June, 1975] BULLETIN OF THE CHEMICAL SOCIETY OF JAPAN, VOL. 48(6), 1907—1913 (1975) 1907

Absolute Configurations and Chiroptical Properties of Optically Active Derivatives of Tricyclo[4.3.0.0^{3,8}]nonane ("Twist-brendane")

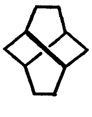
Masao Nakazaki, Koichiro Naemura, and Sigeyuki Harita

Department of Chemistry, Faculty of Engineering Science, Osaka University, Toyonaka, Osaka 560

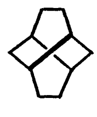
(Received January 13, 1975)

(+)-Tricyclo[4.3.0.0^{3,8}]nonane ("twist-brendane") was synthesized *via* (+)-tricyclo[4.3.0.0^{3,8}]nonan-9-one from (+)-*endo*-2-carboxybicyclo[2.2.2]oct-5-ene. Optically active derivatives of twist-brendane with two functional groups such as (—)-2,9-twist-brendanedione and (—)-9-methylenetwist-brendan-2-one were synthesized from (—)-*endo*-2-carboxybicyclo[2.2.2]oct-5-ene. Absolute configurations of the compounds were established and their chiroptical properties were discussed.

Tricyclo[4.4.0.0^{3,8}]decane ("twistane")[1] belongs to point group D$_2$ and is one of the representatives of tricyclodecanes whose carbon frameworks are inherently chiral. We were the first to obtain twistane in optically active form, and assigned to configuration (**1a**) to (+)-twistane on the basis of the chiroptical property of the intermediate, (+)-2-twistanone.[2] In recent years, Tichý reinvestigated this problem and assigned the opposite configuration (**1b**) to the same dextrorotatory enantiomer.[3]

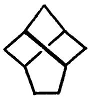


1a

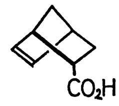


1b

In the preceeding paper, we reported the preparation of (—)-twist-brendane[4] from (—)-*endo*-2-carboxybicyclo[2.2.1]hept-5-ene (**3**) with known absolute configuration[5], and assignment of the absolute configuration (**2**) to (—)-twist-brendane.



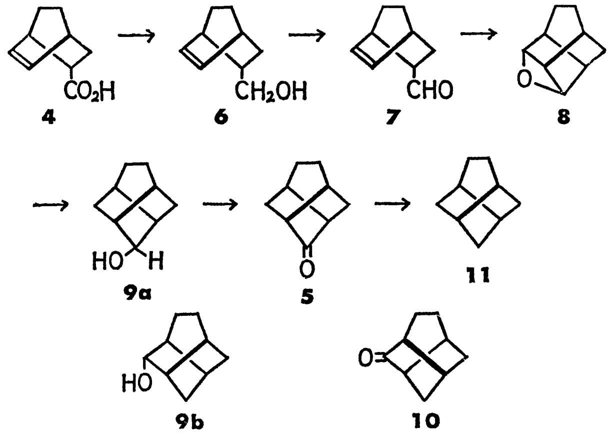
2



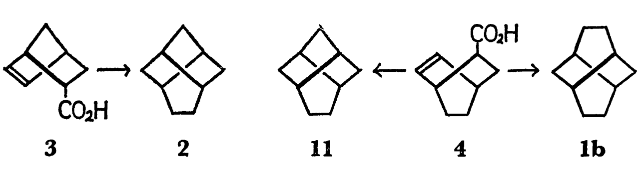
3

In this paper, we wish to report an alternative synthesis of optically active twist-brendane from bicyclo[2.2.2]octane derivative (**4**) which eventually correlates the configuration of (—)-twist-brendane with that of twistane. Since twist-brandane derivatives have rigid structures with well-defined molecular geometry and may afford a suitable model to study intramolecular interactions between the functional groups held in these fixed relative orientations, the syntheses and chiroptical properties of various twist-brendane derivatives will be also described in this paper.

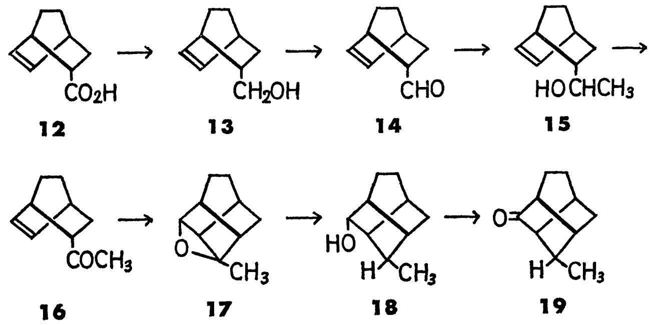
Our first task was the preparation of optically active 9-twist-brendanone (**5**)[6] from *endo*-2-carboxybicyclo[2.2.2]oct-5-ene (**4**) [α]$^{26}_{D}$ +31.8°[7] which was obtained through the optical resolution of racemic acid with the aid of (+)-2-(1-aminoethyl)naphthalene. Reduction of the (+)-carboxylic acid with lithium aluminum hydride followed by oxidation with Collins' reagent gave (+)-unsaturated aldehyde (**7**) which was smoothly converted into the (+)-oxetane (**8**) upon intramolecular Paterno-Büchi photoreaction.[8] Reductive cleavage of (+)-oxetane (**8**) with lithium aluminum hydride in *N*-methylmorpholine[9] afforded (+)-tricyclic alcohol (**9a**), which was oxidized with Jones' reagent to give (+)-ketone. Among two possible courses of the reductive ring fission of the (+)-oxetane (**8**), apparently the one leading to 2-hydroxytwist-brendane (**9b**) was not followed, because the (+)-ketone obtained showed a carbonyl absorption at 1765 cm^{-1} in its IR spectrum and was found to be different from 2-twist-brendanone (**10**) whose structure had been established by unambigous synthesis. These facts indicated that our (+)-ketone was the desired (+)-9-twist-brendanone (**5**). Wolff-Kishner reduction of this (+)-9-twist-brendanone gave a dextrorotatory hydrocarbon (11) [α]$^{21}_{D}$ +177°, which was purified by chromatography and sublimation. Comparison of its NMR, IR, mass spectrum and vpc retention time with those of (—)-twist-brendane (**2**) confirmed that they are enantiomeric. This result gave us a clear information about the configurational relationship between (+)-twist-brendane (**11**) and our starting material (+)-*endo*-2-carboxybicyclo[2.2.2]oct-5-ene (**4**)[10] as shown below.



Since (+)-twistane was derived from this bicyclo[2.2.2]octane derivative (**4**), our previous assignment of the absolute configuration to (+)-twistane by chiroptical method has to be reversed confirming Tichý's new result.



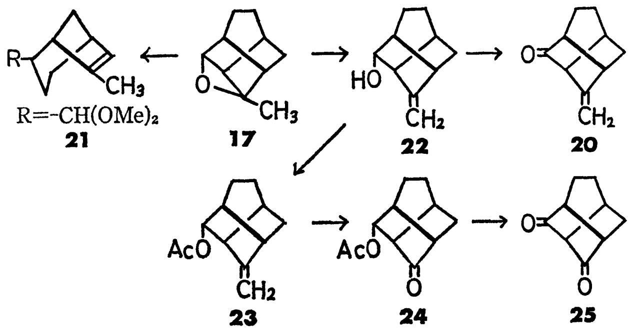
Next our attention was turned to prepare optically active twist-brendane derivatives with two functional groups and investigate their intramolecular interaction in their rigid molecular frameworks. (−)-Aldehyde (**14**) prepared *via* (−)-alcohol (**13**) from (−)-*endo*-2-carboxybicyclo[2.2.2]oct-5-ene (**12**) $[\alpha]^{24}_{D}$ −27.8° was treated with methylmagnesium iodide to give (−)-alcohol (**15**), which was oxidized with Collins' reagent to yield (−)-ketone (**16**). The ring closure leading to twist-brendane framework was again achieved by the Paterno-Büchi reaction. Irradiation of a solution of (−)-ketone (**16**) in benzene with mercury lamp gave a liquid product which was purified by distillation to give (−)-oxetane (**17**). Reductive cleavage of (−)-oxetane (**17**) with lithium aluminum hydride in *N*-methylmorpholine yielded alcohol (**18**), which, without purification, was treated with Collins' reagent to give (−)-ketone (**19**). The structural evidence was obtained on the basis of its following spectral data. The NMR spectrum exhibited sharp doublet signals centered at δ 1.11 (J=7 Hz) for the methyl group and the IR spectrum showed a carbonyl absorption at 1753 cm^{-1}.



12 **13** **14** **15**

16 **17** **18** **19**

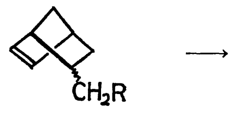
For the preparation of olefinic ketone (**20**), (−)-oxetane (**17**) was treated with perchloric acid in methanol and the product was chromatographed on alumina to give two products. To the minor product (22% yield) eluted with pentane was assigned the structure (**21**) on the basis of its IR spectrum which showed characteristic absorptions at 2839 cm^{-1} due to methoxy group and 3020 and 805 cm^{-1} due to trisubstituted olefin. Elution with ether–pentane afforded the major product (28% yield) whose IR spectrum (3450 cm^{-1} for hydroxyl group and 3050, 1675, 890 and 870 cm^{-1} for terminal methylene group) indicated the structure (**22**) for this olefinic alcohol. Upon Collins' oxidation, (−)-alcohol (**22**) gave (−)-ketone (**20**) whose structure was confirmed by the NMR spectrum data; δ 4.80 and 4.65 (olefinic protons) and 2.95 and 2.70 (two bridge head protons at C_1 and C_3). The olefinic alcohol (**22**) in hand, we diverted our effort to preparation of the twist-brendane with two oxo groups at C_2 and C_4 positions. After protection of hydroxyl group by acetylation, the resulted acetate (**23**) was ozonolyzed in chloroform (at −78 °C) to provide the ketoacetate (**24**) which was purified by chromatography followed by vaccum distillation. Failure in removing the acetyl group by hydrolysis with methanolic potassium hydroxide forced us to take a detour. Reduction of the ketoacetate (**24**) with lithium aluminum hydride followed by Collins' oxidation afforded a solid and the product was purified by sublimation to give diketone (**25**) which showed two carbonyl absorptions at 1785 and 1740 cm^{-1}. The specific rotation of the diketone (**25**) observed in chloroform solution was $[\alpha]_D$ −225° at 17 °C. When the substance was dissolved in methanol and the specific rotation of the solution was observed, there was a gradual change in the rotation from initial value $[\alpha]^{17}_{D}$ −153° to an equilibrium value $[\alpha]^{17}_{D}$ +32.0° during 4 hr.

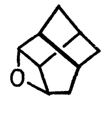


21 **17** **22** **20**

23 **24** **25**

Since inspection of a molecular model of the olefinic ketone (**26**) reveals an interesting feature about the interaction of the double bond and carbonyl group in this unique twist-brendane framework, our final effort was directed to the preparation of this twist-brend-4-en-2-one (**26**). The key intermediate selected for the ketone (**26**) was a new oxetane (**27a**) which was obtained from 2-formylmethylbicyclo[2.2.1]hept-5-ene (**33**) by the Paterno-Büchi reaction. The Diels-Alder reaction of cyclopentadiene with allyl alcohol gave an *endo* and *exo* mixture of 2-hydroxymethylbicyclo[2.2.1]hept-5-ene (**28**) which was converted into the nitrile (**30**) *via* the tosylate (**29**). Upon hydrolysis with alkaline, the nitrile (**30**) afforded carboxylic acid (**31**) which was reduced with lithium aluminum hydride to yield alcohol (**32**). Oxidation of the alcohol (**32**) with Collins' reagent gave a mixture of *endo* and *exo*-2-formylmethylbicyclo[2.2.1]hept-5-ene (**33**). Irradiation was carried out on *endo* and *exo*-mixture of aldehydes (**33**) in benzene. Oxetane (**27a**) was smoothly produced and purified by sublimation to give a solid. Although there are two alternative ways of ring closure leading to (**27a**) and (**27b**), we assigned the structure (**27a**) to the oxetane since this compound could be transformed into 2-twist-brendanone (**10**) *via* 2-twist-brendanol (**34**) by reductive cleavage followed by Collins' oxidation.

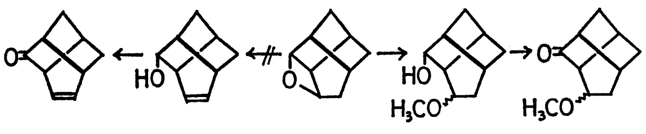




28: R=OH, **31**: R=CO_2H **27a**
29: R=OTs, **32**: R=CH_2OH
30: R=CN, **33**: R=CHO

34 **27b**

Oxetane (**27a**) was treated with perchloric acid in methanol to give an alcoholic product. The product was oxidized with Collins' reagent to yield ketone which was chromatographed on silica gel. A fraction eluted with ether–pentane was distilled to give a ketone, to which the structure (**36**) was assigned to the basis of the following facts. The NMR spectrum exhibited signals at δ 3.75—3.55 due to a proton at C_4 and did not exhibit any signal at the region for olefinic proton. The IR spectrum showed a carbonyl absorption at 1750 cm^{-1} and absorptions for methoxy group at 2830 and 1105 cm^{-1}. The elementary analysis and mass spectrum (m/e 166 M$^+$) were in agreement with the calculated value for $C_{10}H_{14}O_2$. An expected alcohol (**37**) could not be obtained from the oxetane (**27a**) by the method.



26 **37** **27** **35** **36**

Chiroptical Properties

(—)-*endo*-2-Methylbicyclo[2.2.1]heptan-7-one (**38**) is a bicyclic ketone being compared with (+)-9-twist-brendanone (**5**) and shows a positive Cotton effect at about 295 nm in its CD.[11] But (+)-9-twist-brendanone (**5**) exhibited a negative Cotton effect at 285 nm (Fig. 1). An ethano bridge of the tricyclic ketone twisted a center six-membered ring, hached in the formula (**39**) and a projection formula (**40**), where the C=O lies in the "point" of the twist,[12] is drawn for (+)-9-twist-brendanone (**5**). Then the octant rule is applied to both "outer" five-membered rings in this projection formula (**40**). It is obvious that negative contributions coming from the two "outer" rings determine the sign of the Cotton effect.

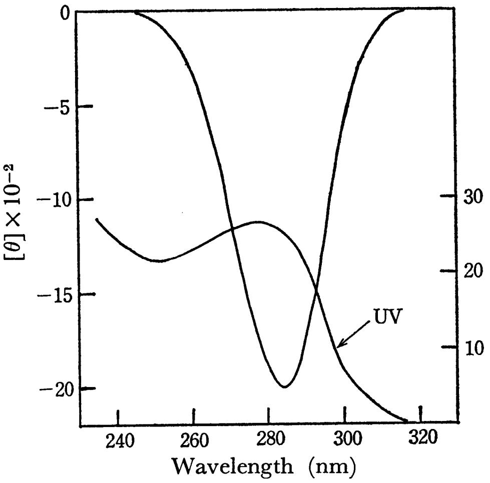


Fig. 1. CD and UV spectra of (+)-9-twist-brendanone (**5**).

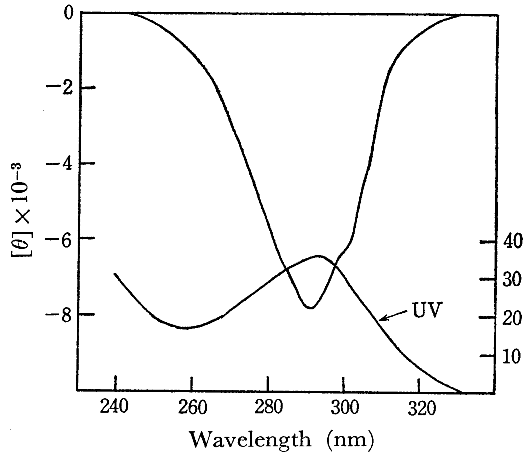


Fig. 2. CD and UV spectra of (—)-9-methyltwist-brendan-2-one (**19**).

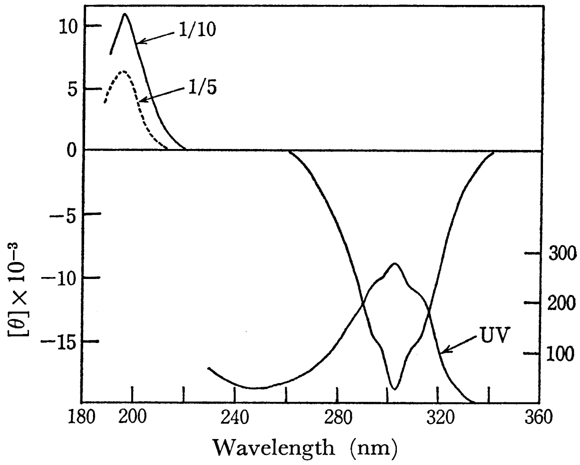
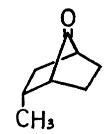
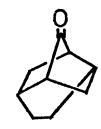


Fig. 3. CD (----) spectrum of (—)-9-methylenetwist-brendan-2-ol (**22**) and CD (——) and UV (——) spectra of (—)-9-methylenetwist-brendan-2-one (**20**).

The chirality of carbon framework of (—)-9-methyl-twist-brendan-2-one (**19**) is the opposite sense in contrast to that of (+)-9-twist-brendanone (**5**). However, (—)-9-methyltwist-brendan-2-one (**19**) exhibited also a negative Cotton effect at 292 nm (Fig. 2). The fact is explained by the same rule as mentioned above. Negative contributions coming from the two "outer" rings of the projection formula (**41**) determine the sign of the Cotton effect. (—)-9-Methylenetwist-brendan-2-ol (**22**) exhibited a strong positive Cotton effect at 195 nm (Fig. 3). (—)-9-Methylenetwist-brendan-2-one (**20**) exhibited a positive Cotton effect at 195 nm and a negative one at 302.5 nm and the intensities of both maximum were increased in contrast to those of the alcohol (**22**) and the saturated ketone (**19**). The negative Cotton effect at around 300 nm is also predictable from the same rule. These facts showed us that the sign of the Cotton effect at around 300 nm exhibited by twist-brendanones was essentially predictable from application of the octant rule to "outer" rings in the projection formula. In other word, the sign of the Cotton effect exhibited twist-brendanones is unequivocally related to a chirality of a middle ring of the projection formula and the concept is adopted for twistanones.[12] For the ketones exhibited a negative Cotton effect, the middle ring adopts P-helicity.

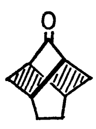


38

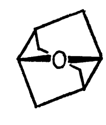


5

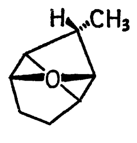
≡



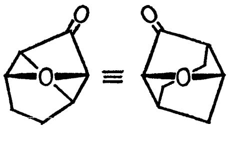
39



40



41



42

There are P-helicity six-membered ring and M-helicity seven-membered ring in (+)-2,9-twist-brendandione (**25**) as shown in the projection formula (**42**) and the diketone exhibited complicating maxima in its CD (Fig. 4). We have never offered a pertinent explanation for the fact.

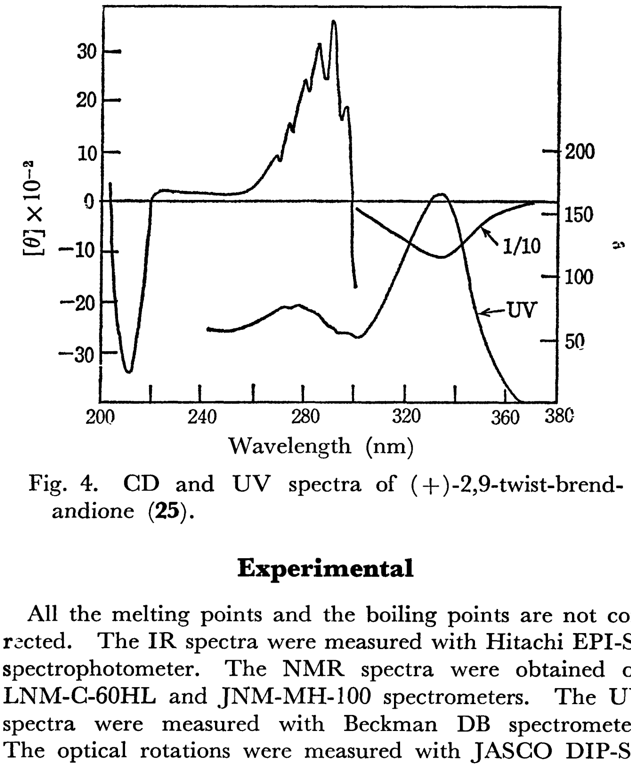


Fig. 4. CD and UV spectra of (+)-2,9-twist-brendandione (**25**).

Experimental

All the melting points and the boiling points are not corrected. The IR spectra were measured with Hitachi EPI-S2 spectrophotometer. The NMR spectra were obtained on LNM-C-60HL and JNM-MH-100 spectrometers. The UV spectra were measured with Beckman DB spectrometer. The optical rotations were measured with JASCO DIP-SL automatic polarimeter. The CD spectra were obtained on JASCO J-20 spectropolarimeter with CD attachment.

(+)-endo-*2-Carboxybicyclo[2.2.2]oct-5-ene (**4**).* A salt of *endo*-2-carboxybicyclo[2.2.2]oct-5-ene with (+)-2-(1-aminoethyl)naphthalene was recrystallized from ethanol and then a dextrorotatory salt was treated with hydrochloric acid to give (+)-carboxylic acid (**4**) mp 42—43 °C, $[\alpha]^{26}_{D}$ +31.8° (*c* 0.54, methanol).

Found: C, 71.21; H, 8.02%. Calcd for $C_9H_{12}O_2$: C, 71.02; H, 7.95%.

(+)-endo-*2-Hydroxymethylbicyclo[2.2.2]oct*-5-*ene (**6**).* Reduction of 10.9 g of (+)-carboxylic acid (**4**) with lithium aluminum hydride in ether gave 8.49 g of alcohol (**6**) bp 95 °C at 5 Torr, $[\alpha]^{25}_{D}$ +4.5° (c 1.1, methanol).

IR (neat film): 3350(s), 3050(w), 2950(s), 2880(m), 1055(m), 1035(m), 1015(m), and 710(s) cm^{-1}.

Found: C, 78.03; H, 10.35%. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21%.

(+)-endo-*2-Formylbicyclo[2.2.2]oct-5-ene (**7**).* To a solution of 59 ml of dry pyridine in 1.34 l of dry methylenechloride was added 36.4 g of chromium trioxide and the mixture was stirred at room temperature for 15 min. Then a solution of 8.4 g of (+)-alcohol (**6**) in 10 ml of dry methylenechloride was added to the mixture and it was stirred at room temperature for further 15 min. An organic layer was separated and a residue was rinsed with the same solvent. Combined organic solutions were washed with dilute hydrochloric acid, satd. aqueous sodium bicarbonate, water and dried over magnesium sulfate. After evaporation of the solvent a residue was distilled to give 6.53 g of (+)-aldehyde (**7**) bp 58 °C at 2 Torr, $[\alpha]^{25}_{D}$ +5.1° (*c* 1.2, methanol).

IR(neat film): 3050(w), 2950(s), 2880(m), 2820(w), 2750(w), 1720(s), 930(w) and 715(s) cm^{-1}.

Since the aldehyde was very sensitive to air, a correct elementary analysis datum was not obtained.

*Photoreaction of (+)-Aldehyde (**7**).* A solution of 6.08 g of (+)-aldehyde (**7**) in 500 ml of benzene was irradiated for 20 hr with mercury lamp (SHL-100 UV, Toshiba) under nitrogen atmosphere. After evaporation of the solvent, a residue was chromatographed on neutral alumina (Woelm Activity III) and a solid eluted with pentane was sublimed to give 2.85 g of (+)-oxetane (**8**) mp 167—170 °C (in sealed tube), $[\alpha]^{23}_{D}$ +148° (*c* 0.78, methanol).

IR(KBr): 2950(s), 2880(m), 1025(m), 935(m), 915(m), 895(m), 870(m), 840(m), 830(m) and 808(w) cm^{-1}.

NMR($CDCl_3$): δ 0.9—1.9(m, 7H), 2.1—2.5(m, 2H), 3.1—3.2(m, 1H), 4.3—4.5(m, 1H) and 4.6—4.8(m, 1H).

Found: C, 79.24; H, 8.86%. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88%.

*(+)-Tricyclo[4.3.0.0^{3,8}]nonan-9-ol (**9a**).* To a solution of 2.78 g of (+)-oxetane (**8**) in 170 ml of *N*-methylmorpholine was added 5.7 g of lithium aluminum hydride and the mixture was heated at reflux for 60 hr. After cooling, a few ml of methanol was added to the reaction mixture and then it was acidified with dilute hydrochloric acid. The mixture was extracted with ether. The extract was washed with satd. aqueous sodium bicarbonate, water and dried over magnesium sulfate. After evaporation of the solvent, a residue was chromatographed on neutral alumina (Woelm, activity III) and a solid eluted with ether–pentane was sublimed to give 1.22 g of (+)-tricyclic alcohol (**10**) mp 162—165 °C (in sealed tube), $[\alpha]^{23}_{D}$ +164° (*c* 0.66, methanol).

IR(KBr): 3350(s), 2930(s), 2880(m), 1090(s), 1075(m), 1030(m), 1010(m) and 875(w) cm^{-1}.

NMR($CDCl_3$): δ 1.2—2.2(m, 12H), 2.34(s, 1H) and 4.12(m, 1H).

Found: C, 78.09; H, 10.43%. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21%.

*(+)-Tricyclo[4.3.0.0^{3,8}]nonan-9-one (**5**).* A solution of 1.38 g of (+)-alcohol (**9a**) in 20 ml of acetone was treated with excess of 8 N Jones' reagent for 2 hr with ice cooling. The reaction mixture was poured into water and it was extracted with ether. The extract was washed with satd. aqueous sodium bicarbonate, water and dried over sodium sulfate. After evaporation of the solvent, a residue was chromatographed on neutral alumina (Woelm, Activity III) and a solid eluted with pentane was sublimed to give 711 mg of ketone (**5**) mp 159—161 °C (in sealed tube) (lit,[9] racemic: mp 141—143 °C), $[\alpha]^{19}_{D}$ +176° (*c* 0.57, methanol).

IR(KBr): 2900(s), 2830(m), 1765(s), 1470(m), 1190(m), 1140(m), 1115(m), 1070(w), 880(m), 840(m), 790(w) and 735(w) cm^{-1}.

NMR(CCl_4): δ 1.4—2.1 (m, 12H).

UV: $\lambda_{\max}^{\text{isooctane}}$ (ε) 379 (27) nm.

CD (c 4.03×10^{-2}, isooctane): $[\theta]_{245}$ 0, $[\theta]_{285}$ −2020, $[\theta]_{320}$ 0.

Found: C, 78.64; H, 8.82%. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88%.

*(+)-Tricyclo[4.3.0.$0^{3,8}$]nonane (**11**).* A solution of 400 mg of 9-twist-brendanone (**5**), 219 mg of potassium hydroxide and 0.38 ml of 80% hydrazine hydrate in 3.5 ml of triethylene glycol was heated at reflux for 2 hr. Then water was allowed to boil out of the solution and the resulting solution was heated at 210 °C for further 5 hr. The reaction mixture was diluted with water and it was extracted with pentane. The extract was washed with water and dried over magnesium sulfate. After evaporation of the solvent, a residue was sublimed to give 134 mg of twist-brendane (**11**) mp 154—157 °C (in sealed tube), $[\alpha]_D^{21}$ +177° (c 0.46, ethanol). The NMR, IR, mass spectra and vpc retention time (10% SE-30 2m at 110 °C) were identical with those of (−)-enantiomer.[4]

(−)-endo*-2-Formylbicyclo[2.2.2]oct-5-ene (**14**).* Reduction of 34.0 g of (−)-*endo*-2-carboxybicyclo[2.2.2]oct-5-ene (**12**) $[\alpha]_D^{20}$ −27.8° with lithium aluminum hydride gave 27.7 g of (−)-*endo*-2-hydroxymethylbicyclo[2.2.2]oct-5-ene (**13**) $[\alpha]_D^{18}$ −4.0° (c 0.12, methanol). Upon oxidation with chromium trioxide, pyridine in dry methylene chloride, 13.8 g of (−)-alcohol (**13**) yielded 9.9 g of (−)-*endo*-2-formylbicyclo[2.2.2]oct-5-ene (**14**) bp 90—4 °C at 18 Torr, $[\alpha]_D^{18}$ −4.5° (c 1.86, methanol).

*(−)-2-(1-Hydroxyethyl)bicyclo[2.2.2]oct-5-ene (**15**).* A solution of 41.1 g of methyl iodide in 150 ml of dry ether was slowly added to a mixture of 6.4 g of magnesium with 100 ml of dry ether at room temperature and then the mixture was gently refluxed for 1 hr. After cooling to room temperature, a solution of 19.8 g of (−)-aldehyde (**14**) in 150 ml of dry ether was added to the Grignard reagent and the reaction mixture was boiled for 4 hr. It was cooled with ice and satd. aqueous ammonium chloride solution was added to the chilled mixture. A separated solid was filtered off and washed with ether. Combined ether solutions were washed with water and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to give 20.2 g of (−)-alcohol (**15**) bp 108—110 °C at 20 Torr, $[\alpha]_D^{20}$ −0.23° (c 1.20, methanol).

IR(neat film): 3350(s), 3030(w), 2930(s), 2880(m), 1135(m), 1085(s), 1030(m), 925(m), 880(m) and 710(s) cm^{-1}.

Found: C, 78.62; H, 10.59%. Calcd for $C_{10}H_{16}O$: C, 78.89; H, 10.59%.

*(−)-2-Acetylbicyclo[2.2.2]oct-5-ene (**16**).* A solution of 9.60 g of (−)-alcohol (**15**) in 10 ml of dry methylene chloride was added to a mixture which was prepared from 42.0 g of chromium trioxide, 67.0 g of dry pryidine and 1000 ml of dry methylene chloride by the usual manner. The mixture was stirred for 15 min at room temperature. After working up as usual, a product was distilled to give 8.14 g of (−)-ketone (**16**) bp 102 °C at 20 Torr, $[\alpha]_D^{18}$ −8.1° (c 2.90, methanol).

IR (neat film): 3050(w), 2950(s), 2880(m), 1710(s), 1355(m), 1170(m) and 710(m) cm^{-1}.

Found: C, 79.97; H, 9.42%. Calcd for $C_{10}H_{14}O$: C, 79.95; H, 9.39%.

*Photoreaction of (−)-2-acetylbicyclo[2.2.2]oct-5-ene (**16**).* A solution of 7.00 g of (−)-ketone (**16**) in 600 ml of benzene was irradiated with mercury lamp (SHL-100UV, Toshiba) for 35 hr. After evaporation of the solvent, a residue was distilled to give 6.03 g of (−)-oxetane (**17**) bp 83—85 °C at 20 Torr $[\alpha]_D^{17}$ −177° (c 1.32, methanol).

IR (neat film): 2950(s), 2880(m), 1390(m), 1155(m), 1105(m), 1025(m), 955(m), 905(m), 890(m), 860(m) and 835(m) cm^{-1}.

Found: C, 79.50; H, 9.53%. Calcd for $C_{10}H_{14}O$: C, 79.95; H, 9.35%.

*(−)-9-Methyltricyclo[4.3.0.$0^{3,8}$]nonan-2-one (**19**).* To a solution of 2.78 g of (−)-oxetane (**17**) in 280 ml of N-methylmorpholine was added 6.9 g of lithium aluminum hydride at room temperature and the mixture was heated at reflux for 65 hr at which time it was cooled and added carefully with methanol, water and hydrochloric acid. The mixture was extracted with ether. The extract was washed with satd. aqueous sodium bicarbonate, water and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to yield 1.62 g of the recovered oxetane (**17**) and a residual liquid was used to the following reaction. A solution of the residue in 5 ml of dry methylene chloride was added to a mixture of 1.58 g of chromium trioxide, 2.5 g of dry pryidine and 50 ml of dry methylene chloride and then the reaction mixture was stirred at room emperature for 15 min. After working up as usual, a crude product was chromatographed on neutral alumina (Woelm, activity III) and an elute with pentane was distilled to give 240 mg of (−)-ketone (**19**) bp 95—100 °C at 20 Torr, $[\alpha]_D^{15}$ −139° (c 0.38, methanol).

IR (neat film): 2950(s), 2870(m), 1753(s), 1455(m), 1380(w), 1300(w), 1180(w) and 1075(w) cm^{-1}.

NMR (CCl_4): δ 1.02(d, J=7 Hz, 3H), 1.4—2.2(m, 9H) and 2.3—2.5 (m, 2H).

UV: $\lambda_{\max}^{\text{isooctane}}$ (ε) 292.5 (37) nm.

CD (c 5.00×10^{-2}, isooctane): $[\theta]_{240}$ 0, $[\theta]_{292}$ −7792, $[\theta]_{299}$ −6433, $[\theta]_{330}$ 0.

Found: C, 79.86; H, 9.45%. Calcd for $C_{10}H_{14}O$: C, 79.95; H, 9.39%.

*(−)-9-Methylenetricyclo[4.3.0.$0^{3,8}$]nonan-2-ol (**22**).* To a solution of 2.99 g of (−)-oxetane (**17**) in 200 ml of methanol was added 100 µl of 70% perchloric acid and then the mixture was kept at 18—20 °C for 20 hr. After dilution with 200 ml of water and saturation with sodium chloride, it was extracted with ether and the extract was washed with water. After drying over magnesium sulfate and evaporation of the solvent, a residue was chromatographed on neutral alumina (Woelm, activity III). First elution with pentane gave a bicyclic compound which was further purified by distillation to give 0.86 g of **21** bp 127—130 °C at 20 Torr, $[\alpha]_D^{18}$ +26.7° (c 1.22, methanol). Followed fraction eluted with pentane gave 1.10 g of the recovered oxetane (**17**). Fractions eluted with ether-pentane (2 : 8 volume) gave an alcoholic product which was distilled to yield 845 mg of **22** bp 135 °C at 20 Torr, $[\alpha]_D^{15}$ −319° (c 1.16, methanol).

17: IR(neat film): 3030(w), 2930(s), 2850(m), 1135(s), 1100(s), 1065(s), 970(m), 900(m) and 800(m) cm^{-1}.

Found: C, 73.18; H, 10.08%. Calcd for $C_{12}H_{20}O$: C, 73.43; H, 10.27%.

22: IR(neat film): 3450(s), 3050(w), 2950(s), 2880(m), 1675(m), 1100(s), 1080(s), 1060(s), 1045(m) 985(m), 890(s), 870(s) and 815(m) cm^{-1}.

Found: C, 79.68; H, 9.42%. Calcd for $C_{10}H_{14}O$: C, 79.95; H, 9.39%.

CD (c 2.60×10^{-2}, isooctane): $[\theta]_{195}$ $+3.09\times10^4$, $[\theta]_{218}$ 0.

*(−)-9-Methylenetricyclo[4.3.0.$0^{3,8}$]nonan-2-one (**20**).* A solution of 595 mg of (−)-unsaturated alcohol (**22**) in 5 ml of dry methylene chloride was added to a mixture which was prepared from 4.8 g of dry pyridine, 3.0 g of chromium trioxide and 900 ml of dry methylene chloride. The reaction mixture was stirred at room temperature for 20 min. An organic layer was separated and a residue was rinsed with the same solvent. Combined organic solutions were

washed with dilute hydrochloric acid, satd. aqueous sodium bicarbonate, water and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to give 522 mg of (−)-ketone (**20**) bp 130 °C at 20 Torr, $[\alpha]^{17}_{D}$ −450° (*c* 0.92, methanol).

IR (neat film): 3050(w), 2950(s), 2870(m), 1750(s), 1675(m), 1075(m), 890(m), 860(m) and 810(m) cm^{-1}.

NMR (CCl_4): δ 1.4—2.0(m, 6H), 2.2—2.6(m, 2H), 2.74—2.95(m, 2H), 4.65(s, 1H) and 4.80(s, 1H).

UV: $\lambda_{max}^{isooctane}$ (ε) 296 sh (245), 303 (278) and 312 sh (213) nm.

CD (*c* 3.71×10^{-3}, isooctane): $[\theta]_{195}$ 1.099×10^{5}, $[\theta]_{220}$ 0. $[\theta]_{260}$ 0, $[\theta]_{294sh}$ -1.469×10^{4}, $[\theta]_{302.5}$ -1.900×10^{4}, $[\theta]_{311sh}$ -1.509×10^{4} and $[\theta]_{338}$ 0.

Found: C, 81.52; H, 8.14%. Calcd for $C_{10}H_{12}O$: C, 81.04; H, 8.16%.

(−)-2-Acetoxy-9-methylenetricyclo[*4.3.0.0*^{3,8}]*nonane* (***23***). To a solution of 3.51 g of (−)-alcohol (**22**) in 15 ml of pyridine was added 5 ml of acetic anhydride at 0—5 °C and then the reaction mixture was stirred for 1 hr at this temperature and for 24 hr at room temperature. After dilution with water, it was extracted with ether. The extract was washed with dilute hydrochloric acid, satd. aqueous sodium bicarbonate, water and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to give 4.24 g of acetate (**23**) bp 118—120 °C at 20 Torr, $[\alpha]^{17}_{D}$ −122° (*c* 1.53, methanol).

IR (neat film): 3050(w), 2950(m), 2870(m), 1730(s), 1685(w), 1365(m), 1250(s), 1230(s), 1053(m), 1040(m) and 880(m) cm^{-1}.

NMR (CCl_4): δ 1.4—1.5 (m, 2H), 1.6—1.8 (m, 4H), 1.88 (s, 3H), 1.9—2.2 (m, 2H), 2.3—2.7 (m, 2H), 4.50 (s, 1H), 4.56 (s, 1H) and 4.60 (s, 1H).

Found: C, 74.81; H, 8.49%. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39%.

(−)-2-Acetoxytricyclo[*3.4.0.0*^{3,8}]*nonan-9-one* (***24***). A solution of 4.00 g of (−)-acetate (**23**) in 140 ml of chloroform was cooled to −78 °C and treated with ozone until blue color persisted. Then the solution was allowed to warm to room temperature and nitrogen was bubled through the solution. The solution was added to a mixture of 5.4 g of zinc dust, 9 ml of acetic acid, 220 ml of chloroform and 900 ml of water and the mixture was stirred for 12 hr at room temperature. An organic layer was separated, washed with aqueous sodium carbonate and then with water, and dried over magnesium sulfate. After evaporation of the solvent, a residue was chromatographed on neutral alumina (Woelm, activity III) and fractions eluted with ether–pentane (2 : 8 volume) were distilled to give 1.33 g of ketone (**24**) bp 138—140 °C at 5 Torr, $[\alpha]^{15}_{D}$ −137° (*c* 0.54, methanol).

IR (neat film): 2950(s), 2870(m), 1775(s), 1735(s), 1370(m), 1250(s), 1230(s), 1205(m), 1190(m), 1050(m), and 1040(s) cm^{-1}.

Found: C, 67.87; H, 7.33%. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27%.

(−)-Tricyclo[*4.3.0.0*^{3,8}]*nonane-2,9-dione* (***25***). A solution of 1.10 g of (−)-acetate (**24**) in 40 ml of dry ether was added to a suspension of 0.32 g of lithium aluminum hydride in 30 ml of dry ether at room temperature and the mixture was heated at reflux for 2 hr. After cooling, saturated aqueous ammonium chloride solution was added to the chilled mixture and a separated solid was filtered off. A filtrate was dried over magnesium sulfate. After evaporation of the solvent a residual diol, without purification, was used to the next reaction. A solution of 0.50 g of the diol in 10 ml of dry methylene chloride was added to a mixture which was prepared from 3.90 g of chromium trioxide, 6.24 g of dry pyridine and 100 ml of dry methylene chloride. After stirring for 15 min at room temperature, an organic layer was separated and a residue was rinsed with the same solvent. Combined organic solutions were worked up by the usual manner and removal of the solvent gave a brown solid, which was sublimed to give 340 mg of diketone (**25**) mp 146—150 °C (in sealed tube), $[\alpha]^{17}_{D}$ −225° (*c* 0.40, chloroform).

IR(KBr): 2950(m), 2870(m), 1785(s), 1740(s), 1450(w), 1185 (w), 1175(w), 1085(w), 1070(w) and 850(w) cm^{-1}.

UV: $\lambda_{max}^{isooctane}$ (ε) 268 sh (72), 273 (76), 278.5 (77), 282 sh (71), 297 (55) and 334 (167) nm.

CD (*c* 4.01×10^{-2}, isooctane): $[\theta]_{203}$ 0, $[\theta]_{211}-3440$, $[\theta]_{219}$ 0, $[\theta]_{269}+989$, $[\theta]_{274}+1547$, $[\theta]_{279}+2446$, $[\theta]_{284.5}+3194$, $[\theta]_{290}+3644$, $[\theta]_{295.5}+1897$, $[\theta]_{298}$ 0, $[\theta]_{334}-11180$ and $[\theta]_{370}$ 0.

Found: C, 72.00; H, 7.16%. Calcd for $C_9H_{10}O_2$: C, 71.98; H, 6.71%.

A Mixture of endo *and* exo-2-*Cyanomethylbicyclo*[*2.2.1*]*hept-5-ene* (***30***). A solution of 26.9 g of a mixture of *endo* and *exo*-2-hydroxymethylbicyclo[2.2.1]hept-5-ene (**28**) which was prepared by the Diels-Alder reaction of allyl alcohol with cyclopentadiene in 95 ml of pyridine was added with 50.0 g of *p*-toluenesulfonyl chloride. The reaction mixture was stirred for 5 hr at 0—5 °C and then kept for further 24 hr at room temperature. It was poured into ice-water and acidified with hydrochloric acid. The mixture was extracted with ether. The extract was washed with saturated aqueous sodium bicarbonate, water and dried over magnesium sulfate. Removal of the solvent gave 56.4 g of tosylate (**29**), which, without purification, was used to the next reaction. A mixture of 56.4 g of tosylate (**29**), 32.5 g of sodium cyanide and 300 ml of dimethylformamide was heated for 12 hr at 120—140 °C. After cooling to room temperature, a solid was filtered off and a filtrate was concentrated under reduced pressure. A residue was added into ice-water and it was extracted with ether. The extract was washed with dilute hydrochloric acid, saturated aqueous sodium bicarbonate and water, and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to give 20.5 g of a mixture of *endo* and *exo*-nitrile (**30**) bp 108—110 °C at 17 Torr.

IR (neat film): 3030(w), 2950(s), 2850(m), 2260(w), 1420(w), 1345(w), 1330(w) and 720(s) cm^{-1}.

Found: C, 81.27; H, 8.34; N, 10.31%. Calcd for $C_9H_{11}N$: C, 81.16; H, 8.33; N, 10.52%.

A Mixture of endo *and* exo-*2-(2-Hydroxyethyl)bicyclo*[*2.2.1*]*-hept-5-ene* (***32***). A mixture of 20.2 g of nitrile (**30**), 26.0 g of potassium hydroxide and 200 ml of ethylene glycol was heated for 7 hr at 140—160 °C. After cooling to room temperature, 300 ml of water was added to the reaction mixture and it was washed with ether to remove neutral compounds. Then the aqueous solution was acidified with hydrochloric acid and it was extracted with ether. The extract was washed with water and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to give 20.1 g of carboxylic acid (**31**) bp 103—110 °C at 3 Torr. A solution of 19.8 g of carboxylic acid (**31**) in 150 ml of dry ether was slowly added to a suspension of 5.5 g of lithium aluminum hydride in 150 ml of dry ether and the reaction mixture was gently refluxed for 4 hr. After cooling with ice, saturated aqueous ammonium chloride solution was added to the chilled reaction mixture. A separated solid was filtered off and a filtrate was washed with water and dried over magnesium sulfate. After evaporation of the solvent, a residue was distilled to yield 17.1 g of a mixture of *endo* and *exo*-2-(2-hydroxyethyl)bicyclo[2.2.1]hept-5-ene (**32**) bp 77—79 °C at 4 Torr.

Found: C, 78.08; H, 10.23%. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21%.

A Mixture of endo *and* exo-*2-Formylmethylbicyclo[2.2.1]hept-5-ene (33).* To a mixture of 24.0 g of chromium trioxide, 38.0 g of dry pyridine and 580 ml of dry methylene chloride was added a solution of 5.52 g of alcohol (**32**) in 10 ml of dry methylene chloride. The reaction mixture was stirred for 15 min at room temperature. An organic layer was separated and a residue was rinsed with the same solvent. Combined organic solutions were worked up the usual manner. After evaporation of the solvent, a residue was distilled to yield 3.67 g of aldehyde (**33**) bp 89—91 °C at 20 Torr.

IR (neat film): 3050(w), 2950(s), 2860(m), 2730(w), 1720(s), 903(w), 830(w) and 725(m) cm^{-1}.

Found: C, 79.24; H, 8.98%. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88%.

Photoreaction of Aldehyde (33). A solution of 3.47 g of aldehyde (**33**) in 300 ml of benzene was irradiated for 15 hr with mercury lamp (SHL-100 UV, Toshiba) under nitrogen atmosphere. After evaporation of the solvent, a residue was chromatographed on neutral alumina (Woelm, acitivity III). An elution with pentane gave a solid which was sublimed to give 1.13 g of oxetane (**27a**) mp 161—163 °C (in sealed tube).

IR (KBr): 2950(s), 2880(m), 1330(s), 1050(s), 985(s), 955(m), 885(m), 840(m) and 800(m) cm^{-1}.

NMR ($CDCl_3$): δ 1.1—2.6 (m, 9H), 3.32—3.50 (m, 1H) and 4.50—4.80 (m, 2H).

Found: C, 78.92; H, 8.91%. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88%.

Tricyclo[4.3.0.0^{3,8}]nonan-2-ol (34). A solution of 848 mg of oxetane (**27a**) in 60 ml of *N*-methylmorpholine was added with 2.0 g of lithium aluminum hydride and the reaction mixture was heated at reflux for 68 hr. After cooling with ice, methanol was carefully added to the chilled reaction mixture and then it was acidified with dilute hydrochloric acid. The mixture was extracted with ether. The extract was washed with saturated aqueous sodium bicarbonate, water and dried over magnesium sulfate. After evaporation of the solvent, a residue was sublimed to yield 655 mg of alcohol (**34**) mp 188—191 °C (in sealed tube).

IR (KBr): 3400(s), 2950(s), 1305(w), 1280(w), 1160(w), 1130(w), 1095(m), 1065(m), 1025(m) and 810(w) cm^{-1}.

NMR ($CDCl_3$): δ 1.1—2.4 (m, 12H) and 3.9—4.1 (m, 1H).

Found: C, 77.72 H, 10.35%. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21%.

Tricyclo[4.3.0.0^{3,8}]nonan-2-one (10). A solution of 522 mg of alcohol (**34**) in 3 ml of dry methylene chloride was added to a mixture of 3.8 g of dry pyridine, 2.4 g of chromium trioxide and 58 ml of dry methylene chloride and then the reaction mixture was stirred for 15 min at room temperature. After working up as the usual manner, the solvent was evaporated and a residue was chromatographed on neutral alumina (Woelm, activity III). A fraction eluted with pentane gave a solid, which was sublimed to yield 329 mg of tricyclo-[4.3.0.0^{3,8}]nonan-2-one (**10**) mp 173—174 °C (in sealed tube). The IR, NMR and mass spectra were in complete agreement with those of authentic sample.[4)]

4-Methoxytricyclo[4.3.0.0^{3,8}]nonan-2-one (36). A solution of 340 mg of oxetane (**27a**) in 20 ml of methanol was added with 20 μl of 70% perchloric acid and the reaction mixture was kept for 24 hr at room temperature. After dilution with water, it was extracted with ether. The extract was washed with water and dried over magnesium sulfate. After evaporation of the solvent, a residue was chromatographed on silica gel and fractions eluted with pentane-ether (8 : 2 volume) gave 290 mg of an oily product, which was used for the next reaction. To a solution of 290 mg of the product in 5 ml of acetone was added excess of 8 N Jones' reagent with ice cooling. After stirring for 15 min at room temperature, it was diluted with water and extracted with pentane. The extract was washed with saturated aqueous sodium bicarbonate and water, and dried over magnesium sulfate. After evaporation of the solvent, a residue was chromatographed on silica gel and fractions eluted with pentane gave an oily product which was distilled to yield 218 mg of 4-methoxytricyclo[4.3.0.0^{3,8}]-nonan-2-one (**36**) bp 125 °C (bath temperature) at 18 Torr.

IR (neat film): 2950(s), 2880(m), 2820(m), 1750(s), 1365(m), 1240(m), 1210(m), 1170(m), 1105(s), 1085(m), 1075(m), 1065(m), 1025(m) and 930(m) cm^{-1}.

NMR (CCl_4): δ 1.6—1.8 (m, 4H), 1.9—2.2 (m, 2H), 2.3—2.6 (m, 4H), 3.24 (s, 3H) and 3.5—3.7 (m, 1H).

Found: C, 71.90; H, 8.36%. Calcd for $C_{10}H_{14}O_2$: C, 72.26; H, 8.49%.

The authors are grateful to Dr. H. Ogura for measurement of the CD spectra.

References

1) H. W. Whitlock, Jr., *J. Amer. Chem. Soc.*, **84**, 3412 (1962). J. Gauthier and P. Deslongchamps, *Can. J. Chem.*, **45**, 297 (1967). A Belanger, J. Poupart, and P. Deslongchamps, *Tetrahedron Lett.*, **1968** 2127. A. Belanger, Y. Lambert, and P. Deslongchamps, *Can. J. Chem.*, **47**, 795 (1969).

2) K. Adachi, K. Naemura, and M. Nakazaki, *Tetrahedron Lett.*, **1968**, 5467.

3) M. Tichý, *ibid.*, **1972**, 2001. M. Tichý and J. Sicher, *Collect. Czech. Chem. Commum.*, **37**, 3106 (1972).

4) K. Naemura and M. Nakazaki, This Bulletin, **46**, 888 (1973).

5) J. A. Berson, J. S. Walia, A. Remanick, S. Suzuki, P. Reynolds-Warnhoff, and D. Willner, *J. Amer. Chem. Soc.*, **83**, 3986 (1961).

6) Presented at the 28th Annual Meeting of the Chemical Society of Japan, Tokyo, April, 1973, Preprint, Vol. III, p. 1343.

7) Tichý reported that *endo*-2-carboxybicyclo[2.2.2]oct-5-ene of specific rotation +48.2° was 95% optically pure.

8) R. Srinivasan, *J. Amer. Chem. Soc.*, **82**, 775 (1960). N. C. Yang, M. Nussin, and D. R. Coulson, *Tetrahedron Lett.*, **1965**, 1925.

9) R. R. Sauers and J. A. Whittle, *J. Org. Chem.*, **34**, 3579 (1969). R. R. Sauers, W. Schinski, M. M. Mason, E. O'Hara, and Byrne, *ibid.*, **38**, 642 (1973).

10) K. Mislow and J. G. Berger, *J. Amer. Chem. Soc.*, **84**, 1956 (1962). J. A. Berson and D. Willner, *ibid.*, **84**, 675 (1962). J. A. Berson, R. T. Luibrand, N. G. Kundu, and D. G. Morris, *ibid.*, **93**, 3074 (1971).

11) D. A. Lightner and D. E. Jackman, *ibid.*, **96**, 1939 (1974).

12) G. Snatzke and F. Werner-Zamojska, *Tetrahedron Lett.*, **1972**, 4275.