, H-1, H-7), 7.78–8.67 (complex multiplet, H-2, H-6, H-8–H-13), 8.92 (doublet of doublets, H-3, H-5), 9.3–9.85 (multiplet, H-4).

Anal. Calcd. for $C_{13}H_{18}O$: C, 82.06; H, 9.53. Found: C, 81.83; H, 9.48.

This ketone could also be formed by direct cyclopropanation of **5** as described for the synthesis of **10**-OH in which attack by diazomethane at the carbonyl group with subsequent ring expansion did not effectively compete.

*Reduction of 11*

Treatment of 50 mg of **11** with $LiAlH_4$ by the general procedure described above gave 50 mg (99%) of an alcohol which was shown by g.l.c. and n.m.r. to be sterically homogeneous and by i.r. to be **10**-OH.

*General Procedure for the Preparation of p-Bromobenzenesulfonates (Brosylates)*

Equimolar amounts of alcohol and *p*-bromobenzene-

[5]The analyses on the TCEP capillary column were carried out by D. C. Wigfield, Carleton University, Ottawa, Canada to whom we express our thanks.

sulfonyl chloride were dissolved in dry pyridine (*ca.* 2 ml per g acid chloride) and the solution allowed to stand in a refrigerator at 0 °C until the deposition of pyridine hydrochloride appeared to be complete. This usually took several days. Water was then added to the mixture and the resulting crystalline mass of crude brosylate collected by filtration. The crystals were washed well with $H_2O$ and 10% aqueous $Na_2CO_3$, dried, and recrystallized from hexane.

*anti-Tricyclo[4.4.1.1$^{2,5}$]dodecan-11-yl p-Bromobenzenesulfonate, 7-OBs*

The brosylate isolated in 60% yield by the above procedure had m.p. 79.5–80 °C (dec.); n.m.r.: 2.33 (multiplet, aromatic ring protons); 5.13 (broad singlet, $w_{1/2}$ = 11 Hz, H-11*s*), 7.4–9.3 (multiplet, all other protons).

Anal. Calcd. for $C_{18}H_{23}SO_3Br$: C, 54.14; H, 5.80; S, 8.03; Br, 20.01. Found: C, 54.35; H, 5.76; S, 9.13; Br, 20.21.

*anti-Tricyclo[4.4.1.1$^{2,5}$]dodec-3-en-11-yl p-Bromobenzenesulfonate, 6-OBs*

The brosylate isolated in 60% yield by the above procedure had m.p. 87–88 °C (dec.); n.m.r.: 2.33 (multiplet, aromatic protons), 4.05 (singlet, $w_{1/2}$ = 4 Hz, H-3, H-4), 5.05 (triplet, $J$ = 5.5 Hz H-11*s*), 7.4–9.0 (multiplet, all other protons).

Anal. Calcd. for $C_{18}H_{21}SO_3Br$: C, 54.41; H, 5.33; S, 8.07; Br, 20.11. Found: C, 54.54; H, 5.40; S, 8.15; Br, 20.27.

*anti-Tetracyclo[5.4.1.1$^{2,6}$.0$^{3,5}$]tridecan-12-yl p-Bromobenzenesulfonate, 10-OBs*

The brosylate isolated in 65% yield by the above procedure had m.p. 120.5–121 °C (dec.); n.m.r.: 2.25 (multiplet, aromatic protons), 4.53 (triplet, $J$ = 6.2 Hz, H-12*s*), 7.5–8.8 (multiplet, H-1, H-2, H-6–H-11, H-13), 9.04 (doublet of doublets, $J$ = 3.6, 8 Hz, H-3, H-5), 9.3–9.9 (multiplet, H-4).

Anal. Calcd. for $C_{19}H_{23}SO_3Br$: C, 55.48; H, 5.63; S, 7.79; Br, 19.43. Found: C, 55.60; H, 5.70; S, 7.77; Br, 19.44.

*Kinetic Studies*

Acetolysis rates of the three brosylates **7**-OBs, **6**-OBs, and **10**-OBs were measured by the usual procedure (*cf.* 27). Solutions *ca.* 0.01 *M* in brosylate were prepared in glacial acetic acid buffered with *ca.* 0.025 *M* NaOAc and divided equally among 12 sample tubes which were then sealed. The tubes were placed simultaneously in an oil bath at the appropriate temperature. After a short thermal equilibration period (*ca.* 10 min), the zero sample was removed and cooled quickly to room temperature. Other samples were similarly removed at appropriate times. After all samples had been taken, 1-ml aliquots of each were added to 5 ml of *ca.* 0.005 *M* $HClO_4$ in glacial acetic acid and the excess $HClO_4$ titrated with *ca.* 0.005 *M* NaOAc in glacial acetic acid to the bromophenol blue end point. Each run was followed for at least 2.5 half-lives, infinity samples being taken after at least 8 half-lives. No color developed in runs on **7**-OBs and **10**-OBs but **6**-OBs samples turned yellow particularly at long reaction times. All runs gave good first-order plots. One run on each compound was carried out at a concentration of *ca.* 0.005 *M* in brosylate. This did not affect the obtained rate constants. The data are given in Table 2.

*Product Studies*

Samples of the brosylates, *ca.* 0.01 *M*, were prepared in glacial acetic acid containing 0.02 *M* NaOAc and heated at an appropriate temperature for more than 10 half-lives. The solutions were cooled to room temperature, diluted with pentane, and the pentane solution extracted with $H_2O$. The $H_2O$ washes were back-extracted with pentane and the combined pentane solutions washed with $H_2O$ and 10% aqueous $NaHCO_3$ and dried ($MgSO_4$). The mixture was filtered and the solvent removed to leave an oily product which was analyzed spectroscopically and by g.l.c. on several columns. The mixtures were reduced with $LiAlH_4$ and hydrogenated over Pd-on-charcoal by the general procedures described above. None of the large number of products was identified. Our preliminary data is collected in Table 2 and discussed briefly in the text.

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