# Synthesis of Cyclic Ethers *via* Bromine Assisted Epoxide Ring Expansion

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Neighbouring group participation by epoxide oxygen in the opening of bromonium ions results in the stereoselective synthesis of cyclic ethers. 9-Oxabicyclo[6.1.0]non-4-ene gives *trans,trans*-2,6-dibromo-9-oxabicyclo[3.3.1]nonane and *trans,trans*-2,5-dibromo-9-oxabicyclo[4.2.1]nonane. Sequential bromination and Bu_3SnH reduction converts 1,2-epoxyhex-5-ene into *cis*- and *trans*-2,5-dimethyltetrahydrofuran and 2-methyltetrahydropyran while (+)-*cis*-limonene oxide is converted into non-chiral cineole.

Many dibrominated cyclic ethers have been isolated from marine sources.[1] The biosynthesis of these systems is unknown but the bromine assisted cyclisation of unsaturated epoxides, a mechanism originally proposed by Bu'Lock,[2] has recently been invoked as a possible biosynthetic route to microcladallene A.[3]
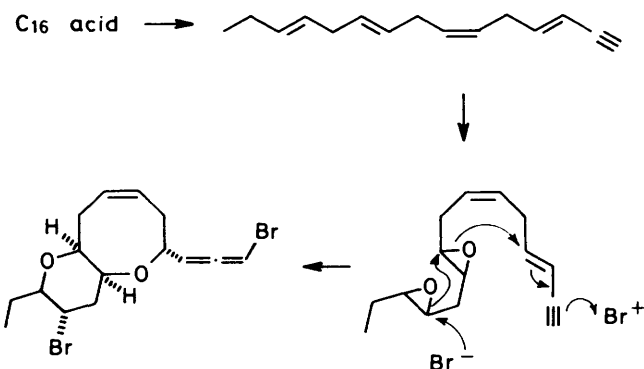

Microcladallene A

To our knowledge no chemical precedent for such a bromine assisted cyclisation of unsaturated epoxides has been reported, although cyclisations of unsaturated epoxides by mercury(II) electrophiles[4] and episulphides by halogens[5] have been established. The anchimeric assistance of epoxide oxygen during solvolyses of esters of 2-substituted-2,3-epoxypropan-1-ols has also been reported.[6] We report here that the bromine assisted ring expansion of unsaturated epoxides is a general and stereoselective route to cyclic ethers.[7]

Results

Epoxidation of cyclo-octa-1,5-diene (1) with 1 equiv. of *m*-chloroperbenzoic acid (MCPBA) gave the monoepoxide 9-oxabicyclo[6.1.0]non-4-ene (2) in good yield. Addition of bromine to compound (2) in carbon tetrachloride at 0 °C gave a 1.2:1 mixture of *trans,trans*-2,6-dibromo-9-oxabicyclo[3.3.1]nonane (3)[8] and *trans,trans*-2,5-dibromo-9-oxabicyclo[4.2.1]nonane (4);[8] no other diastereoisomers were detectable. Changing the solvent to acetonitrile at 20 °C had no effect on the ratio of (3) to (4). Slightly better selectivity was observed however in dichloromethane at −78 °C where the ratio of (3) to (4) was 2:1. Addition of iodine to the monoepoxide (2) at 20 °C in acetonitrile gave a 2:1 mixture of the bicyclic di-iodides (5) and (6). Compounds (5) and (6) were also identified by comparison of

their ^{13}C-{^1H} n.m.r. spectroscopic data with those reported in the literature,[8] and again no other diastereoisomers were detectable.

(1) **(2)** **(3)** X = Br **(4)** X = Br
(5) X = I **(6)** X = I

(7) **(8)** **(9)**
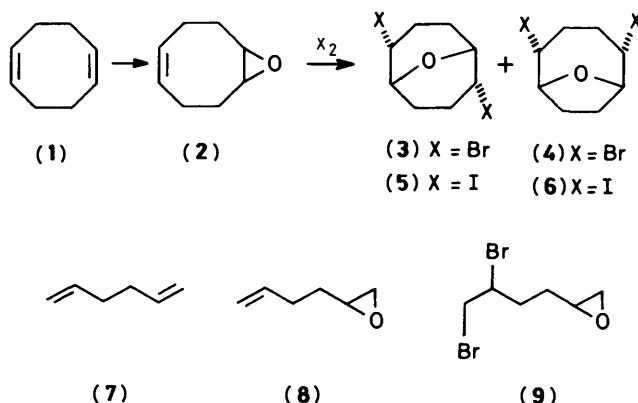
Hexa-1,5-diene (7) was epoxidised with 1 equiv. of MCPBA to give 1,2-epoxyhex-5-ene (8). Addition of bromine to (8) in carbon tetrachloride at 20 °C gave a complex mixture of dibromo compounds, none of which was 5,6-dibromo-1,2-epoxyhexane (9) [an authentic sample having been prepared from (7) by bromination and subsequent epoxidation]. Reduction of the above mixture of dibromides with tributyltin hydride gave a mixture of the known cyclic ethers *trans*-2,5-dimethyltetrahydrofuran (10), *cis*-2,5-dimethyltetrahydrofuran (11), 2-methyltetrahydropyran (12), and oxepane (13). The ratios of (10)—(13) were measured by integration of the g.l.c.
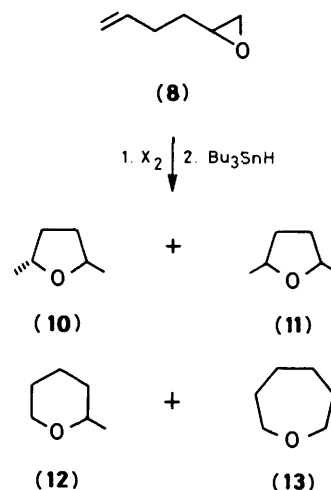

(8)

(10) + **(11)**

(12) + **(13)**

Table. Halogenation–reduction product ratios for (8)

X$_2$	$t/°C$	Solvent	(10)	(11)	(12)	(13)
Br$_2$	20	CCl$_4$	75		20	5
Br$_2$	20	MeCN	45	30	25	0
Br$_2$	−78	CH$_2$Cl$_2$	25	35	40	0
I$_2$	20	MeCN	20	60	20	0

data, and are given in the Table. The bromination–reduction selectivities in acetonitrile at 20 °C and in dichloromethane at −78 °C, together with the results for the analogous iodination–reduction of (8), are also given in the Table.

Bromination of 7-oxabicyclo[4.1.0]hept-3-ene (14) in carbon tetrachloride gave the known, 3,4-dibromo-7-oxabicyclo[4.1.0]-heptane (15)[9] as a single product.
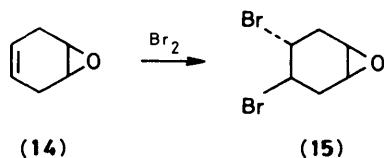

Bromine was added to 1,2-epoxyocta-7-ene (16) in carbon tetrachloride to give after work-up a single compound, 7,8-dibromo-1,2-epoxy-octane (17). Compound (17) was identified by comparison of its spectroscopic data with those of an authentic sample prepared from octa-1,7-diene by bromination and subsequent epoxidation.
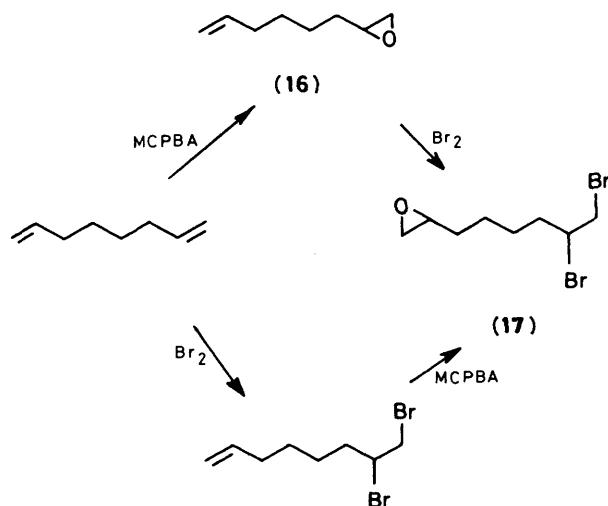

Addition of bromine to cyclohexene and an excess of oxirane in carbon tetrachloride furnished 2-bromoethyl *trans*-2-bromo-cyclohexyl ether (18), identified by its spectroscopic character-istics and elemental analysis, while 1-methylcyclohexene under the same conditions gave a 1:1 mixture of (19) and (20).

(+)-*cis*-Limonene oxide (21) was isolated from a commercial sample of a 1:1 mixture of (+)-*cis*-(21) and (+)-*trans*-(22) isomers by a known method.[10] Bromination of the (+)-*cis* isomer (21) in carbon tetrachloride gave a mixture of two dibromo compounds (t.l.c. analysis and [1]H n.m.r. spectroscopy), which on reduction gave a single optically inactive product identified as cineole (23) by comparison with an authentic sample. Bromine was added in portions (10 mol%) to a 1:1 mixture of (21) and (22) and the reaction monitored by [1]H n.m.r. spectroscopy. After the addition of 50 mol% of bromine,
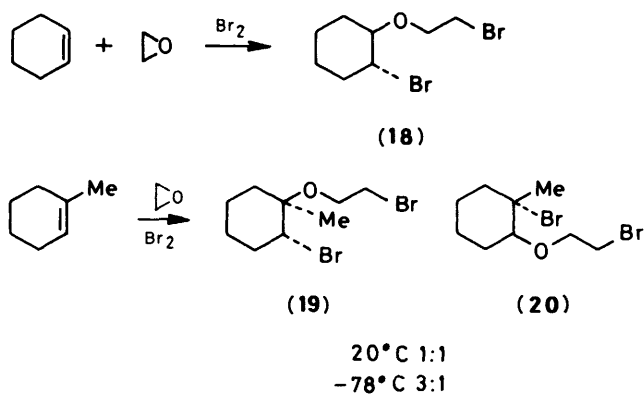

the methyl singlets due to (21) (δ 1.33, 1.68) had virtually disappeared whilst those due to (22) (δ 1.31, 1.70) remained; subsequent work-up gave pure (+)-*trans*-limonene oxide (22).
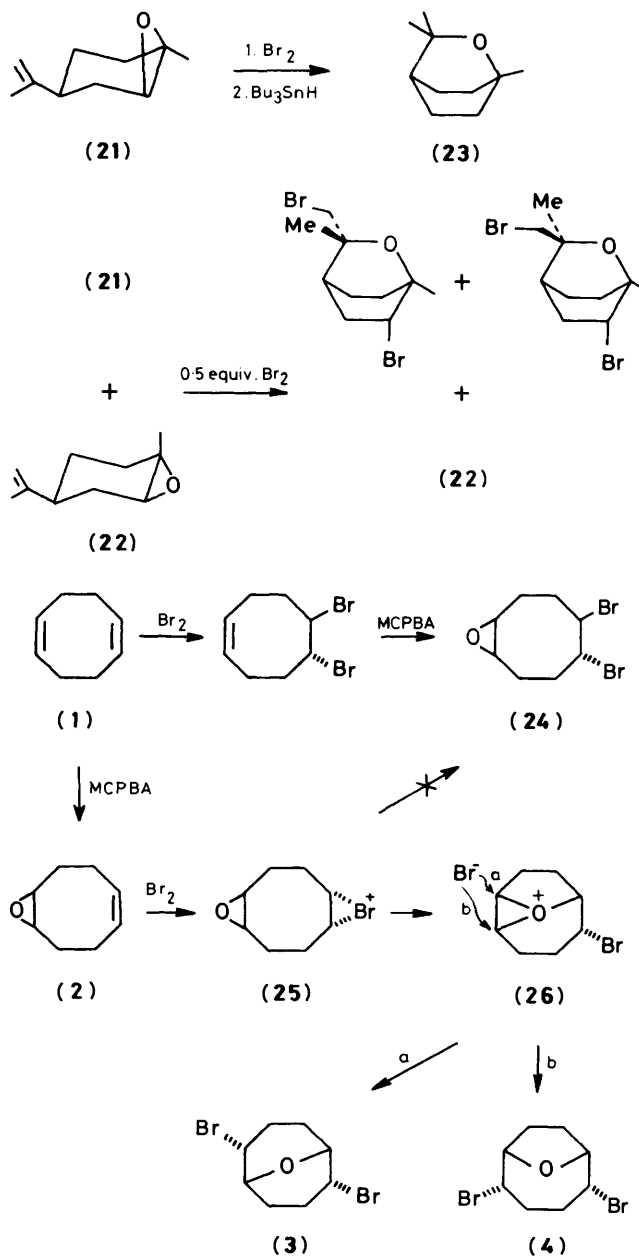
Discussion

Whereas sequential bromination and epoxidation of cyclo-octa-1,5-diene (1) gives *trans*-4,5-dibromo-9-oxabicyclo[6.1.0]-nonane (24),[11] sequential epoxidation and bromination gives a mixture of the ring expanded compounds (3) and (4). The stereo-selective formation of only the *trans,trans*-(3) and *trans,trans*-(4) diastereoisomers from the monoepoxide (2) is consistent with neighbouring group participation by the epoxide oxygen in the opening of bromonium ion (25) to produce the oxonium species (26). A similar mechanism accounts for the formation of (5) and (6) in the iodination of (2).

This bromine-assisted ring expansion of epoxides is not dependent on the particular conformational properties of the cyclo-octane ring. Thus bromination of compound (8) leads to products containing 5-, 6-, or 7-membered rings and not to the dibromo epoxide (9). Six possible dibromo products (27)—(32) can be envisaged, which on reduction yield the known cyclic ethers (10)—(13). Since the reduction proceeded in over 90% yield the ratios of the reduced products were assumed therefore to reflect approximately the ratios of corresponding bromin-ation products.
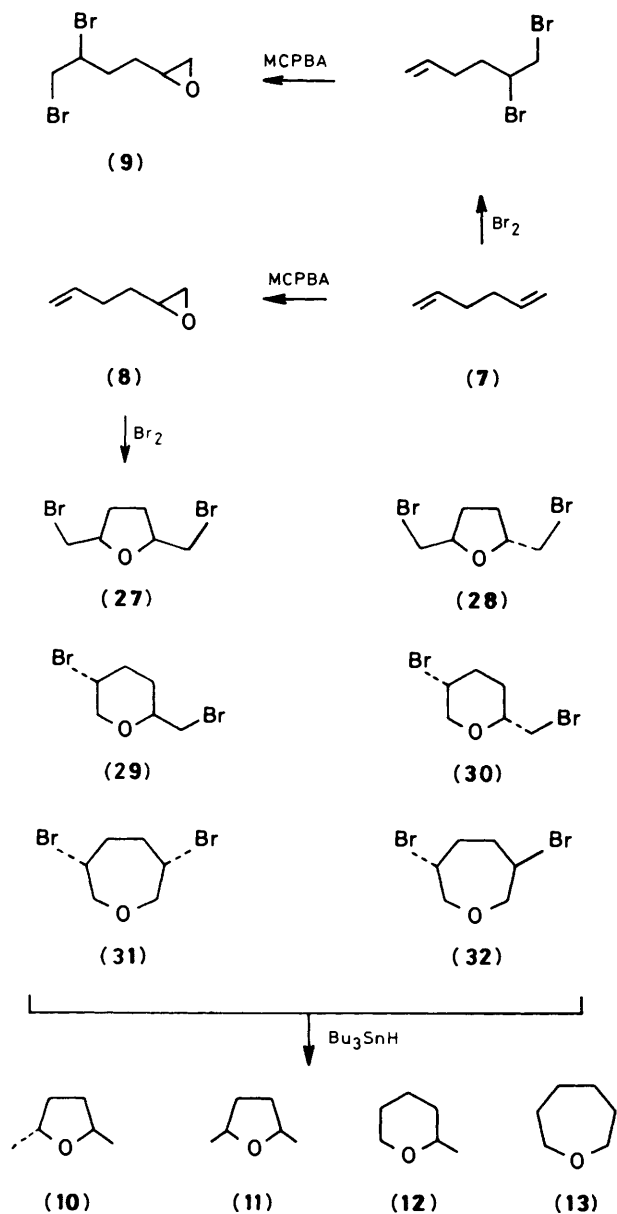
The preferred formation of the 5- and 6-ring ethers (10)—(12) over the oxetane ring is consistent with a 5-*exo-tet* process leading to compounds (27)—(30) being stereoelectronically favourable, whereas an unfavourable 6-*endo-tet* process is required to produce compounds (31) and (32). The preference for tetrahydrofuran formation (Table) is consistent with bromide opening the intermediate oxonium species at the sterically less hindered carbon atom.
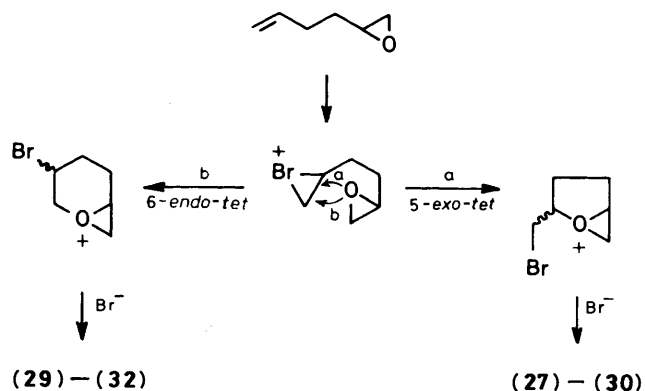
Bromination of the epoxides (14) and (16) gives the simple addition products. Presumably epoxide oxygen participation is not occurring due to structural constraints in the former case and entropy factors in the latter. The intermolecular opening of
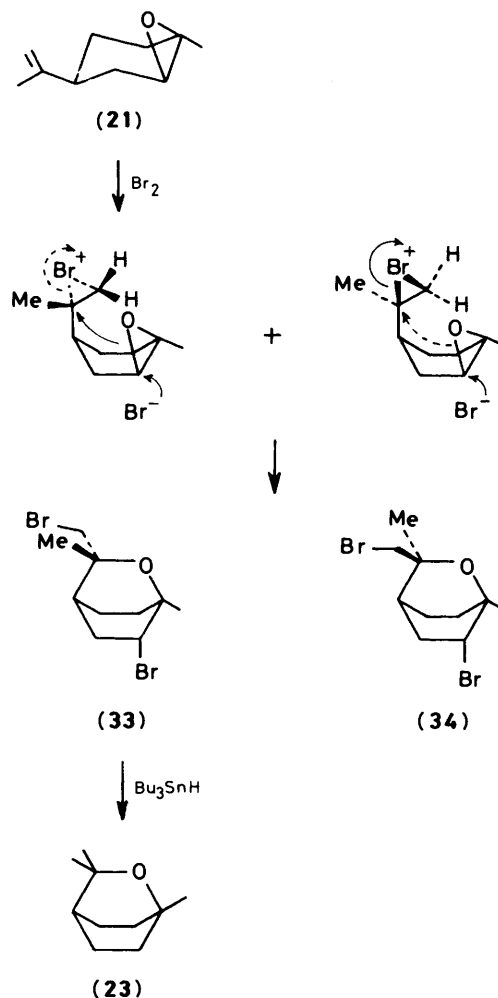
a bromonium ion, demonstrated by the formation of (18)—(20) was not observed when thiirane or methyloxirane was used in place of oxirane.

Consistent with the epoxide oxygen participating in the opening of both possible diastereoisomeric bromonium ions, followed by bromide opening of the resulting oxonium ions at the less hindered carbon atom, bromination of optically active (+)-*cis*-limonene oxide (21) gave a mixture of two dibromo compounds (33) and (34), both of which reduced to non-chiral cineole (23).

For a 1:1 mixture of *cis*- and *trans*-limonene oxides (21) and (22), brominative cyclisation of (21) occurs much faster than normal dibromination of (22). This implies that the formation of the initial bromonium ions is reversible and that the cyclisation is much more rapid than dibromination. It is not structurally possible for *trans*-limonene oxide to undergo the cyclisation reaction.

Experimental

N.m.r. spectra were obtained in $CDCl_3$ solutions on Bruker WH 300 (^{1}H, 300 MHz) or AM250 (^{13}C, 62.896 MHz) spectrometers. G.l.c. analyses were performed on a 10% Carbowax on Chromosorb W column at 100 °C. *cis*- and *trans*-Limonene oxide is commerically available (Aldrich) as a 1:1 mixture. Light petroleum refers to the fraction b.p. (40—60 °C).

Monoepoxidation of Dienes.—Method A.[11] To a slurry of MCPBA (50 mmol, 9 g) in chloroform (60 ml) at 0 °C, the diene (0.05 mol) in chloroform (20 ml) was added rapidly with stirring. The mixture was stirred at 20 °C for 24—30 h, after which the precipitate of *m*-chlorobenzoic acid was removed by addition of 10% aqueous sodium hydroxide (20 ml). The organic layer was washed with water (2—3 × 100 ml) until the washings were neutral, and then dried ($MgSO_4$). The epoxides were purified by distillation.

9-Oxabicyclo[6.1.0]*non-4-ene* (2) (70%), b.p. 95 °C at 30 mmHg (lit.,[4] 97—100 °C at 40 mmHg) as a colourless liquid; δ 1.9—2.5 (m, 8 H), 2.9—3.1 (m, 2 H), and 5.5—5.6 (m, 2 H); $v_{max.}$ 2 890—3 000 (CH), 1 650w (C=C), and 900s cm^{-1} (C–O); m/z (c.i.) 142 (M^+ + NH_4).

1,2-Epoxyhex-5-ene (8) (65%), b.p. 113—114 °C at 760 mm Hg (lit.,[4] 113—114 °C) as a colourless liquid; δ 1.5—1.62 (m, 4 H), 2.45—2.93 (m, 3 H), 4.73—5.06 (m, 2 H), and 5.74—5.89 (m, 2 H); $v_{max.}$ 2 900s (C–H), 1 630v (C=C), and 1 150s cm^{-1} (C–O); m/z (c.i.) 126 (M^+ + NH_4).

Method B.[12] The diene (50 mmol) in dichloromethane (70 ml) containing anhydrous sodium carbonate (7 g) was stirred at 20—25 °C whilst peracetic acid (7.8 ml, 37% in AcOH, 1 equiv.), previously saturated with sodium acetate trihydrate, was added. Stirring was continued (14 h) and the mixture was diluted with water (100 ml). The dichloromethane layer was washed successively with aqueous sodium carbonate and brine before being dried ($MgSO_4$). The epoxides were purified by distillation.

7-Oxabicyclo[4.1.0]*hept-3-ene* (14) (70%), b.p. 152 °C at 760 mmHg (lit.,[13] 152—154 °C at 760 mmHg) as a colourless liquid; δ 2.38—2.58 (m, 4 H), 3.21—3.23 (br s, 2 H, O–CH–CH), and 5.42—5.45 (br s, 2 H, CH=CH); $v_{max.}$ 2 900s (CH), 1 648 v (C=C), and 890s cm^{-1} (C–O); m/z (c.i.) 108 (M^+ + NH_4).

1,2-Epoxyoct-7-ene (16) (62%), b.p. 65 °C at 10 mmHg (lit.,[14] 67 °C at 10 mmHg) as a colourless liquid; δ 1.41—2.01 (m, 8 H), 2.44—2.89 (m, 3 H), and 4.91—5.91 (m, 3 H); $v_{max.}$ 2 920s (C–H), 1 640w (C=C), and 910m cm^{-1} (C–O); m/z (c.i.) 144 (M^+ + NH_4).

Bromination of 9-Oxabicyclo[6.1.0]*non-4-ene* (2).—The title compound (2) (1 g, 8 mmol) in carbon tetrachloride (30 ml) was stirred at 20 °C during the addition of bromine (0.5 ml, 0.01

mol) in carbon tetrachloride (20 ml). After 2 h the reaction mixture was washed successively with aqueous sodium thiosulphate (2%, 50 ml) and water (3 × 100 ml), and then dried ($MgSO_4$). Evaporation of the solvent under reduced pressure gave a mixture of two compounds which were collected as one fraction by flash chromatography (5:1 light petroleum–diethyl ether). The two compounds, *trans-trans*-2,6-dibromo-9-oxabicyclo[3.3.1]nonane (3) and *trans-trans*-2,5-dibromo-9-oxabicyclo[4.2.1]nonane (4), (2.0 g, 87%), were identified by their ^{13}C-{^{1}H} n.m.r. spectroscopic data, which also indicated a ratio of *ca.* 1.2:1. ^{13}C-{^{1}H} N.m.r. compound (3), δ 69.71 (C-1), 50.30 (C-2), 32.17 (C-3), and 26.09 (C-4) (lit.,[8] 71.6, 51.6, 27.8, and 23.3); compound (4), δ 81.99 (C-3), 53.38 (C-2), 27.98 (C-1), and 32.48 (C-4) (lit.,[8] 81.8, 53.4, 27.9, and 32.4).

9-Oxabicyclo[6.1.0]*non-4-ene* (2) was brominated as described above, except that acetonitrile was the solvent. The ^{13}C-{^{1}H} n.m.r. data showed an approximately 1:1 mixture of (3):(4) (2.1 g, 88%) as before. Compound (2) was then brominated as before but in dichloromethane at −78 °C. The ^{13}C-{^{1}H} n.m.r. data showed an approximately 2:1 mixture of (3):(4) (1.7 g, 75%).

Iodination of Compound (2).—Compound (2) (1 g, 8 mmol) in acetonitrile (30 ml) was stirred at 20 °C during the addition of iodine (2.5 g, 9 mmol) in acetonitrile (30 ml). After 2 h the reaction mixture was washed successively with aqueous sodium thiosulphate solution (2%, 50 ml) and water (3 × 100 ml), and then dried ($MgSO_4$). Evaporation of the solvent under reduced pressure gave a mixture of two compounds which were collected as one fraction by flash chromatography (5:1 light petroleum–diethyl ether). The two compounds, *trans-trans*-2,6-di-iodo-9-oxabicyclo[3.3.1]nonane (5) and *trans-trans*-2,5-di-iodo-9-oxabicyclo[4.2.1]nonane (6), (2.5 g, 75%) were identified by their ^{13}C-{^{1}H} n.m.r. data: compound (5) δ 71.11 (C-1), 33.62 (C-2), 29.76 (C-3), and 28.12 (C-4) (lit.,[8] 70.6, 33.3, 30.0 and 29.1); compound (6), δ 83.45 (C-2), 36.23 (C-3), 31.14 (C-4), and 34.62 (C-1) (lit.,[8] 83.1, 35.7, 30.7, and 34.3).

Reductions with Bu_3SnH.—Tributyltin hydride[15] (30 mmol) in ether (30 ml) was added dropwise to the dibromide (15 mmol) in diethyl ether (30 ml) at 0 °C over a period of 2 h. The reaction mixture was heated under reflux (24 h). Products were identified by g.l.c. analysis by co-injection with authentic samples and the product ratios determined by calibration of the g.l.c. with known concentrations of authentic samples.

Brominations of 1,2-Epoxyhex-5-ene (8).—1,2-Epoxyhex-5-ene (8) (3.6 g, 20 mmol) in carbon tetrachloride (30 ml) was stirred at 20 °C during the addition of bromide (1.1 ml, 22 mmol) in carbon tetrachloride (30 ml). After 2 h the reaction mixture was washed successively with aqueous sodium thiosulphate (2%, 100 ml) and water (3 × 100 ml), and then dried ($MgSO_4$). Evaporation of the solvent under reduced pressure gave a mixture of no less than four compounds as shown by t.l.c. The mixture (3.8 g, 15 mmol) was reduced by the method given above. G.l.c. showed the presence of four compounds, which were identified by co-injection with known samples as *trans*- and *cis*-2,5-dimethyltetrahydrofuran (10) and (11), 2-methyltetrahydro-2*H*-pyran (12), and oxepane (13), in the ratio 75:20:5 (91% yield).

Compound (8) was brominated as above but with acetonitrile as the solvent. Reduction followed by g.l.c. analysis, as carried out before, showed a 30:45:25 ratio of (10):(11):(12) (90% yield). No oxepane formation was observed.

1,2-Epoxyhex-5-ene (8) was brominated as above but with dichloromethane as the solvent and the reaction mixture held in a dry ice–acetone bath at −78 °C. Reduction followed by g.l.c.

analysis, as described above, showed a 35:25:40 ratio of (10):(11):(12) (92% yield).

Preparation of 5,6-Dibromo-1,2-epoxyhexane (9).—Hexa-1,5-diene (7) (4.1 g, 50 mmol) in carbon tetrachloride (40 ml) was stirred at 20 °C during the addition of bromine (2 ml, 50 mmol) in carbon tetrachloride. The reaction mixture was stirred for 2 h and then evaporated under reduced pressure. Without purification, the reaction mixture was epoxidised by MCPBA as described in method A. Purification by flash chromatography (5:1 light petroleum–diethyl ether) gave 5,6-dibromo-1,2-epoxyhexane (9) as a colourless oil (5.2 g, 40% overall yield); δ 1.8—2.2 (m, 4 H), 2.60—2.65 (m, 2 H), 2.94—2.96 (m, 1 H), and 3.8—4.3 (m, 3 H); $v_{max.}$ 2 960s (CH), 1 154s (C–O), and 630w cm^{-1} (CBr); *m/z* (e.i.) triplet 256, 258, 260 of relative intensity 1:2:1, $[(M^+ - 2), M^+, (M^+ + 2)]$.

Bromination of 7-Oxabicyclo[4.1.0.]hept-3-ene (14).—7-Oxabicyclo[4.1.0]hept-3-ene (14) (1 g, 10 mmol) in carbon tetrachloride (30 ml) was stirred at 20 °C during the addition of bromine (0.5 ml, 10 mol) in carbon tetrachloride (20 ml). The reaction mixture was washed successively with aqueous sodium thiosulphate (2%, 100 ml) and water (3 × 100 ml) and then dried (MgSO₄). Evaporation of the solvent under reduced pressure gave a white solid which was recrystallised from hot hexane to give white crystals of 4,5-dibromo-1,2-epoxycyclohexane (15) (1.9 g, 68% yield), m.p. 57 °C (lit.,[9] 56—58 °C); δ 4.18—4.34 (m, 2 H), 3.22—3.25 (m, 2 H), and 2.41—3.03 (m, 4 H); $v_{max.}$ 2 920s (CH), 1 080s (C–O), and 650w cm^{-1} (CBr); *m/z* (c.i.) triplet 272, 274, 276 of relative intensity 1:2:1, $[(M^+ - 2) + NH_4, M^+ + NH_4, (M^+ + 2) + NH_4]$.

Bromination of 1,2-Epoxyoct-7-ene (16).—1,2-Epoxyoct-7-ene (16) (1 g, 8 mmol) in carbon tetrachloride (30 ml) was stirred at room temperature during the addition of bromine (0.5 ml, 10 mmol) in carbon tetrachloride (20 ml). The reaction mixture was washed successively with aqueous sodium thiosulphate (2%; 100 ml) and water (3 × 100 ml), and then dried (MgSO₄). Evaporation of the solvent under reduced pressure gave 7,8-dibromo-1,2-epoxyoctane (17) as a colourless oil, which was further purified (1.4 g, 62%) by flash chromatography (5:1 light petroleum–diethyl ether); δ 1.42—2.3 (m, 8 H), 3.84 (dd, 1 H, *J* 10.4, 4.4 Hz, CHBr₂), 3.6 (t, 1 H, *J* 10 Hz, CHBr₂), 4.14 (m, 1 H, CHBr), 2.89 (m, H, O·CH·CH), and 2.73 (t, 1 H, *J* 4.5 Hz, O·CH·CH); $v_{max.}$ 2 960s (CH), 1 125s (C–O), and 620w cm^{-1} (CBr); *m/z* (e.i.): triplet 284, 286, 288 of relative intensity 1:2:1 $[(M^+ - 2), M^+, and (M^+ + 2)]$.

Bromination of Cyclohexene–Oxirane Mixture.—Cyclohexene (2 ml, 20 mmol) and oxirane (3 ml, 60 mmol) in carbon tetrachloride (30 ml) were stirred at room temperature. Bromine (1 ml, 22 mmol) in carbon tetrachloride (20 ml) was added dropwise over a period of 1 h. The reaction mixture was washed successively with aqueous sodium thiosulphate (2%, 50 ml) and water (3 × 100 ml) and then dried (MgSO₄). Flash chromatography (5:1 light petroleum–ether) yielded 2-bromoethyl 2-bromocyclohexyl ether (18) (3.9 g, 65%) (Found: C, 33.35; H, 4.9. $C_8H_{14}Br_2O$ requires C, 33.6; H, 4.9%); δ 1.2—2.6 (8 H, m, CH₂), 3.32—4.0 (5 H, m, CH₂Br, CH₂, CHO), and 4.43 (1 H, m, CHBr); $v_{max.}$ 2 860br (CH), 1 100s (COC), and 640s cm^{-1} (CBr); *m/z* (e.i.) 284, 286, 288, relative intensity 1:2:1 $(M^+ - 2, M^+, M^+ + 2)$.

Bromination of 1-Methylcyclohexene–Oxirane Mixture.—1-Methylcyclohexene (1.2 ml, 10 mmol) and oxirane (1.5 ml, 30 mmol) in carbon tetrachloride (30 ml) were stirred together at 20 °C. Bromine (0.5 ml, 10 mmol) in carbon tetrachloride (20

ml) was added dropwise over a period of 1 h. The mixture was washed successively with aqueous sodium thiosulphate (2%, 50 ml) and water (3 × 100 ml) and then dried (MgSO₄). Evaporation of solvent gave, after flash chromatography (5:1 light petroleum–diethyl ether), two isomers, 2-bromoethyl 1-methyl-2-bromocyclohexyl ether (19) and 2-bromoethyl 2-methyl-2-bromocyclohexyl ether (20) (2.1 g, 70%). Integration of the methyl peaks in the ¹H n.m.r. spectrum [(19), δ 1.32 (s, 3 H, Me); (20), 1.96 (s, 3 H, Me)] gave the ratio of (33):(34) as 1:1. $v_{max.}$ 2 900br (CH), 1 100br (CO), and 640s cm^{-1} (CBr); *m/z* (c.i.) 302 $(M^+ + 2)$, 300 (M^+), and 298 $(M^+ - 2)$.

The above reaction was repeated at −78 °C. Integration of the methyl groups gave the ratio of (91):(20) as 3:1.

Preparation of (+)-cis-Limonene Oxide (21).—(+)-cis- and *trans*-Limonene oxide (10 ml, 60 mmol) was added at 20 °C to water (50 ml) containing two drops of perchloric acid and then left for 2 h. It was then filtered and the filtrate evaporated under reduced pressure. Distillation, b.p. 81 °C (at 15 mmHg) (lit.,[10] 113—115 °C at 50 mmHg), gave pure *cis*-limonene oxide (21) (3.5 ml, 70%); δ 1.33 (s, 3 H, Me), 1.68 (s, 3 H, Me), 1.28—2.02 (m, 7 H), 2.95 (d, 1 H, *J* 5.3 Hz, CH–O), and 4.63 (d, 2 H, *J* 1 Hz, 2 × CH=); $v_{max.}$ 2 960s (CH), 1 640s (C=C), and 840s cm^{-1} (C–O); *m/z* (e.i.) 152 (M^+); $[\alpha]_D^{25}$ +55° (neat), [lit.,[10] $[\alpha]_D^{25}$ +55° (neat)].

Bromination of Pure (+)-cis-Limonene Oxide (21).—(+)-cis-Limenone oxide (21) (1 ml, 6 mmol) in carbon tetrachloride (20 ml) was stirred at 20 °C during the addition of bromine (0.3 ml, 6 mmol) in carbon tetrachloride (10 ml). The reaction mixture was washed successively with aqueous sodium thiosulphate (2%; 50 ml) and water (3 × 50 ml) and then dried. Evaporation of the solvent under reduced pressure gave an oil which showed two overlapping spots on t.l.c. (5:1 light petroleum–diethyl ether). This mixture was reduced by tributyltin hydride by the procedure stated above. Evaporation of the ether under reduced pressure, followed by flash chromatography gave cineole (23) (0.6 g, 66%), whose ¹H n.m.r. spectrum was superimposable on that obtained from an authentic sample and which co-injected with cineole on g.l.c.

A 1:1 mixture of *cis*- and *trans*- limonene oxides (21) and (22) (2 g, 13 mmol) in carbon tetrachloride (25 ml) was stirred at room temperature during the addition of 1 ml portions of bromine in carbon tetrachloride (1.3 mmol/ml). The reaction mixture was monitored by 300 MHz ¹H n.m.r. spectroscopy after each addition. After the addition of 7 ml of the bromine solution the ¹H n.m.r. spectrum showed that two singlets at δ 1.33 and 1.68, which were present in the ¹H n.m.r. spectrum of (21), had disappeared. The solvent was removed under reduced pressure and flash chromatography (5:1 light petroleum–diethyl ether) gave two fractions. The second, more polar, fraction consisted of two compounds, as shown by t.l.c. The first fraction gave *trans*-(+)-limonene oxide (22) (0.1 g) δ 1.31 (s, 3 H, Me), 1.70 (s, 3 H, Me), 1.24—1.84 (m, 7 H), 3.1 (m, 1 H, O·CH·CH), and 4.65 (m, 2 H); $v_{max.}$ 2 960s (CH), 1 640s (C=C), 1 200s (C–O), and 840s (C–O); *m/z* (e.i.) 152 (M^+).

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