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STEREOSPECIFIC ENDO HYDROBORATION OF TRICYCLO[6.2.1.$0^{2,6}$]-UNDEC-2(6)-ENE. AN EXAMPLE OF PRODUCT DEVELOPMENT CONTROL IN ADDITION REACTIONS OF BRIDGED POLYCYCLIC COMPOUNDS

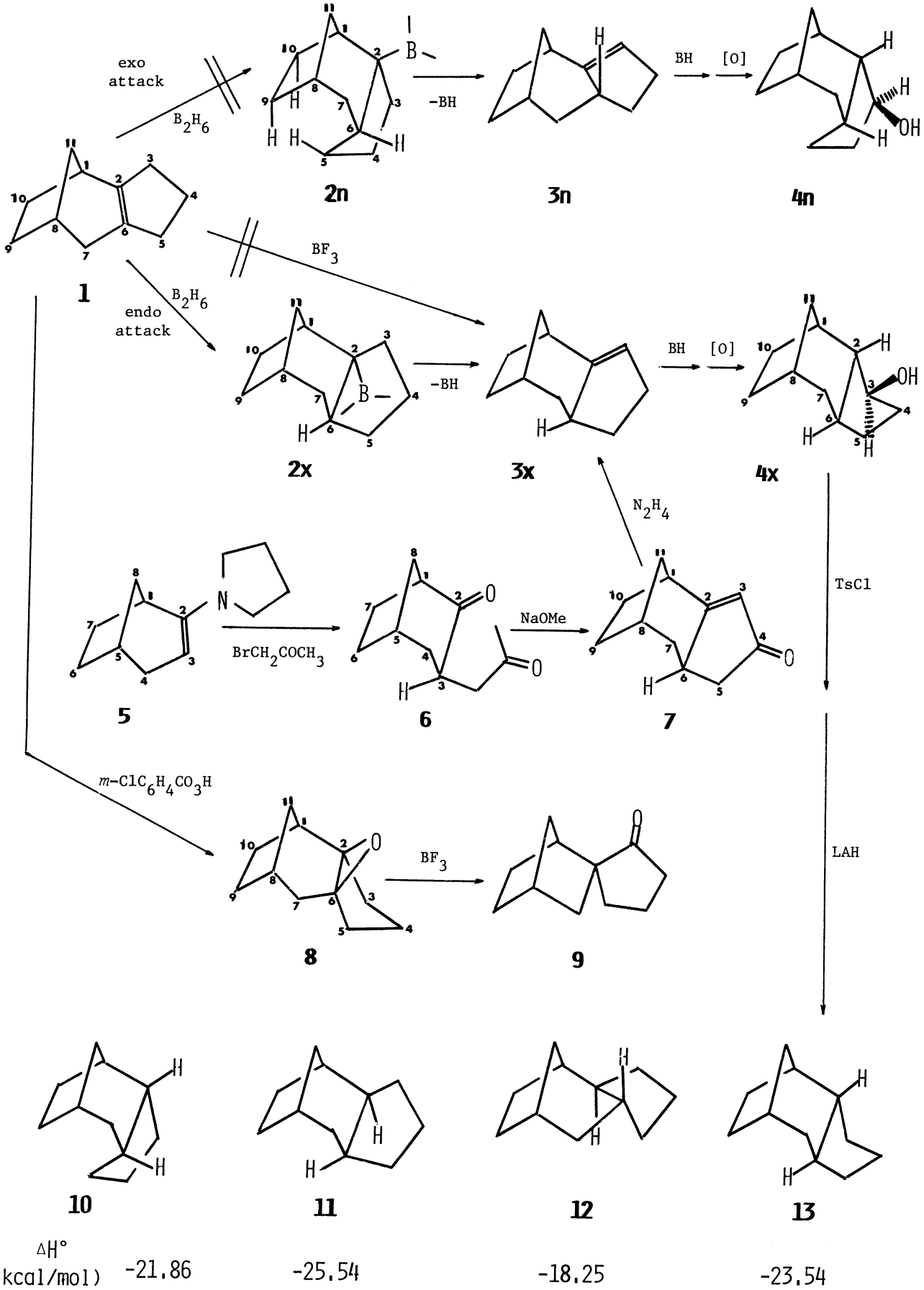
Naotake TAKAISHI, Yoshiaki INAMOTO,* and Koji AIGAMI
Tochigi Research Laboratories, Kao Soap Company, Ltd.
2606 Akabane, Ichikaimachi, Tochigi 321-34

Hydroboration of the title olefin **1** took place under product development control to give exclusively the *endo*-2-*exo*-6 isomer **4x** of tricyclo-[6.2.1.$0^{2,6}$]undecan-*exo*-3-ol through the diborane attack on the endo side, which was considered to be more hindered on the basis of the formation of the *exo*-epoxide **8**.

Steric approach control has been the most important factor in determining the stereochemistry of many addition reactions of polycyclic compounds.[1] For example, hydroboration,[1a,b] lithium aluminum hydride reduction,[1a] and cycloporpane cleavage[1c] occur through the predominant attack of the reagents from less hindered sides of the molecules. However, we discovered that the hydroboration of tricyclo[6.2.1.-$0^{2,6}$]undec-2(6)-ene (**1**)[2] took place exclusively on the more congested side. This apparently anomalous result could be interpreted in terms of product development control which had been scarcely observed in addition reactions of bridged polycyclic compounds.

Tricyclo[6.2.1.$0^{2,6}$]undec-2(6)-ene (**1**; 7.4 g, 50 mmol), prepared by phosphoric acid catalyzed dehydration-rearrangement of *exo*-norbornan-2-spiro-1'-cyclopentan-2'-ol,[3] was treated in tetrahydrofuran (50 mL) at room temperature with sodium borohydride (1.9 g, 50 mmol), boron trifluoride etherate (9.5 g, 67 mmol), and 30% hydrogen peroxide (5 mL) in the usual manner.[1a] The crude product (6.5 g) showed only one major VPC peak (88% of the combined peak areas) which was isolated by VPC fractionation in 65% yield: bp 75-78°C (0.1 mm); IR (neat) 3300(br), 2940, 2910, 1440, 1340, 1080, 1040, 920 cm^{-1}; ^1H NMR ($CDCl_3$) δ_H 0.8-2.4(complex m, 16H), 2.61 (s, 1H; O**H**), 3.83(m, 1H; C**H**OH); ^{13}C NMR ($CDCl_3$) δ_C 24.61(t), 26.07(t), 29.08(t), 31.84(t), 34.11(d), 34.31(d), 37.97(t), 40.08(t), 41.71(d), 43.69(d), 77.28(d; **C**HOH); mass spectrum *m/e* (rel intensity) 166(5, M^+), 148(28), 122(100), 109(31), 94(23), 93(51), 81(38), 80(80), 79(58), 67(52), 41(39).

These spectra suggested a secondary tricycloundecanol structure for the product. Indeed, this product was found identical with *endo*-2-*exo*-6-tricyclo[6.2.1.-$0^{2,6}$]undecan-*exo*-3-ol (**4x**) prepared by hydroboration of *exo*-6-tricyclo[6.2.1.$0^{2,6}$]-undec-2-ene (**3x**) which was synthesized independently from bicyclo[3.2.1]octan-2-one enamine (**5**) via the route shown in the scheme. Alkylation of **5** gave two isomeric products in ca. 2:1 ratio, and the minor constituent rearranged in the presence of sodium methoxide catalyst to the major component before they cyclized to the tri-



	10	11	12	13
$\Delta H°$ (kcal/mol)	-21.86	-25.54	-18.25	-23.54

cycloundecenone **7**. This indicated that the C-3 center of the alkylation product epimerized fast to produce the more stable equatorial isomer **6**. An endo configuration for C-2 of **4x** is suggested on the basis of the probable[1a,1b,4a] exo hydroboration on **3x**, and is supported by the result that the hydrocarbon obtained from **4x** by tosylation and lithium aluminum hydride reduction was different from the *exo*-2-*exo*-6 isomer **11**,[2] and hence should have the structure **13**. Therefore, *endo*-2-*exo*-6-*exo*-3-hydroxy stereochemistry is considered unequivocal for **4x**.

On the other hand, epoxidation of **1** (0.79 g, 5 mmol) by treating with *m*-chloroperbenzoic acid (85% purity; 0.97 g, 4.8 mmol) in chloroform (20 mL) at room temperature for 2 h gave a single isomer of the epoxy derivative, which was purified by VPC fractionation to afford a 78% yield of the epoxide: IR (neat) 2920, 1450, 1290, 1190, 1090, 940, 880, 820 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ_H 0.8-2.6(complex m); ^{13}C NMR ($CDCl_3$) δ_C 19.73(t), 27.22(t), 27.47(t), 29.53(t), 31.14(d), 31.43(t), 32.87(t), 35.65(t), 36.07(d), 64.09(s), 69.68(s); mass spectrum *m/e* (rel intensity) 164(3, M^+), 107(13), 106(39), 104(29), 97(100), 93(13), 91(17), 79(28), 67(23), 66(14).

The *exo*-2,6-epoxy structure **8** was assigned to this product for the following reasons. An exo attack of peracid to **1** was presumed from the similar reactions with α-cedrene,[4a] bicyclo[3.2.1]oct-2-ene,[4b] and norbornene.[4c] The exo oxirane structure also explains well the relatively high field ^{13}C NMR methylene signal (δ_C 19.73) as due to steric compression of the oxygen exerted on the C-11 methano bridge. Predominant (97%) formation of the *exo*-keto isomer **9**[5] of norbornan-spiro-cyclopentanone on treatment[6] of the epoxide (0.5 g, 3.1 mmol) with boron trifluoride etherate (1 mL, 8 mmol) in ether (15 mL) at room temperature for 2 h is consistent with the exo structure **8**, in considering that the rearrangement proceeds most favorably when the ruptured and the migrating bonds adopt a trans antiparallel disposition.[7] The exo oxirane structure **8** is also supported indirectly by the fact[8] that β-patchoulene oxide (the *endo*-epoxidated 1,5,11,11-tetramethyl-**1**) rearranged, in contrast to **8**, to a bridgehead alcohol likewise through a trans antiparallel transition state.

It has been demonstrated that the stereoselection in the peracid oxidation is controlled primarily by the steric hindrance to reagent approach.[4] Therefore, the reaction serves as a criterion for the steric congestion on the molecule. The above exo epoxidation clearly showed more steric hindrance against the reagent approach on the endo than on the exo side of **1**. Then, the endo diborane attack on **1** can not be a result of steric approach control. As a matter of fact, consideration of the relative stabilities of transition states suggests a preferable endo attack, as discussed below, and the reaction being under product development control.

The isolated product **4x** can not be the direct hydroboration-oxidation product of the starting 2(6)-ene **1**, but the intermediacy should be presumed of the 2(3)-ene **3x** which is formed[9] by the elimination in the tertiary alkylborane **2x**. This reaction scheme is strongly supported by the experimental results that **1** did not isomerize to **3x** under BF_3 catalysis in tetrahydrofuran, and that diborane prepared beforehand gave the same result as did the reagent formed *in situ* from BF_3-$NaBH_4$.[10] Now, **2x** would be more stable than **2n**, the exo hydroboration product, if relative stabilities of alkylboranes **2n** and **2x** are roughly approximated by those of the corresponding hydrocarbons **10** and **11** which are represented by the calculated heats of formation ΔH°.[11] Assuming the similarity of the transition states with the product

alkyl boranes, **2x** should be formed predominantly over **2n** under product development control. In contrast to this, hydroboration of the 2-ene **3x** is shown to occur as usual under steric approach control. The exo hydroboration product **4x** is less stable than the endo attack product, judging from the relative stability between the *endo*-2-*exo*-6 hydrocarbon **13** and the *exo*-2-*exo*-6 hydrocarbon **11**. Nevertheless, the former isomer was actually produced.

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