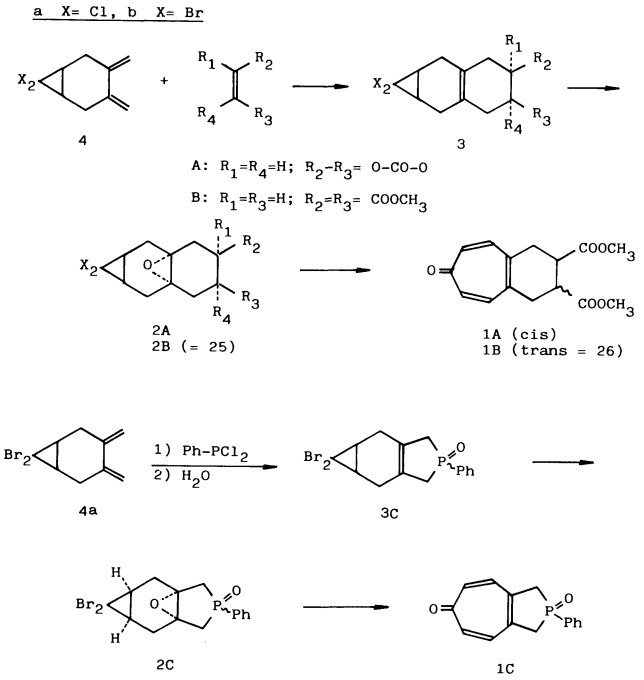
One Pot Synthesis of Substituted Tropones from 7,7-Dihalo-2,3-(or 3,4-)epoxybicyclo[4.1.0]heptane Derivatives

Masahiko KATO,* Shigeyuki YAMAMOTO, Shigeki NOMURA, and Toshio MIWA
Faculty of Science, Osaka City University, Sugimoto-3, Sumiyoshi-ku, Osaka 558
(Received June 7, 1989)

In order to obtain a scope and limitations of the reaction for newly developed tropone synthesis, some substituted 2,3- and 3,4-epoxy-7,7-dihalobicyclo[4.1.0]heptanes have been prepared and treated with several acids. We found that (1) the epoxy-carbons of starting materials should have, at least, one substituent which may stabilize the carbenium ion formed by cleavage of the epoxide with acid, (2) as halogens in the starting materials, bromine is superior to chlorine, (3) use of 20 molar equivalent of TFA to a substrate in chloroform at refluxing temperature or use of each 5 molar equivalent of TCA and water to a substrate in toluene at 100 °C is recommended.

Since Birch and Parham et al. reported independently the synthesis of substituted tropones, phenols, and alkyl phenyl ethers have been used as starting materials for the synthesis of many kinds of substituted tropones.[1,2] On the other hand, specifically functionallized tropones have been prepared via [4+2] or [4+3] cycloadditions of dienes to elaborated dienophiles in short pathway.[3]

In a short communication, we have described a novel synthetic procedure for 4,5-annelated tropones (**1**), in which the epoxides (**2**), obtained by oxidation of the adducts (**3**) of 7,7-dibromo-3,4-bis(methylene)bicyclo[4.1.0]heptane (**4**) to dienophiles, were treated with trifluoroacetic acid (TFA).[4] Fukazawa et al. have recently reported the synthesis of 1,11-*o*-benzeno[2]orthocyclo[2](4,5)troponophanes by similar treatment of elaborated epoxides.[5]



In order to extend our synthetic method of 4,5-annelated tropones to that of simply substituted tropones, several substrates, substituted 3,4-(or 2,3-)epoxy-7,7-dihalobicyclo[4.1.0]heptanes, were synthesized starting from either substituted 1,4-dihydrobenzenes, which are obtainable by Birch reduction of aromatic hydrocarbons, or 1,2-dihydrobenzene derivatives. These compounds are successively treated with dihalocarbene and *m*-chloroperbenzoic acid (mCPBA) or treated inversely with these reagents.

Using these substrates, we studied how the yields of tropones will be affected by the change of the reaction conditions and of the functionality of the starting materials.

Banwell et al. have reported a new synthetic method for halotropones by the allylic oxidation of 7,7-dihalobicyclo[4.1.0]hept-2(or 3-)enes, in which the oxidized allylic carbon is transformed to a carbonyl carbon and one of halogens of the starting materials remains unchanged.[6] On the other hand, one of the special features of our method is that the dihalomethylene carbon is transformed to the carbonyl carbon of tropones.

Results and Discussion

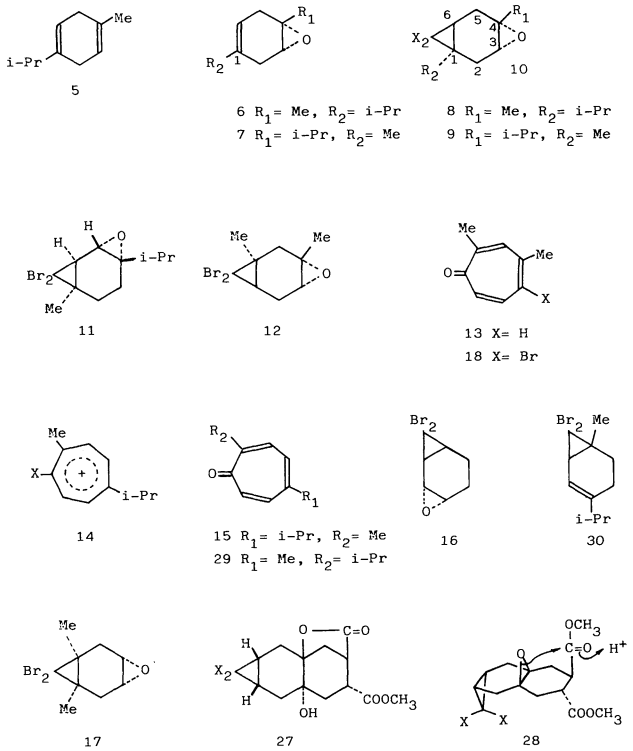
Epoxidation of γ-terpinene (**5**) gave two epoxides,[7] in which one with higher R_f-value was confirmed to be 4,5-epoxy-1-isopropyl-4-methyl-1-cyclohexene (**6**) and the other with lower one was to be 4,5-epoxy-4-isopropyl-1-methyl-1-cyclohexene (**7**) by the result of ^{1}H NMR spectra with use of Sievers' shift reagent.[7]

Dihalocarbene addition[8] to these epoxides **6** and **7** gave the corresponding dihalo-epoxy-bicyclo[4.1.0]-heptanes **8** and **9**, respectively. The stereochemistry of the epoxides to the dihalomethylene carbon was established to be the anti configuration (**10**) by the examination of the coupling constants of methine protons to the adjacent methylene protons.[9]

The anti stereochemistry (**11C**) of 7,7-dibromo-2,3-epoxy-3-isopropyl-6-methylbicyclo[4.1.0]heptane (**11**) was also established by the ^{1}H NMR spectra in the absence or presence of the Sievers' shift reagent (see Experimental).

Trifluoroacetic Acid as Reagent on 7,7-Dibromo-

a X= Cl, b X= Br



3,4-epoxy-1,3-dimethylbicyclo[4.1.0]heptane (12).[10] The application of the above mentioned synthetic method to that of simply substituted tropones was examined with dimethyl derivative **12**. Though the yields were rather low, use of 20 equivalent moles of TFA to the equivalent mole of the substrate in chloroform gave tropone **13** with the best result. Toluene is the next choice as solvent but polar ones such as acetonitrile were unsatisfactory (Table 1).

The Position of Epoxides and the Substitution Pattern in the Starting Epoxides. The position of epoxide in the bicyclo[4.1.0]heptane moiety is not limited to the 3,4-position. When 7,7-dibromo-2,3-epoxy-3-isopropyl-6-methylbicyclo[4.1.0]heptane (**11**) was dissolved in TFA at 0—5 °C, a dark red solution was obtained. Its spectral data show clearly the formation of bromotropylium cation (**14b**)[11] in satisfactory yield. Prolonged heating of **11** with TFA in chloroform gave a fair yield of 2-methyl-5-isopropyltropone (**15**). Whereas, 7,7-dibromo-2,3-epoxybicyclo[4.1.0]heptane (**16**) and 7,7-dibromo-1,6-dimethyl-3,4-epoxybicyclo[4.1.0]heptane (**17**)[10] gave no tropone derivatives at all under the same conditions (TFA–chloroform). In the former case, benzylidene dibromide was an isolable product (70%).

Comparison between Several Reagents Using 7,7-

Table 1. The Reaction Conditions and Yields for the Formation of 2,4-Dimethyltropone **13** from **12**

Entry	Reagent[a]/equiv	Solvent	Temperature/°C	Time/h	Yield/%[b]
1	TFA 20	Nil	72	16	19
2	TFA 10	$CHCl_3$	Reflux	21	27
3	TFA 20	$CHCl_3$	Reflux	20	32
4	TFA 20	CH_3CN	80	20	8.5
5	TFA 20	Benzene	80	20	14
6	TFA 20	Toluene	110	20	20
7	TFA 20[c]	$CHCl_3$	Reflux	24	18
8	PPA excess	Nil	80	20	—

a) TFA=trifluoroacetic acid; PPA=polyphosphoric acid. b) Isolated yields of **13**. c) Added silica gel in catalytic amount as a catalyst.

Table 2. The Yields of Tropone **15** Obtained from **9a** under Different Acid Conditions

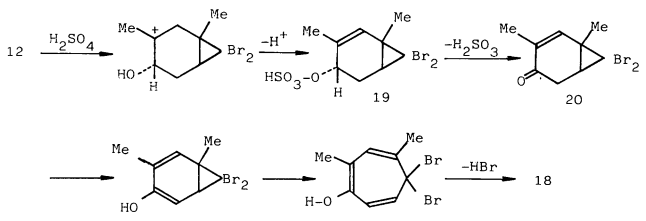
Entry	Reagent acid	pK_a	Acid used[a]	Solvent	Temperature/°C	Time/h	Yield/%[b]
1	$CH_2ClCOOH$[d]	2.9	5	Toluene	100	4	14.7
2	$CHCl_2COOH$[d]	1.3	5	Toluene	100	4	71
3	CCl_3COOH[d]	0.7	1	Toluene	100	4	18.7
4	CCl_3COOH[d]	0.7	3	Toluene	100	4	42.7
5	CCl_3COOH[d]	0.7	5	Toluene	r.t.[c]	23	48.1
6	CCl_3COOH[d]	0.7	5	Toluene	100	4	73.2
7	CF_3COOH	0.2	5	Toluene	70	4	43.8
8	98%HCOOH	3.7	20	Dioxane	Reflux	4	23.5
9	CCl_3COOH[d]	0.7	5	Dioxane	Reflux	4	20.5
10	*p*-TsOH	−7	5	Dioxane	Reflux	4	15.0
11	35% HCl	−7	5	Dioxane	Reflux	4	28.2
12	60% $HClO_4$	−10	5	Dioxane	Reflux	4	40.7
13	CH_3SO_3H	−7	5	CH_3CN	Reflux	22	18.3

a) Acid used is shown in equivalent moles per mole of **9a**. b) Isolated yields are shown. c) r.t.=room temperature. d) Equivalent molar amount of water to the anhydrous acid is present.

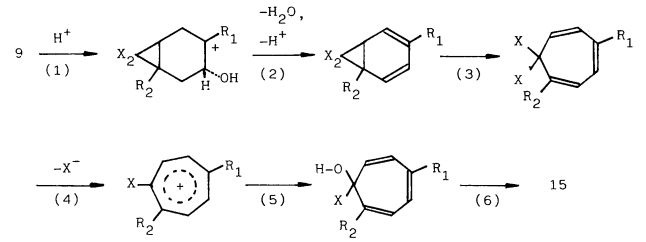
Dichloro-3,4-epoxy-1-methyl-4-isopropylbicyclo[4.1.0]-heptane (9a) as a Substrate. As a case of dichloro-derivatives as the starting materials, we studied the tropone synthesis from an epoxide (**9a**) using several acids as a reagent and obtained **15** in a variety of yields as shown in Table 2. Trichloroacetic acid (TCA) was selected as a standard reagent to determine the preferable amount of reagents to be used in the reaction (Entries 3—6). As a result, the use of five equimolar amounts of wet TCA (see the next section) to the starting epoxide in toluene at 100 °C gave the best result of all. The same acid in dioxane under similar conditions gave a lower yield of tropone **15** (Entry 9). With wet dichloroacetic acid (DCA), **9a** gave **15** in 71% yield, almost the same as that obtained with TCA. With wet monochloroacetic acid (MCA), it gave **15** as low as 15% yield. Treatment of **9a** with TFA in toluene at 70 °C gave a rather low yield of tropone but better than that with TFA in chloroform (Tables 3 and 4). Owing to their low solubilities in toluene, aqueous acids and sulfonic acids were used in dioxane, instead of toluene, but the results were unfavorable for obtaining **15**. Thus, we obtained reasonable results with wet DCA or TCA in toluene at 100 °C for 4 h.

It should be mentioned here that, when epoxide **12** was refluxed in dichloromethane in the presence of concd sulfuric acid, 5-bromo-2,4-dimethyltropone (**18**) was obtained in a fair yield. It is reasonable to assume that the tropone **18** may be formed via a conjugated enone **20** through oxidation of allylic sulfate **19** (Scheme 1). The formation of 4-chlorotropone from 7,7-dichloro-4-hydroxybicyclo[4.1.0]hept-2-ene by oxidation has recently been reported.[6]

The Effects of Water Present in the Reaction Mixture. We also studied the effects of water upon the yield of tropone because this reaction may contain dehydration and hydrolysis steps as shown in Scheme 2.



Scheme 1.



Scheme 2.

Curves A and B (Fig. 1) show the relationship between the yields of tropone **15** and the amounts of added water when the equivalent mole of **9a** and 5 equivalent moles of TCA are heated at 100 °C with appropriate amounts of water in toluene for 4 h. The difference between the curves A and B depends on the timing of the addition of water. From these curves, it is clear that the yield is very low (28%) under anhydrous conditions, and this is gradually improved as the increase in the amount of added water until it reached to the maximum (74%) at 5 equivalent moles to the starting material. The curve B showed constantly lower yields by ca. 15% than the curve A.

It has been shown that TCA exists in a bimolecular association form (**21**) in benzene (K_{dim}=25) at the concentration higher than 0.7 mol dm^{-3}.[12,13] Because it is assumed that the behavior of TCA in toluene will be almost the same as that in benzene, the low reactivity under the anhydrous conditions may be attributed to the lowered acid strength of TCA by bimolecular association. As the increase in the amount of water, the epoxide may be effectively protonated by the cooperative action of water and dimeric TCA to give tropone **15** in the improved yields (Scheme 3). Epoxides of cyclic olefins are generally cleaved mostly in the trans sense by carboxylic acids to give trans-diol monoacylates,[14] but, in the special

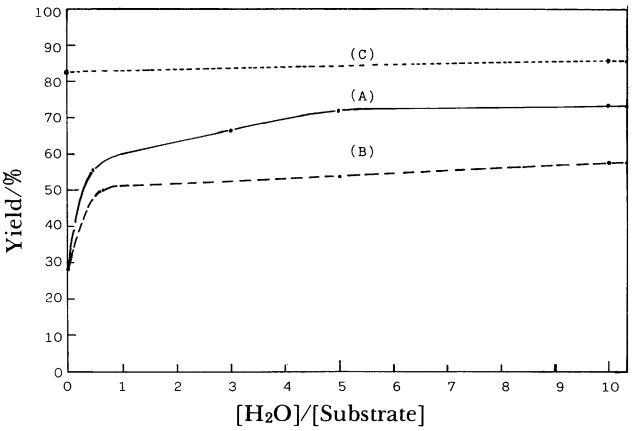
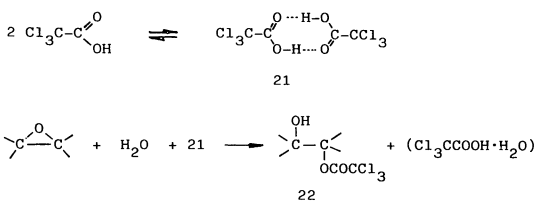


Fig. 1. The effect of added water on the yield of tropone **15**. Curve A and B: starting from **9a** and TCA as reagent. Timing of addition; A, at the start of reaction. B, after heating for 1 h. Curve C: starting from **9b** and TFA as reagent.



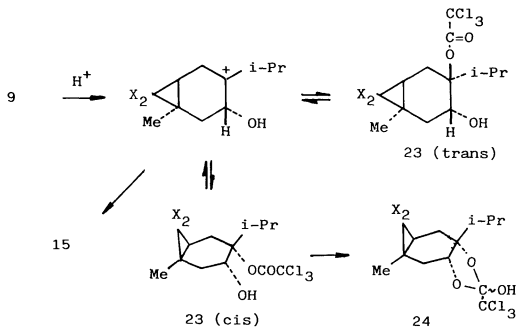
Scheme 3.

cases as *trans*- and *cis*-stilbene oxides, cis-opening becomes dominant and gives mainly one of the diastereomers of diol monotrichloroacetates by the reaction with anhydrous TCA.[12] In our case, the lowered yields by 15% obtained when water was added after initial heating of the epoxide with anhydrous TCA for 1 h suggest that the epoxide may open the ring in part to a cis-diol monotrichloroacetate (**23**), which forms an intramolecular cyclic semi-orthoester, dioxolanol (**24**).[15] This compound seems to be fairly stable to dehydration and the remaining trans-diol part in epoxide-opening could give the tropone **15**.

Using the bromide (**9b**) as a substrate and TFA as a reagent, the yields of **15** were not altered in the absence or presence of water (curve C) (Fig. 1).

This fact may be explained by the tendency of the existence of TFA as a monomer–solvent complex in dilute benzene solution or a monomer–dimer equilibrium in nonpolar aprotic solvents[16] and by the general tendency of opening epoxides to trans-diol monotrifluoroacetates, which can not form any stable dioxolanol rings (Scheme 4).

The Effects of the Species of Halogens in the Starting Material. Although 7,7-dibromo-3,4-epoxy-4-isopropyl-1-methylbicyclo[4.1.0]heptane (**9b**) gave high yield of **15** with either TFA or wet TCA, the corresponding dichloride (**9a**) gave a lower yield of **15** with TFA but gave a higher yield (73%) with wet TCA in toluene at 100 °C. The formal exchange of methyl and isopropyl groups in **9a** and **9b** forms **8a** and **8b**, respectively. With these compounds, similar results to those of **9a** and **9b** were obtained. Whereas, an epoxide of 1,1-dibromo-1a,2,3,4,5,6,7,7a-octahydro-1*H*-cyclopropa[*b*]naphthalene-4,5-*trans*-dicarboxylic ester (**25b**) gave a fair yield of tropone **26** with TFA, but the corresponding dichloro derivative (**25a**) gave **26** in very low yield making use of either acid (Table 3). When this chloride **25a** was treated with DCA–water (in the molar ratio of 1 : 1) in toluene at 100 °C for 24 h, it gave a crystalline lactone (**27a**) in 50.4%. This may be formed from **25a** through opening of the epoxide by protonation on carbonyl and lactonization (see **28**) followed by the attack of water to the carbonium ion formed. With use of TCA on **25a**, the same lactone **27a** was also characterized by ^{1}H NMR, which might resist the introduction of two double bonds in the norcarane moiety and, hence, might retard the formation of a tropone ring.



Scheme 4.

Conclusion

From the above described experiments, in order to obtain tropones in high yields, the structures of the starting epoxy-7,7-dihalobicyclo[4.1.0]heptene derivatives and the reaction conditions to be selected may be as follows: (1) The epoxy carbons of the starting materials should have, at least, one substituent which may stabilize carbenium cations. (2) In most cases, 7,7-dibromonorcarene epoxides gave better yields than the corresponding dichloro derivatives. (3) Epoxides in either position, 2,3 or 3,4, of the norcarane moiety gave reasonable yields of tropones. (4) It is worthwhile trying both TFA in chloroform and wet TCA (or DCA) in toluene as reagents. To use TCA (or DCA) in

Table 3. Variation in the Yields of Tropones Caused by the Changes of Halogen Species in the Starting Materials

S.M.[a]	Reagent acid	Acid used[b]	Solvent	Temperature	Reaction time/h	Product (Yield/%)[c]
8a	TFA[e]	20	$CHCl_3$	Reflux	24	**29** (26)
	TCA[e]	5[d]	Toluene	100 °C	4	**29** (32)
	TCA	5[d]	Toluene	100 °C	7	**29** (43)
8b	TFA	20	$CHCl_3$	Reflux	24	**29** (62)
	TCA	5[d]	Toluene	100 °C	4	**29** (74)
9a	TFA	20	$CHCl_3$	Reflux	24	**15** (29)
	TCA	5[d]	Toluene	100 °C	4	**15** (73)
9b	TFA	20	$CHCl_3$	Reflux	24	**15** (80)
	TCA	5[d]	Toluene	100 °C	4	**15** (83)
25a	TFA	20	$CHCl_3$	Reflux	24	**26** (6.3)
	TCA	5[d]	Toluene	100 °C	4	**26** (7.7)
	TCA	5[d]	Toluene	100 °C	24	**26** (6.6)
25b	TFA	20	$CHCl_3$	Reflux	24	**26** (42)

a) S.M.= starting material. b) Acid used is shown in equivalent moles per mole of S.M. c) Isolated yield. d) Five equivalent moles of water to S.M. is added. e) TFA=trifluoroacetic acid. TCA=trichloroacetic acid.

toluene, the water content in the reaction mixture is important. Use of each 5 molar amount of acid and water to one molar amount of the substrates at the start of the reaction is recommended. (5) Reactions in less polar aprotic solvents gave better yields than those in more polar aprotic ones.

Experimental

General Procedure. The NMR spectra were taken on JEOL Models GX 400 (^{1}H; 400 MHz, ^{13}C; 100 MHz), FX 100 (^{1}H; 100 MHz, ^{13}C; 25 MHz), or a Hitachi Model R-90H (^{1}H; 90 MHz) Ft-NMR spectrometer. Deuteriochloroform was used as solvent in every case unless otherwise specified. The IR spectra were recorded on a JASCO Model A-102 spectrometer and the UV on a Hitachi Recording spectrometer Model 323. The yields shown in Tables 1—3 and Fig. 1 are the isolated ones under the procedure described below.

7,7-Dibromo-3,4-bis(methylene)bicyclo[4.1.0]heptane (4b). To an ice-cooled solution of triphenylphosphine (9.32 g, 35.6 mmol) in chlorobenzene (50 mL) was added dropwise bromine (6.54 g, 40.9 mmol) in chlorobenzene (50 mL).[17] After stirring for 50 min, the reaction mixture was warmed to 120 °C and then *anti*-4,4-dibromo-9-oxatricyclo[5.3.0.0^{3,5}]-decane[18] (10.0 g, 33.9 mmol) was added in one portion to the mixture. The mixture was stirred at 120 °C for 2 h and then cooled. After dilution with chloroform, it was washed successively with 5% aqueous sodium hydrogencarbonate and saturated brine and then dried. After concentration, the product was separated with column chromatography (silica gel/benzene), and purified by recrystallization. *anti*-[3,4-*cis*-Bis(bromomethyl)]-7,7-dibromobicyclo[4.1.0]heptane. Colorless crystals, 13.4 g (95.6%). Mp 98.0—98.5 °C. IR (Nujol mull) ν_{max}: 1440, 1334, 1236, 1210, 1022, 860, 756, 708, 684 cm^{-1}. ^{1}H NMR (100 MHz) δ=3.20—3.50 (4H, m), 1.60—2.40 (8H, m). Found: C, 24.30; H, 2.68%. Calcd for $C_9H_{12}Br_4$: C, 24.58; H, 2.75%.

From *syn*-4,4-dibromo-9-oxatricyclo[5.3.0.0^{3,5}]decane (7.0 g, 23.6 mmol), the *syn*-[3,4-*cis*-bis(dibromomethyl)] derivative was obtained as an oil in 86% yield under the same conditions. IR (liq. film) ν_{max}: 1442, 1292, 1242, 1224, 1066, 750, 728, 684 cm^{-1}. ^{1}H NMR (100 MHz) δ=3.18—3.50 (4H, m), 1.20—2.42 (8H, m).

To an ice-cooled solution of the *anti*-(or *syn*-)[3,4-*cis*-bis(bromomethyl)] derivative (8.55 g, 19.4 mmol) dissolved in anhydrous tetrahydrofuran (THF) was added potassium *t*-butoxide (5.13 g, 45.7 mmol) in several portions and the mixture was stirred at room temperature for 4 h. Inorganic precipitates were filtered off and the filtrate was concentrated to dryness. The residue was taken in ether and insoluble materials were again filtered. The ether solution was washed successively with water and saturated brine and then dried. After evaporation of the solvent, the product was purified with chromatography (silica gel/hexane) to give bis(methylene) derivative (**4b**) as a colorless oil (40—50% yield). Because this diene is very susceptible to polymerization, it should be stored as a dilute hexane solution in a refrigerator and used directly after filtration from white insoluble polymeric material and evaporation of the solvent. **4b** ^{1}H NMR (100 MHz) δ=5.25 (2H, br s), 4.82 (2H, br s), 2.89 (2H, dd, J=18.5, 6.0 Hz), 1.80—2.20 (4H, m).

7,7-Dichloro-3,4-bis(methylene)bicyclo[4.1.0]heptane (4a). Diene **4a** was obtained from bis(*p*-toluenesulfonate) of 7,7-dichloro-3,4-bis(hydroxymethyl)bicyclo[4.1.0]heptane (8.4 g, 15.8 mmol) and potassium *t*-butoxide (4.42 g, 39.4 mmol) in anhydrous THF (110 mL) in 68% yield as a colorless oil. **4a** bp 43—45 °C (0.02 Torr; 1 Torr≈133.322 Pa) [lit, 50—60 °C (0.02 Torr)].[19] ^{1}H NMR (100 MHz) δ=5.25 (2H, s), 4.82 (2H, s), 2.77 (2H, dd, J=15.4, 8.8 Hz), 2.25 (2H, dd, J=15.4, 5.9 Hz), 1.8—1.9 (2H, m).

General Procedure for Epoxidation of Substituted Bicyclo-[4.1.0]heptenes. A solution of an olefin (2.0 mmol) and mCPBA (3.2 mmol) in dichloromethane (10 mL) was stirred at room temperature for 3.5 h to 20 h until no starting olefin had been detected by TLC. After filtration from colorless crystals and evaporation of the solvent under reduced pressure, the residue taken in ether was washed successively with 5% aq. sodium hydrogensulfite, water, 5% aq. sodium hydrogencarbonate, and saturated brine, and then dried. Evaporation of the solvent gave product(s), which was separated and purified with chromatography (silica gel/ethyl acetate–benzene (5:95 v/v)).

Dimethyl 1,1-Dibromo-1a,2,3,4,5,6,7,7a-octahydro-1*H*-cyclopropa[*b*]naphthalene-4,5-*trans*-dicarboxylate *anti*-Epoxide (25b). To a solution of dimethyl fumarate (584 mg, 4.05 mmol) in benzene (2 mL) and ether (1 mL) was added slowly a solution of diene **4b** (1.13 g, 4.05 mmol) in ether (1 mL) and the resulting solution was stirred at room temperature for 5 days. After evaporation of the solvents, the residue was purified with column chromatography (20 g of silica gel/benzene). The adduct (1.68 g, 98%), mp 154—155 °C. IR (Nujol mull) ν_{max}: 1726, 1442, 1326, 1200, 1178, 1002, 730, 720 cm^{-1}. ^{1}H NMR (90 MHz) δ=3.62 (6H, s), 2.65—2.90 (2H, m), 1.66—2.33 (10H, m). Found: C, 42.78; H, 4.29%. Calcd for $C_{15}H_{18}O_4Br_2$: C, 42.68; H, 4.30%.

To a solution of the adduct (235 mg, 0.56 mmol) in dichloromethane (2.5 mL) was added mCPBA (70% purity, 155 mg, 0.9 mmol) in one portion and the mixture was stirred for 20 h at room temperature. After usual workup, the product was purified with column chromatography (silica gel/benzene–ethyl acetate (9:1 v/v)). **25b** (220 mg, 91%), mp 103—105 °C (decomp). IR (Nujol mull) ν_{max}: 1726, 1440, 1330, 1200, 1168, 1000, 962, 728 cm^{-1}. ^{1}H NMR (90 MHz) δ=3.61 (6H, s), 1.50—3.30 (12H, m). ^{13}C NMR (100 MHz) δ=174.6 (s), 173.7 (s), 59.3 (s), 58.0 (s), 51.9 (q, may be two peaks in one), 40.5 (d), 39.2 (s), 38.5 (d), 31.8 (t), 31.4 (t), 27.3 (t), 26.3 (t), 24.1 (d). Found: C, 41.10; H, 4.13%. Calcd for $C_{15}H_{18}O_5Br_2$: C, 41.12; H, 4.14%.

A small amount of a diol was eluted afterward. Diol mp 169—170 °C. IR (Nujol mull) ν_{max}: 3520, 1722, 1710, 1446, 1298, 1200, 1054, 1020, 888, 714 cm^{-1}. ^{1}H NMR (90 MHz) δ=3.71 (3H, s), 3.66 (3H, s), 3.2—3.4 (1H, m), 2.75 (1H, br s), 1.4—2.5 (11H, m). ^{13}C NMR (100 MHz) δ=176.8 (s), 174.9 (s), 70.4 (s), 68.4 (s), 52.4 (q), 52.0 (q), 41.2 (s), 38.5 (d), 38.3 (d), 34.5 (t), 32.2 (t), 31.5 (t), 30,8 (t), 28.0 (d), 26.7 (d). Found: C, 38.91; H, 4.45%. Calcd for $C_{15}H_{20}O_6Br_2 \cdot (1/2\ H_2O)$: C, 38.73; H, 4.55%.

***anti*-Epoxide of Dimethyl 1,1-Dichloro-1a,2,3,4,5,6,7,7a-octahydro-1*H*-cyclopropa[*b*]naphthalene-4,5-*trans*-dicarboxylate (25a).** A solution of diene (**4a**) (328 mg, 1.73 mmol) and dimethyl fumarate (255 mg, 1.73 mmol) in benzene (20 mL) was refluxed for 67 h. After evaporation of the solvent, the residue was purified with column chromatography (silica gel/benzene–ethyl acetate (9:1 v/v)). An oily adduct was

obtained (323 mg, 55.4%). ^{1}H NMR (90 MHz) δ=3.64 (3H, s), 3.65 (3H, s), 2.69—2.93 (2H, br m), 1.9—2.55 (8H, br m), 1.78—1.90 (2H, b).

The adduct was stirred with mCPBA (80% purity , 232 mg, 1.07 mmol) in dichloromethane (4.8 mL) for 26 h at room temperature. Usual work-up gave colorless crytals (315 mg, 93%). **25a** mp 149—150 °C. IR ($CHCl_3$) ν_{max}: 3010, 2960, 2930, 1732, 1438, 1310, 1260, 1200, 1170, 1080, 1050, 1004, 978 cm^{-1}. ^{1}H NMR (90 MHz) δ=3.62 (6H, br s), 3.05—1.5 (12H, m). Found: C, 51.61; H, 5.21%. Calcd for $C_{15}H_{18}O_5Cl_2$: C, 51.59; H, 5.20%.

7,7-Dibromo-3,4-epoxy-1,3-dimethylbicyclo[4.1.0]heptane (12). 7,7-Dibromo-1,3-dimethylbicyclo[4.1.0]hept-3-ene[10] (135 mg, 0.48 mmol) and mCPBA (70%, 135 mg, 0.78 mmol) (stirring for 19 h) gave **8** as a colorless liquid (130 mg, 91%), bp 50—55 °C (0.6 Torr), which was a mixture (85:5) of the anti and syn isomers. The NMR spectra of the major product, *anti*-**12**: ^{1}H NMR (400 MHz) δ=2.87 (1H, br s), 2.50 (1H, dd, J=16.4, 9.1 Hz), 2.08 (2H, s), 1.94 (1H, br d, J=16.4 Hz), 1.41 (3H, s), 1.33 (1H, bd, J=9.1 Hz), 1.27 (3H, s). ^{13}C NMR (100 MHz) δ=56.8 (d, J=176.7 Hz), 56.0 (s), 48.4 (s), 33.5 (t, J=129.4 Hz), 29.5 (d, J=183.6 Hz), 27.9 (q, J=131.5 Hz), 25.0 (s), 22.7 (q, J=127.9 Hz), 22.4 (t, J=128.4 Hz). Found: C, 36.54; H, 4.12%. Calcd for $C_9H_{12}OBr_2$: C, 36.51; H, 4.09%.

7,7-Dibromo-2,3-epoxybicyclo[4.1.0]heptane (16). To a 1:1 mixture of 7,7-Dibromobicyclo[4.1.0]heptane and 2-heptene (680 mg) in carbon tetrachloride was added mCPBA (680 mg, 3.95 mmol) and the mixture was stirred overnight. After usual workup as above, a colorless oil (647 mg) was obtained. Separation with column chromatography on silica gel gave epoxide **16** as a pure material (256 mg, 71%). ^{13}C NMR (25 MHz) δ=49.2 (d, J=181 Hz) and 52.4 (d, J=177 Hz) (C_2, C_3), 31.4 (s, C_7), 28.8 (d, J=171 Hz) and 27.4 (d, J=171 Hz) (C_1, C_6), 19.6 (t, J=129 Hz) and 16.6 (t, J=132 Hz) (C_4, C_5).

***anti*-7,7-Dibromo-3,4-epoxy-1,6-dimethylbicyclo[4.1.0]heptane (17).** From 7,7-dibromo-1,6-dimethylbicyclo[4.1.0]-hept-3-ene[10] and mCPBA, epoxide **17** was obtained in 77.3% yield. Mp 91 °C, [lit, mp 91—94 °C].[11] ^{1}H NMR (90 MHz) δ=3.03 (2H, s), 2.18 (4H, s), 1.24 (6H, s). ^{13}C NMR (25 MHz) δ=56.6 (s), 51.3 (d), 30.1 (t), 26.2 (s), 22.8 (q).

Epoxidation of a Mixture of 4-Isopropyl-1-methyl- and 1-Isopropyl-4-methyl-7,7-dibromobicyclo[4.1.0]hept-3-ene. Oxidation of a mixture (292 mg, 0.99 mmol) described below with mCPBA in dichloromethane gave a mixture of the corresponding epoxides (158 mg, 51.5%), consisting mainly of 7,7-dibromo-3,4-epoxy-4-isopropyl-1-methylbicyclo[4.1.0]-heptane (**9b**), which was separated with column chromatography (see below).

7,7-Dibromo-2,3-epoxy-3-isopropyl-6-methylbicyclo[4.1.0]-heptane (11). 7,7-Dibromo-3-isopropyl-6-methylbicyclo[4.1.0]hept-2-ene **30** (1.0 g, 3.3 mmol) (see below) and mCPBA (80% purity, 1.04 g, 6.5 mmol) was stirred in dichloromethane (15 mL) at room temperature for 3.5 h. *anti*-**11** was obtained as a colorless oil (1.02 g, 95%) in almost pure state after purification with chromatography. *anti*-**11**, bp 80—85 °C (3 Torr, sublimative distillation). IR (liquid film) ν_{max}=2950, 2920 (sh), 2870, 1362, 1125, 1035, 972, 748, 720 cm^{-1}. ^{1}H NMR (400 MHz) δ=3.082 (s, H_2), 1.800 (s, H_1), 1.905 (ddd, J=14.4, 5.3, 6.3 Hz) and 1.810 (ddd, J=14.4, 5.8, 9.5 Hz) (H_{4a} and H_{4b}), 1.415 (ddd, J=14.7, 6.3, 9.3 Hz) and 2.030 (ddd, J=14.7, 5.3, 5.8 Hz) (H_{5a} and H_{5b}), 1.378 (s, 6-Me), 1.519 (sept, 1H), 0.980 (d, J=6.8 Hz) and 0.941 (d, J=7.1 Hz) (2Me). ^{13}C NMR (100 MHz) δ=34.5 (d, 166 Hz, C_1), 55.8 (d, 178, C_2), 64.3 (s, C_3), 22.4 (t, 128, C_4), 27.5 (t, 125, C_5), 28.7 (s, C_6), 25.8 (q, 126, 6-Me), 42.6 (s, C_7), 35.1 (d, 131, **C**HMe$_2$), 17.8 (q) and 17.4 (q) (CH**Me**$_2$). MS m/z (%): 326 (M+4, 0.3), 324 (M+2, 0.6), 322 (M^+, 0.3), 311 (1.7), 309 (3.7), 307 (2.0, M—Me), 228 (41), 226 (85), 224 [M—(*i*-Pr), 44], 71 (100). The effect of Sievers' shift reagent on the ^{1}H NMR spectrum of *anti*-**11** (deshielding shifts calculated against H_2 shift as 100): H_1 (32.5), 6-Me (6.9), 3-C**H**Me$_2$ (80.5), 3-CH**Me**$_2$ (30.0).

Epoxidation of 1-Isopropyl-4-methyl-1,4-cyclohexadiene (5). Treatment of γ-terpinene (1.34 g, 9.64 mmol) with mCPBA (70% purity, 2.39 g, 9.68 mmol) in dichloromethane (50 mL) for 22.5 h at room temperature gave a mixture of epoxides **6** and **7** as a colorless liquid (1.61 g), which was separated with column chromatography (silica gel/hexane–ether (5:1 v/v)) to give pure samples of 4,5-epoxy-4-isopropyl-1-methyl-1-cyclohexene **7** (380 mg, 25.4%; R_f (hexane–ether 10:1 v/v)=0.26) and 4,5-epoxy-1-isopropyl-4-methyl-1-cyclohexene **6** (570 mg, 38.1%; R_f=0.20). **6** ^{1}H and ^{13}C NMR: see Tables 4 and 5. MS m/z (%): 153 (6.8), 152 (M^+, 56), 137 (44), 134 (35.5), 123 (25.6), 119 (62), 109 (100). **7** ^{1}H and ^{13}C NMR: see Tables 4 and 5. MS m/z (%): 153 (2.1), 152 (M^+, 17), 139 (11), 137 (7.0), 134 (24), 119 (36), 109 (35.5), 71 (100).

Dibromocarbene Addition to 1-Isopropyl-4-methyl-1,4-cyclohexa-1,4-diene (5): General Procedure (Method A).[20] To an ice-cooled solution of diene **5** (197 mg, 1.42 mmol) in benzene (13 mL) was added, in one portion, potassium *t*-butoxide (247 mg, 2.2 mmol) and *t*-butyl alcohol (3.2 mL). To this solution was added a solution of bromoform (0.35 mL, 4.0 mmol) in benzene (1.6 mL) in a period of 5 min at 0—5 °C, and stirring was continued for 7 h at the temperature. The mixture was then diluted with benzene and the organic layer was separated, and washed with water and saturated brine. After drying and concentration, the residual oil was purified with column chromatography (silica gel/hexane) to give a mixture of two carbene-adducts (292 mg, 67%), 7,7-dibromo-4-isopropyl-1-methylbicyclo-[4.1.0]hept-3-ene and 7,7-dibromo-1-isopropyl-4-methylbicyclo[4.1.0]hept-3-ene. This mixture was used for epoxidation without further purification (see above).

Dibromocarbene Addition to 1-Isopropyl-4,5-epoxy-4-methyl-1-cyclohexene (6): General Procedure (Method B).[8,19] To a solution of epoxide **6** (293 mg, 1.93 mmol), benzyltriethylammonium chloride (4.4 mg) in bromoform (0.25 mL, 2.86 mmol) was added aq. sodium hydroxide (880 mg, 22 mmol/1.05 mL H_2O) under ice-cooling and the mixture was stirred at room temperature for 23 h. The resulting brown viscus mixture was diluted with water and ether and then filtered through hyflosupercel. The filtrate was extracted with ether and the combined ether extracts were washed with water and saturated brine, and then dried. Concentration gave a yellow liquid (510 mg) which was purified with column chromatography (silica gel/benzene) to give a colorless oil, bp 85 °C (3 Torr, sublimative distillation). **8b** (237 mg, 38%). ^{1}H and ^{13}C NMR: see Tables 4 and 5. MS m/z (%): 326 (M+4, 0.4), 324 (M+2, 1.1), 322 (M^+, 0.8), 311 (5.1), 309 (11.4), 308 (2.9), 307 (7.9), 306 (3.9), 304 (2.0), 233 (44.8), 231 (89.5), 229 (48).

7,7-Dibromo-3,4-epoxy-4-isopropyl-1-methylbicyclo[4.1.0]-

Table 4. ^{1}H NMR Data of Compounds, **6**, **7**, **8a**, **8b**, **9a**, and **9b** (400 MHz in $CDCl_3$)[a]

	H_3[b]	H_{2a}	H_{2b}	H_6	H_{5a}	H_{5b}	Me	$C\underline{H}Me_2$	$CH\underline{Me}_2$
6	3.123	2.25—2.6[m]		5.162	2.25—2.6[m]		1.37[s]	2.15[sept]	0.993[d]
									0.982[d]
									(6.8)
7	3.071[s]	2.14—2.23[m]		5.193[s]	2.14—2.23[m]		1.64[s]	1.556[sept]	1.006[d]
									0.970[d]
									(6.8)
8a	2.89[bs]	1.94[dd]	2.22[d]	1.21[dd]	1.85[dd]	2.23[dd]	1.27[s]	1.603[sept]	1.02[d]
(X=Cl)		(16.3)	(16.3)	(9.5)	(16.1)	(16.1)			0.94[d]
		(2.7)		(1.5)	(1.5)	(9.3)			(6.8)
8b	2.887[bs]	1.928[dd]	2.310[dd]	1.327[dd]	1.782[dd]	2.306[dd]	1.28[s]	1.632[sept]	1.035[d]
(X=Br)		(16.7)	(16.7)	(9.3)	(15.9)	(15.9)			0.950[d]
		(2.8)	(1.5)	(1.2)	(1.2)	(9.3)			(6.8)
9a	2.871[bs]	2.21[dd]	2.14[dd]	1.298[dd]	1.93[dd]	2.23[dd]	1.375[s]	1.500[sept]	0.991[d]
(X=Cl)		(16.0)	(16.0)	(9.2)	(16.3)	(16.3)			0.918[d]
		(1.9)	(2.0)	(1.7)	(1.7)	(9.2)			(6.8)
9b	2.87[bt]	2.22[dd]	2.26[dd]	1.43[dd]	1.85[dd]	2.32[dd]	1.42[s]	1.52[sept]	0.99[d]
(X=Br)		(16.4)	(16.4)	(9.6)	(16.1)	(16.1)			0.97[d]
		(2.4)	(2.0)	(1.6)	(1.7)	(9.6)			(7.0)

a) The chemical shift of each proton is shown in ppm without parentheses and the coupling constants are shown in Hz in parentheses. b) In this table, for the convenience of comparison with compounds **8** and **9**, **6** and **7** are numbered as counterclockwise starting from C_1 in the structural formula **6** and **7**, which are different from the IUPAC nomenclature.

Table 5. ^{13}C NMR Data of Compounds; **6**, **7**, **8a**, **8b**, **9a**, and **9b**. (100 MHz in $CDCl_3$)[a,b]

Compound	C_1(s)	C_2(t) or C_5	C_3(d)	C_4(s)	C_5(t) or C_2	C_6(d)	C_7(s)	Me(q)	$C\underline{H}Me_2$ (d)	$CH\underline{Me}_2$ (q)
6	137.8	27.2	56.5	51.9	30.6	113.9	—	23.0	34.6	21.4
										21.1
7	128.4	24.7	57.7	62.6	30.9	116.5	—	23.2	34.8	18.6
										17.5
8a	31.6	19.8	57.5	54.8	23.7	29.6	71.8	22.7	35.6	23.7
		(123)	(170)		(129)	(164)		(127)	(129)	19.8
8b	31.1	21.9	57.7	55.0	26.1	30.9	49.2	22.7	37.9	19.1
		(123)	(176)		(129)	(163)		(126)	(125)	17.4
9a	24.0	18.3	56.5	61.0	27.6	29.5	72.1	25.3	34.9	18.3
		(126)	(175)		(128)	(163)		(129)	(128)	17.5
9b	23.8	20.8	56.7	60.9	29.7	30.9	49.0	28.1	35.0	18.5
			(178)			(167)		(131)	(128)	17.6

a) Chemical shifts are shown in ppm without parentheses and coupling constants are shown in Hz in parentheses ($J_{^1H-^{13}C}$). They are obtained by the NOE measurements of ^{13}C NMR spectra. s=singlet, d=doublet, t=triplet, q=quartet. b) In this table, for the convenience of comparison with compounds **8** and **9**, **6** and **7** are numbered as counterclockwise starting from C_1 in the structural formula **6** and **7**, which are different from the IUPAC nomenclature.

heptane (9b) (Method A). From epoxide **7** (505 mg, 3.3 mmol), potassium *t*-butoxide (1.01 g, 9.3 mmol), and bromoform (0.80 mL, 9.2 mmol) in benzene (45 mL), a colorless oil **9b** (305 mg, 28.2%) was obtained along with unchanged epoxide **7** (240 mg, 48%). **9b**, bp 85 °C (3 Torr, sublimative distillation). ^{1}H and ^{13}C NMR: see Tables 4 and 5. MS *m/z* (%): 326 (M+4, 0.2), 324 (M+2, 0.36), 322 (M^+, 0.19), 311 (35), 309 (73), 307 (40), 228 (48), 226 (100), 224 (51), 71 (100).

Dibromocarbene Addition to 1-Isopropyl-4-methyl-1,3-cyclohexadiene (Method B). α-Terpinene (13.6 g, 0.1 mol), benzyl triethylammonium chloride (213 mg, 1 mmol), bromoform (25.3 g, 0.1 mol), and aq. sodium hydroxide (30.8 g, 0.77 mol/H_2O 60 mL) at room temperature for 5 h gave a yellow liquid which was concentrated under reduced pressure to eliminate recovered bromoform and the diene (bp 50—51 °C/10 Torr, 5.12 g). The residue (11 g) was purified with column chromatography (silica gel 250 g/hexane) giving a colorless oil, 7,7-dibromo-3-isopropyl-6-methylbicyclo[4.1.0]hept-2-ene (**30**) (7.7 g, 40% to consumed diene), which was used without further purification (see above).

7,7-Dichloro-3,4-epoxy-1-isopropyl-4-methylbicyclo[4.1.0]-heptane (8a): General Procedure for Dichlorocarbene Addition (Method C).[21] To an ice-cooled solution of a mixture of epoxides (**6** contaminated with **7**) (5.0 g, 32.8 mmol) and potassium *t*-butoxide (20.5 g, 164 mmol) in *t*-butyl alcohol (185 mL) and anhydrous benzene (440 mL) was added dropwise purified chloroform (13.1 mL, 164 mmol) in a period of 10 min and the solution was stirred at the temperature for 2 h and then at room temperature for 17 h. Usual workup (see above method A) gave a yellow liquid (5.92 g), which was separated with column chromatography (silica gel/hexane–ether (10:1 v/v)). From the initial eluate, **8a** (0.29 g) was obtained as a pure material and, from the

latter one, **9a** (1.27 g) was obtained along with unchanged epoxides (3.2 g). **8a**, bp 80—90 °C (4 Torr, sublimative distillation). ^{1}H and ^{13}C NMR: see Tables 4 and 5. Found: C, 55.95; H, 6.81%. Calcd for $C_{11}H_{16}OCl_2$: C, 56.18; H, 6.86%.

7,7-Dichloro-3,4-epoxy-4-isopropyl-1-methylbicyclo[4.1.0]-heptane (9a). Epoxide **7** (236 mg, 1.56 mmol), potassium *t*-butoxide (876 mg, 7.80 mmol) and *t*-butyl alcohol (8.8 mL) in benzene (21 mL) was treated with purified chloroform (0.64 mL, 7.92 mmol) as described above (Method C). Usual workup and purification gave **9a** as a pure material (190 mg, 52%). bp 80—90 °C (4 Torr, sublimative distillation). IR (liq. film) ν_{max}: 1460, 1423, 1380, 1362, 1050, 1010, 970, 930, 880, 822, 810 cm^{-1}. ^{1}H and ^{13}C NMR: see Tables 4 and 5. MS *m/z* (%): 238 (M+4, 0.02), 236 (M+2, 0.12), 234 (M^+, 0.25), 223 (1.1), 221 (6.7), 219 (10.9), 195 (10.2), 193 (65.8), 191 (100). Found: C, 56.10; H, 6.90%. Calcd for $C_{11}H_{16}OCl_2$: C, 56.18; H, 6.86%.

Dichloride 9a. General Procedure for Dichlorocarbene Addition (Method D).[8] To an ice-cooled solution of epoxide **7** (330 mg, 2.13 mmol) in chloroform (0.52 mL, 6.5 mmol) containing benzyltriethylammonium chloride (10 mg), and a drop of ethanol was added dropwise aq. sodium hydroxide (1.04 g/1.4 mL H_2O). The mixture was stirred at below 10 °C for 2 h and allowed to stand at room temperature. Usual workup as described in method B gave a pale yellow oil (394 mg), which was purified with column chromatography (silica gel/benzene) to give a colorless oil **9a** (261 mg, 51.2%).

Characterization of 2-Bromo-5-isopropyl-1-methyltropylium Cation (14b). To a solution of *anti*-epoxide **11** (27.2 mg) dissolved in deuteriochloroform (0.35 mL) was added TFA (0.05 mL) in an NMR tube under ice-cooling to give a colorless solution. After standing 3 min at room temperature, an orange red color developed and a dark red solution was obtained after 10 min. ^{1}H NMR (100 MHz) δ=9.34 (1H, d, J=11 Hz), 9.02 (1H, d, J=11 Hz), 8.82 (1H, dd, J=11, 2 Hz), 8.60 (1H, dd, J=11, 2 Hz), 3.49 (1H, sept, J=7 Hz), 3.15 (3H, s), 1.49 (6H, d, J=7 Hz). ^{13}C NMR (25 MHz) δ=168.9 (s), 158.8 (s), 157.2 (s), 156.4 (d), 152.7 (d), 150.6 (d), 148.6 (d), 40.9 (d), 33.0 (q), 23.5 (q). In order to take UV spectrum, a sample of **11** (8.9 mg) dissolved in cold TFA (0.25 mL) was warmed at room temperature for 5 min. Then the mixture was diluted to 10 mL with concd sulfuric acid. This solution (0.2 mL) was further diluted with concd sulfuric acid to 10 mL. UV λ_{max} (log ε): 210 (end absorp., 4.03), 253.5 (4.20), 329 (3.82), 424 nm (3.17).

General Procedure for Tropone Synthesis with Trifluoroacetic Acid (Method E): 2,4-Dimethyltropone (13). To epoxide **12** (259 mg, 0.88 mmol) dissolved in chloroform (5.4 mL) was added TFA (1.35 mL, 17.5 mmol), and the mixture was stirred for 19 h at 75 °C (bath temperature). After concentration to dryness, the residue taken in dichloromethane was washed successively with water, 5% aq. sodium hydrogencarbonate, and brine, and then dried. After concentration, the product was purified with chromatography (silica gel/benzene–ethyl acetate (9:1 v/v)). **13** bp 90—100 °C (30 Torr, sublimative distillation). A pale yellow oil. IR (liq. film) ν_{max}: 1632, 1604, 1574, 1526, 1372, 1246, 1036, 824 cm^{-1}. ^{1}H NMR (400 MHz) δ=7.27 (1H, s), 7.02 (1H, dd, J=8.1, 12.0 Hz), 6.96 (1H, br d, J=12.0 Hz), 6.79 (1H, br d, J=8.1 Hz), 2.34 (3H, s), 2.28 (3H, s). ^{13}C NMR (100 MHz) δ=186.6 (s), 150.6 (s), 144.6 (s), 138.8 (d), 137.2 (d), 135.7 (d), 130.7 (d), 26.7 (q), 23.0 (q). UV (95% C_2H_5OH) λ_{max}=234, 321 nm. MS *m/z* (%): 134 (M^+, 75), 106 (30), 105 (23), 91 (100), 77 (16), 65 (14).

5-Isopropyl-2-methyltropone (15) from 11 (Method E). To an ice-cooled solution of epoxide **11** (262 mg, 0.82 mmol) in chloroform (4.0 mL) was added dropwise TFA (0.64 mL, 8.3 mmol), and the solution was stirred at the temperature for 30 min and the resulting dark red solution was heated at 75 °C for 16 h. Workup and purification as usual gave tropone **15** (58.2 mg, 43.2%) as a pale yellow oil. **15**, bp 100—110 °C (30 Torr, sublimative distillation). IR (liq. film) ν_{max}: 1628, 1578, 1526, 1460, 1394, 1370, 1168, 862 cm^{-1}. ^{1}H NMR (400 MHz) δ=7.33 (1H, d, J=11.3), 7.08—7.07 (2H, two peaks), 6.95 (1H, d, 11.3), 2.77 (1H, sept, J=6.8 Hz), 2.26 (3H, s), 1.22 (6H, d, J=6.8 Hz). ^{13}C NMR (100 MHz) δ=186.9 (s), 153.3 (s), 149.8 (s), 139.5 (d), 136.9 (d), 135.8 (d), 129.6 (d), 37.4 (d), 23.0 (q), 22.4 (q). MS *m/z* (%): 162 (M^+, 44), 147 (4), 134 (8), 120 (12), 119 (100), 117 (8), 91 (15). UV (95% C_2H_5OH) λ_{max}: 216 (sh), 235, 321 nm. Found: C, 79.62; H, 8.76%. Calcd for $C_{11}H_{14}O \cdot (1/5\ H_2O)$: C, 79.67; H, 8.75%.

5-Isopropyl-2-methyltropone (15) from 9b. Similar treatment (method E) of dibromide **9b** (246 mg, 0.78 mmol) in chloroform (4.8 mL) and water (0.138 mL) with TFA (1.2 mL, 15 mmol) for 24 h at the refluxing temperature gave tropone **15** (104 mg, 85%), which was identical with a sample obtained from **11**.

General Procedure for Tropone Synthesis with Trichloroacetic Acid (Method F): 5-Isopropyl-2-methyltropone 15 from 11. A solution of trichloroacetic acid (817 mg, 5 mmol) in toluene (7 mL) was refluxed under separation of water with a Dean–Stark apparatus for 2 h. To this solution was added water (90 mg, 5 mmol) and **11** (324 mg, 1.0 mmol) dissolved in toluene (2.0 mL). The resulting dark red solution was warmed at 100 °C for 4 h. The solution was diluted with ether and washed several times with 5% aq sodium hydrogencarbonate until this reacts alkaline to litmus paper. The ethereal solution was washed with water then saturated brine and dried. Evaporation of the solvent remained a red liquid (235 mg), the ^{1}H NMR spectrum of which showed it contained mainly tropone **15** with small amount of toluene. Column chromatographic separation on silica gel (10 g) gave a pure sample of **15** (93 mg), which was distilled with a sublimation apparatus at 100—110 °C/30 Torr giving a pale yellow oil (82 mg, 50%).

5-Isopropyl-2-methyltropone (15) from 9a (Method F). TCA (896 mg, 5.44 mmol) in toluene (8.0 mL) was refluxed under separation of water with a Dean–Stark apparatus for 2 h. To this solution was added a solution of epoxide **9a** (244 mg, 1.12 mmol) in toluene (2.0 mL) and water (0.10 mL, 5.4 mmol). The mixture was stirred for 4 h at 100 °C. Usual workup gave a pure sample of **15** (133 mg, 74%).

Dimethyl 7-Oxo-1,2,3,4-tetrahydro-7*H*-benzocycloheptene-*trans*-2,3-dicarboxylate (26). To epoxide **25b** (208 mg, 0.48 mmol) dissolved in chloroform (3.0 mL) was added TFA (0.74 mL, 9.6 mmol) under cooling and the resulting solution was stirred at 75 °C for 22 h (Method E). Usual workup gave a crude product, which was purified with chromatography (silica gel/benzene–ethyl acetate–methanol (5:4:1 v/v)). **26** (54.8 mg, 42%) mp 124—125 °C. IR (Nujol mull) ν_{max}: 1742, 1714 (sh), 1638, 1578, 1436, 1244, 1196 cm^{-1}. UV (95% EtOH) λ_{max} (log ε): 228 (4.40), 231.5 (4.40), 318 (4.11) nm. ^{1}H NMR (90 MHz) δ=6.80 (4H, s; protons on the

α- and β-carbons to the tropone carbonyl show almost identical chemical shift), 3.68 (6H, s), 2.80—3.13 (6H, m). ^{13}C NMR (25 MHz) δ=186.9 (s), 173.7 (s), 140.0 (d), 139.5 (s), 138.8 (d), 52.4 (q), 40.7 (d), 34.8 (t). Found: C, 65.15; H, 5.84%. Calcd for $C_{15}H_{16}O_5$: C, 65.21; H, 5.84%.

Isolation of Lactone 27a from Dichloro-epoxide 25a. Epoxide **25a** (113 mg, 0.32 mmol), dichloroacetic acid (0.14 mL, 1.68 mmol), and water (0.030 mL, 1.66 mmol) dissolved in toluene (2.0 mL) was stirred at 100 °C for 24 h. The mixture was diluted with ether and washed successively with 5% aq. sodium hydrogencarbonate, water and saturated brine, and then dried. After concentration, the residue was purified with chromatography (silica gel/benzene–ethyl acetate (9:1 v/v)). **27a** (54.8 mg, 50.5%) mp 182.5—184 °C. IR ($CHCl_3$) ν_{max}: 3450, 1780, 1720, 1440, 1358, 1182, 1065, 1042, 1000, 920, 902, 810 cm^{-1}. ^{1}H NMR (400 MHz) δ=3.76 (3H, s), 3.71 (1H, s), 3.07 (1H, ddd, *J*=5.4, 3.9, 1.2 Hz), 3.01 (1H, ddd, *J*=6.7, 3.9, 1.2 Hz), 2.47 (1H, d, *J*=15.6 Hz), 2.41 (1H, d, *J*=12.7 Hz), 2.20 (1H, dd, *J*=16.6, 9.5 Hz), 2.15—2.22 (1H, m), 2.11 (1H, dd, *J*=16.6, 2.4 Hz), 1.97—2.01 (1H, m), 1.95 (1H, dt, *J*=9.3, 2.1 Hz), 1.82—1.88 (2H, m), 1.79 (1H, dt, *J*=5.6, 3.2 Hz). ^{13}C NMR (100 MHz) δ=85.8 (s), 67.0 (s), 66.4 (s), 53.0 (q), 42.5 (d), 39.6 (d), 37.7 (t), 33.8 (t), 32.3 (t), 25.7 (d), 25.6 (t), 24.7 (d). MS *m/z* (%): 336 (3.8), 334 (6.0), 272 (48), 270 (71), 258 (66), 256 (100), 213 (45), 212 (66), 211 (64), 210 (78), 175 (24). Found: C, 50.03; H, 4.82%. Calcd for $C_{14}H_{16}C_{12}O_5$: C, 50.17; H, 4.81%.

Ring Opening of 7,7-Dibromo-3,4-epoxy-1-isopropyl-4-methylbicyclo[4.1.0]heptane (8b): 2-Isopropyl-5-methyltropone (29). Treatment of epoxide **8b** (176 mg, 0.54 mmol) with TCA (453 mg, 2.73 mmol) and water (0.048 mL, 2.7 mmol) under the conditions described in method B gave tropone **29** (65.4 mg, 74%) after purification. A pale yellow oil, bp 110 °C (30 Torr, sublimative distillation). IR ($CHCl_3$) ν_{max}: 1620, 1565, 1520, 1460, 1200, 1156, 1020, 840 cm^{-1}. ^{1}H NMR (400 MHz) δ=7.15 (1H, d, *J*=11.5 Hz), 6.93 (2H, two peaks), 6.76 (1H, d, *J*=11.5 Hz), 3.38 (1H, sept, *J*=6.8 Hz), 2.27 (3H, d, *J*=1.3 Hz), 1.13 (6H, d, *J*=6.8 Hz). Found: C, 81.11; H, 8.71%. Calcd for $C_{11}H_{14}O$: C, 81.44; H, 8.70%.

Ring Opening of 7,7-Dichloro-3,4-epoxy-1-isopropyl-4-methylbicyclo[4.1.0]heptane (8a): 2-Isopropyl-5-methyltropone (29). Treatment of epoxide **8a** (212 mg, 0.93 mmol) with TCA (744 mg, 4.52 mmol) and water (0.08 mL, 4.4 mmol) under the conditions described in method B gave tropone **29** (62.4 mg, 43%).

Ring Opening Reaction of 2,3-Epoxy-7,7-dibromobicyclo-[4.1.0]heptane (16). To an ice-cooled solution of epoxide **16** (189 mg, 0.70 mmol) in chloroform (4.0 mL) was added TFA (0.54 mL, 7.0 mmol). The resulting solution was stirred at room temperature for 1.5 h and then at the refluxing for 19 h (Method E). Usual workup and purification gave benzylidene dibromide as a colorless oil (122 mg, 70%), which showed the identical IR and NMR spectra with those of an authentic sample. IR (liq. film) ν_{max}: 1496, 1454, 1228, 1146, 824, 696 cm^{-1}. ^{1}H NMR (100 MHz) δ=7.4—7.7 (2H, m), 7.2—7.4 (3H, m), 6.66 (1H, s).

Ring Opening of 7,7-Dibromo-3,4-epoxy-1,3-dimethylbicyclo[4.1.0]heptane (12) with Sulfuric Acid: Formation of 5-Bromo-2,4-dimethyltropone (18). To epoxide **12** (153 mg, 0.52 mmol) dissolved in dichloromethane (3.0 mL) was added concd sulfuric acid (0.5 mL) and the mixture was stirred and refluxed for 22 h. The mixture was poured onto ice and extracted with dichloromethane. The organic layer was washed with water and saturated brine and then dried. After concentration, the residue was purified with column chromatography (silica gel/benzene–ethyl acetate (9:1 v/v)). **18** colorless crystals, mp 90—91 °C. IR (Nujol mull) ν_{max}: 1616, 1576, 1502, 1370, 1276, 1230, 828 cm^{-1}. UV λ_{max}: 236.5, 326 nm. ^{1}H NMR (100 MHz) δ=7.40 (1H, dd, *J*=12.9, 1.0 Hz), 7.37 (1H, s), 6.96 (1H, d, *J*=12.9 Hz), 2.47 (3H, s), 2.21 (3H, d, *J*=1.0 Hz). ^{13}C NMR (25 MHz) δ=185.5 (s), 149 (s), 143 (s), 141 (d), 138 (d), 135.5 (d), 128.5 (s), 30.2 (q), 23 (q). Found: C, 50.79; H, 4.27%. Calcd for C_9H_9OBr: C, 50.73; H, 4.26%.

The authors wish to thank Mr. Jun-ichi Goda and Mr. Tetsuya Shimada of our University for the elementary analyses and measurements of mass spectra.

References

1) F. Pietra, *Chem. Revs.*, **73**, 293 (1973) and references cited therein.

2) a) M. Sato, S. Ebine, and J. Tsunetsugu, *J. Chem. Soc., Chem. Commun.*, **1974**, 846; b) T. Hiyama, Y. Ozaki, and H. Nozaki, *Tetrahedron*, **30**, 2661 (1974).

3) a) J. Ciabattoni and G. A. Berchtold, *J. Am. Chem. Soc.*, **87**, 1404 (1965); *J. Org. Chem.*, **31**, 1336 (1966); b) M. Oda, R. Breslow, and J. Pecoraro, *Tetrahedron Lett.*, **1972**, 4419; c) R. Noyori, S. Makino, and H. Takaya, *J. Am. Chem. Soc.*, **93**, 1272 (1971); d) D. L. Boger and C. E. Brotherton, *ibid.*, **108**, 6713 (1986).

4) M. Kato, S. Nomura, H. Kobayashi, and T. Miwa, *Chem. Lett.*, **1986**, 281.

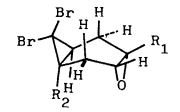
5) Y. Fukazawa, T. Okajima, T. Fujihara, and S. Usui, *Tetrahedron Lett.*, **29**, 5961 (1988).

6) M. G. Banwell and R. Onrust, *Tetrahedron Lett.*, **26**, 4543 (1985); C. M. Amon, M. G. Banwell, and G. L. Gravatt, *J. Org. Chem.*, **52**, 4851 (1987).

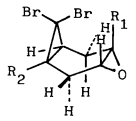
7) S. A. Kozhin and E. I. Sorochinskaya, *Zhurn. Obshchei Khim.*, **37**, 1608 (1967). The assignments done by these authors with use of the IR spectra were found to be ambiguous. We determined them by ^{1}H NMR with use of Sievers' shift reagent as follows: In the presence of 16.5 mol% of the reagent, deshielding shifts for each proton of **6** and **7** are as follows (shifts calculated against H_5 shift as 100): **6** H_2 (33.7), 4-Me (50.9), C**H**Me$_2$ (18.9), CH**Me**$_2$ (12.1, 12.5). **7** H_2 (29.4), 1-Me (20.6), C**H**Me$_2$ (69.1) CH**Me**$_2$ (30.1, 32.7). A largely lower field shift of the methyl signal for **6** suggests the proximity of the methyl group to the epoxy-oxygen and that of the isopropyl methine signal for **7** does the proximity of this to the epoxy oxygen.

8) E. V. Dehmlow and S. S. Dehmlow, "Phase Transfer Catalysis," in Monographs in Modern Chemistry, ed by H. F. Ebel, Verlag Chemie, Weinheim (1980), Vol. 11, pp. 177—228.

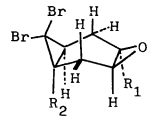
9) From consideration of a molecular model, it is reasonable to assume that the syn isomer must exist in the conformation of **10C**, but not in **10D**, owing to the strong steric interaction of the epoxy oxygen against the endo-halogen atom present in **10D**. Whereas, the anti isomer may exist in either form **10A** or **10B**, in which **10A** must be more



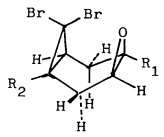
anti-10b-A



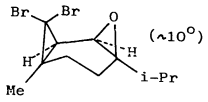
anti-10b-B



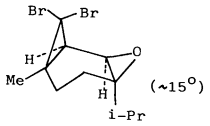
syn-10b-C



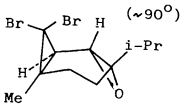
syn-10b-D



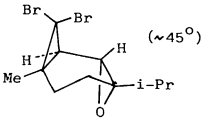
syn-11-A



syn-11-B



anti-11-C



anti-11-D

thermodynamically stable than **10B** because the conformation of **10B** is more strained than that of **10A** with repulsion of the endo-halogen against to the alkyl substituent on a epoxy-carbon. The coupling constants, $J_{3,2a}$ and $J_{3,2b}$ in **10** fell into similar values of 1.5—2.8 Hz, but $J_{6,5a}$ and $J_{6,5b}$ showed different values of 1.2—1.7 Hz and 9.2—9.6 Hz, respectively (Table 4). These data suggest the dihedral angle of the C_3–H_3 bond to the C_2–H_{2a} one is similar to that of the C_3–H_3 bond to the C_2–H_{2b} one, both are near to the angle of 60°, and the dihedral angle of the C_6–H_6 bond to the C_5–H_{5a} bond is quite different from that of the C_6–H_6 bond to the C_5–H_{5b} one, the one may be nearly 180° and the other is nearly 60°. Of **10A–10D**, the conformation of **10A** can only content these requirement.

10) L. A. Last, E. R. Fretz, and R. M. Coates, *J. Org. Chem.*, **47**, 3211 (1982).

11) K. M. Harmon, "Cycloheptatrienylium Ions," in "Carbonium Ions," ed by G. A. Olah and P. v. R. Schleyer, John-Wiley & Sons, Inc., New York (1973), Vol. 4, p. 1620.

12) G. Berti and F. Bottari, *J. Org. Chem.*, **25**, 1286 (1960).

13) R. P. Bell and M. H. M. Arnold, *J. Chem. Soc.*, **1935**, 1432. Dielectric constant of benzene (2.3) is similar to that of toluene (2.4) at 25 °C.

14) R. E. Parker and N. S. Isaacs, *Chem. Revs.*, **59**, 757 (1959).

15) J. Hine, D. Richard, and R. Perz, *J. Org. Chem.*, **38**, 110 (1973).

16) M. Kirszenbaum, J. Corset, and M. L. Josien, *J. Phys. Chem.*, **75**, 1327 (1971).

17) J. de Wit and H. Wynberg, *Recl. Trav. Chim. Pays-Bas*, **92**, 281 (1973).

18) M. Oda, N. Morita, and T. Asao, *Tetrahedron Lett.*, **21**, 471 (1980).

19) a) D. Davalian and P. J. Garratt, *J. Am. Chem. Soc.*, **97**, 6883 (1975); b) D. Davalian, P. J. Garratt, W. Koller, and M. M. Mansuri, *J. Org. Chem.*, **45**, 4183 (1980).

20) a) G. L. Thompson, W. E. Heyd, and L. A. Paquette, *J. Am. Chem. Soc.*, **96**, 3177 (1974); b) E. Vogel, D. Kerimis, N. T. Allison, R. Zellerhoff, and J. Wassen, *Angew. Chem.*, **91**, 579 (1979).

21) W. v. F. Doering and A. K. Hoffman, *J. Am. Chem. Soc.*, **76**, 6162 (1954).