STEREOCHEMICAL STUDIES. LXV.*

SYNTHETIC STUDIES IN THE TRICYCLO[4,4,0,$0^{3,8}$]DECANE AND TRICYCLO[4,3,1,$0^{3,7}$]DECANE SERIES: THE SYNTHESIS OF TWISTENE**

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Synthesis of twistene starting from methyl 2,6-cyclohexadiene-1-carboxylate *via* the corresponding *endo,endo*-bicyclo[2,2,2]octane-2,5-dicarboxylic acid (*III*) is described. The *endo,endo*-bicyclo-[2,2,2]octane-2,6-dicarboxylic acid (*X*) which arises as a by-product gives the hitherto unknown tricyclo[4,3,1,$0^{3,7}$]decane. This system was obtained also by reductive cleavage of compounds with the tetracyclo[4,4,0,$0^{2,4}$,$0^{3,8}$]decane system. From equilibration study of the diesters of the acids *III* and *X* the 2,6 and 2,5 interactions between the *endo*-methoxycarbonyl groups were estimated to be about 2·8 kcal/mol and 0·3 kcal/mol, respectively.

Our interest in model compounds of well-defined fixed molecular geometry directed our attention to the tricyclo[4,4,0,$0^{3,8}$]decane (twistane) system[1]. Its unique geometry with completely rigid skeleton makes this system interesting as a potential stereochemical model of great utility. Moreover, the twistane system is chiral, offering thus the possibility of studying the optical properties of optically active molecules containing twisted boat forms[2,3]. Three independent syntheses have been described[1,4-6], only two of them being in principle capable of affording derivatives substituted on the $C_{(4)}-C_{(5)}$ bridge. In this communication we describe a further synthesis of this system which leads to the only one possible olefin – twistene – and which at the same time gives the hitherto unknown isomeric tricyclo[4,3,1,$0^{3,7}$]decane.*** The route of this synthesis enables moreover to obtain optically active twistane derivatives.

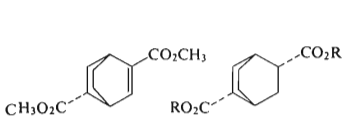
Diels–Alder condensation or methyl 4,5-dihydrobenzoate[7-9] with methyl acrylate gave the diester *I* together with a lesser amount of the position isomer *VIII*. The diesters were assigned *endo*-configuration from the known steric course of the Diels–Alder reaction. The mixture of esters was not separated but was subjected to catalytic

* Part LXV: Tetrahedron Letters *1972*, 711

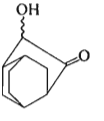
** The results of this paper have in part already been reported in preliminary form[3].

*** According to a note in ref.[1], this hydrocarbon was obtained by Doering and Krantz; however, no details or constants are given.

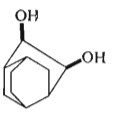
hydrogenation which proceeded with a high degree of stereospecificity. The product consisted of the saturated diesters *II* and *IX* in a 7 : 3 ratio, together with only 15% of other isomers. The pure ester *II*, m.p. 40–41°C, was obtained in 40% yield (67% of the actual content) by crystallisation of the reduction product from pentane at −20°C. From the mother liquors it was possible to obtain the position isomeric diester *IX*, m.p. 47–48°C. Hydrolysis of the ester *II* gave an acid, m.p. 234·5–235°C which could be resolved into enantiomers *via* the brucine salt. From the 2,5- and 2,6-diacids only the first is chiral and therefore the resolvable acid must have the structure *III*.



I *II*, R = CH_3; *III*, R = H



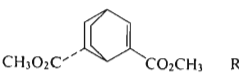
IV



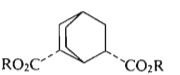
V

VI

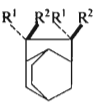
VII



VIII



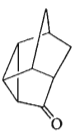
IX, R = CH_3; *X*, R = H



XIa: R^1 = OH, R^2 = H; *b*: R^1 = H, R^2 = OH

XII

XIII

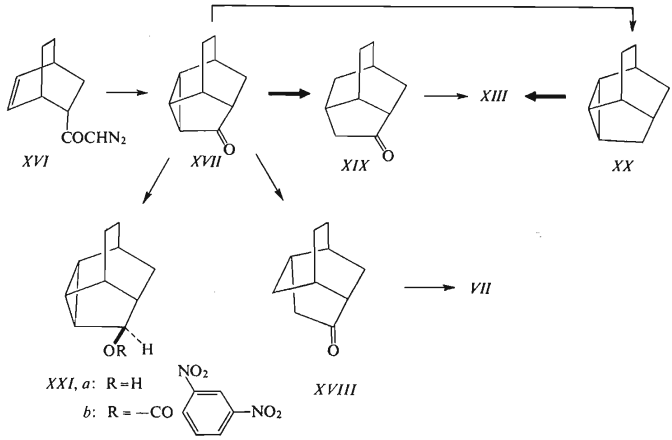


XIV

XV

Acyloin condensation of the diester *II* with sodium in liquid ammonia[10] gave the acyloin *IV* which on hydrogenation on Adam's catalyst furnished the diol *V* in 49% yield. This diol reacts smoothly with periodate affording the starting acid *III*; this constitutes a proof of *endo,endo*-configuration of the acid *III*. The infrared spectrum of the diol *V* exhibits a strong hydrogen bonding between the hydroxyls ($\Delta\nu$ = = 81 cm^{-1}) showing that the hydroxyl groups in the diol are *cis* to each other and leading to an unequivocal assignment of configuration represented by the structure *V*. This diol is the first 4,5-disubstituted twistane derivative synthesized. Transformation of the diol *V* into its cyclic thiocarbonyl derivative followed by heating in trimethylphosphite[11] afforded in 50% yield twistene *VI*, m.p. 128·5–129°C. Its structure

was confirmed by catalytic hydrogenation to a hydrocarbon, m.p. 163–165°C, which was identical with an authentic twistane *VII*, prepared by another route.



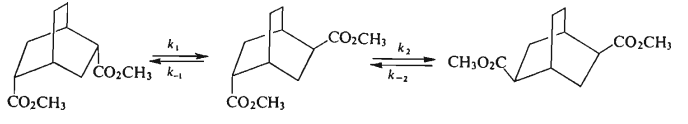
SCHEME 1

The same reaction sequence applied to the position isomeric diester *IX*, afforded an olefin, m.p. 95–96°C which must be tricyclo[4,3,1,$0^{3,7}$]decene (*XII*). Its catalytic hydrogenation gave the hydrocarbon *XIII* of m.p. 91°C. In order to obtain an additional confirmation of the proposed structure *XIII* we prepared this compound by an independent way. It is known[12] that reduction of the tetracyclic ketone *XIV* with lithium in ammonia is stereospecific and gives rise to the ketone *XV*. We prepared therefore the tetracyclic ketone *XVII* by an intramolecular carbene addition[13,14] from the *endo*-diazo ketone *XVI* which in turn was obtained from the *endo*-bicyclo-[2,2,2]oct-5-ene-2-carboxylic acid (Scheme 1). Now, the reduction of the ketone *XVII* should lead predominantly to the ketone *XIX*, the other possible product being 4-twistanone (*XVIII*). In accord with our expectations, the catalytic reduction of the ketone *XVII* in the presence of palladium on calcium carbonate[15] resulted in formation of only 10% of 4-twistanone (*XVIII*) together with 90% of another ketone *XIX*. The ketone *XIX*, m.p. 114–116°C, became the sole product when the reduction was carried out with lithium in liquid ammonia. Wolff-Kishner reduction of this compound afforded a hydrocarbon, melting at 91°C which was identical with the product of reduction of the olefin *XII*. We may therefore assign without any doubt the hydrocarbon of m.p. 91°C the structure *XIII*.

In the absence of a conjugated group, the third cyclopropane bond, the $C_{(2)}-C_{(3)}$ bond, could in principle also undergo reductive cleavage under formation of protoadamantane system. To study this possibility, we prepared and reduced the tetracyclic hydrocarbon *XX*. However, the reduction product consisted almost exclusively of the hydrocarbon *XIII*, showing thus that in this case the steric and electronic factors operate in the same direction. Attempts to open the cyclopropane ring by a solvolytic reaction failed. Reduction of the ketone *XVII* with lithium aluminium hydride gave an alcohol, presumably of the configuration *XXIa*. Acetolysis of the 2,4-dinitrobenzoate of this compound (*XXIb*) afforded as the only product an acetate which did not contain double bond and reduction of which with lithium aluminium hydride followed by oxidation gave back the pure tetracyclic ketone *XVII*.

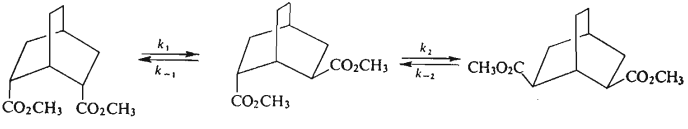
Interaction between Methoxycarbonyl Groups in the 2,6- *and* 2,5-*Positions*

In connection with determination of mutual interactions between various substituents on a six-membered ring systems which we had undertaken some time ago[16-19] it was of considerable interest to equilibrate the diesters *II* and *IX*, and thus to determine the magnitude of the 1,3- and also of the 1,4-interaction, if any, between two methoxycarbonyl groups in the "classical" boat form of cyclohexane. The equilibration with sodium methoxide of the esters *II* and *IX* gave – as expected – in both cases three compounds (according to gas liquid chromatography) in the ratio 56·3 : : 25·5 : 18·2 and 66·9 : 7·1 : 26·0, respectively.



II 1·82% *XXII* 56·3% *XXIII* 25·5%

$k_1 = 1{\cdot}45 \cdot 10^{-1}$ $k_2 = 1{\cdot}12 \cdot 10^{-1}$
$k_{-1} = 4{\cdot}70 \cdot 10^{-2}$ $k_{-2} = 2{\cdot}48 \cdot 10^{-1}$



IX 7·3% *XXIV* 66·6% *XXV* 26·1%

$k_1 = 1{\cdot}44 \cdot 10^{-1}$ $k_2 = 2{\cdot}34 \cdot 10^{-1}$
$k_{-1} = 1{\cdot}58 \cdot 10^{-2}$ $k_{-2} = 5{\cdot}98 \cdot 10^{-1}$

SCHEME 2

To each peak in the chromatogram the corresponding isomer was ascribed on the basis of the kinetic study of the equilibration, without isolating any compound. The reasoning is as follows (for the 2,6-system): We know that the second peak in the gas-chromatogram corresponds to the starting *endo,endo*-ester *IX* (Scheme 2) and therefore we have to ascribe the two other isomers *XXIV* and *XXV* to the two remaining peaks (the first and third, denoted as *A* and *B*, respectively) in the chromatogram. Starting from the *endo,endo*-isomer *IX*, the equilibration must first give rise to the *endo,exo*-isomer *XXIV* which only then may afford the *exo,exo*-epimer *XXV*. We therefore measured the rate of formation of the two remaining isomers and compared the observed concentration changes with the changes computed* on the basis of the final equilibrium composition (Scheme 2) for both possible configurational assignments to the observed chromatographic peaks (*i.e.* for the sequence $IX \rightleftarrows A \rightleftarrows B$ and $IX \rightleftarrows B \rightleftarrows A$). Whereas the results of computation for the first sequence were in an excellent agreement with the found values ($\Sigma\Delta^2 \sim 2\%$ of k_1) the fit for the second sequence was very poor ($\Sigma\Delta^2 \sim 100\%$ of k_1). This comparison shows unequivocally that the most populated isomer has the *endo,exo*-configuration (*XXIV*). The same reasoning, when applied to the 2,5-series, shows that also in this case the *endo,exo*-epimer (*XXII*) is the most stable one.

Before calculating the interactions, we must consider the symmetrical properties of the individual isomers. In the 2,6-series, the isomers *IX* and *XXV* are symmetrical whereas the epimer *XXIV* exists as a (±) pair; this isomer is therefore preferred entropically by the term $\boldsymbol{R} \ln 2$ which at the equilibration temperature (55·4°C) leads to the free energy change $\Delta G = 0{\cdot}51$ kcal : : mol. In the 2,5-series, all the three isomers are (±) pairs, however, they differ in their symmetry number: isomers *II* and *XXIII* have $\sigma = 2$ whereas the isomer *XXII* has $\sigma = 1$ being thus favoured again by $\Delta G = \boldsymbol{RT} \ln 2 = 0{\cdot}51$ kcal/mol. These considerations are necessarily of approximate character. It is, for example, very probable that even isomers *IX* and *XXV* are not symmetrical on the molecular level, *i.e.* that the bicyclo[2,2,2]octane skeleton is slightly twisted in one or another direction which makes the compounds *IX* and *XXV* non-resolvable dl-pairs. However, this does not alter in principle our conclusions because the system may twist in all isomers and the resulting relative entropical situation remains essentially the same as if we considered the system in the strictly eclipsed position.

As the equilibration data show, the energy difference between the *endo,exo*- and the *exo,exo*-isomers in both series is not far from that calculated from the entropy contribution and therefore there is practically no enthalpy difference between them, in accord with what one would have expected. On the other hand, the free energy difference between the *endo,endo*- and the *endo,exo*-isomer *IX* and *XXIV* in the 2,6-system is $\Delta G = 1{\cdot}66$ kcal/mol whereas in the 2,5-system it is again relatively small being 0·84 kcal/mol. After the necessary entropy correction this leaves the energy difference $\Delta G^{corr} = 1{\cdot}66 - 0{\cdot}51 = 1{\cdot}15$ for the first and $\Delta G^{corr} = 0{\cdot}84 - 0{\cdot}51 = 0{\cdot}33$ kcal/mol for the second system.

The "*syn*-axial" interactions in the 2,6-diester are

$$CO_2CH_3/CO_2CH_3 = 2\,CO_2CH_3/H - H/H + \Delta G^{corr},$$

* We are indebted to Dr A. Vítek for writing the pertinent program[20] and for performing the calculations. The system was described by a system of linear differential equations integrated by the Kutta-Merson method[24]. The computations were carried out on a Gier computer.

where the first three terms are the values of 2,6-interactions and ΔG^{corr} is the found energy difference between the *endo,endo*- and *endo,exo*-isomers corrected for the entropy change. If we take the interaction CO_2CH_3/H as the *syn*-axial interaction in the chair form of cyclohexane[19] (*i.e.* as $^1/_2$ A value of the methoxycarbonyl group[21] and H/H as zero, we obtain the value of the 2,6-"*syn*-axial" interaction CO_2CH_3 / / CO_2CH_3 = 1·1 + 1·66 = 2·77 kcal/mol. Similarly as in the case of hydroxyl group, this value is again very close to values found for 1,3-*syn*-axial interactions between other groups in cyclohexane systems. Analogous equation may be written for the 2,5-diesters, but instead of 2,6-, the 2,5-interactions need to be considered. Since in this case the 2,5-interactions CO_2CH_3/H and H/H very probably equal zero the resulting value of the 2,5-interaction is 0·33 kcal/mol. It is interesting to find some interaction even between relatively distant groups; this interaction, if real, may be caused by hindered rotation of the unsymmetrical methoxycarbonyl groups.

EXPERIMENTAL

Cyclohexa-1,5-diene-1-carboxylic Acid

The preparation of 1,4-dihydrobenzoic acid was carried out essentially as described in Organic Syntheses[7,8]. To a stirred and cooled solution of benzoic acid (100 g) in methanol (500 ml) and liquid ammonia (3000 ml) sodium (65 g) was added during 1 h. After evaporation of the ammonia a 15% KOH (800 ml) was added followed by hydroquinone (0·5 g). The solution was distilled until all methanol was removed and the residue was refluxed for 2 h under nitrogen. The cold mixture was acidified with conc. HCl under cooling, extracted with ether several times, the ethereal layer washed with water, dried and the solvent taken down. The residue was taken into pentane, the solution was treated with anhydrous magnesium sulphate and charcoal, filtered, cooled to −70°C and the product filtered off. One or two crystallisations of this crude product from pentane at −20°C gave 41 g of the pure acid, m.p. 31−32°C (lit.[7] gives m.p. 26°C). The acid deteriorates when exposed to air for longer periods. *Methyl ester* b.p. 93°C/15 Torr was prepared from the acid and diazomethane. For $C_8H_{10}O_2$ (138·2) calculated: 69·55% C, 7·30% H; found: 69·86% C, 7·28% H.

Dimethyl *endo,endo*-Bicyclo[2,2,2]octane-2,5-dicarboxylate (*II*) and Dimethyl *endo,endo*-Bicyclo[2,2,2]octane-2,6-dicarboxylate (*IX*)

A mixture of methyl cyclohexa-1,5-diene-1-carboxylate (135 g), methyl acrylate (135 g) and a trace of hydroquinone was heated to 100−110°C for 10 h in an autoclave. The reaction mixture was fractionated and the portion boiling at 106−109°C/0·4 Torr collected; yield 157 g (71%). For $C_{12}H_{16}O_4$ (224·3) calculated: 64·27% C, 7·19% H; found: 64·26% C, 7·32% H. Hydrogenation of the distillate (157 g) in the presence of Adams catalyst (1·0 g) in methanol (200 ml) followed by distillation gave a mixture (152 g, 96%) boiling at 103−104°C/0·4 Torr which consisted, according to vapour phase chromatography, principally of two compounds in a 7 : 3 ratio. Three crystallisations from light petroleum at −20°C afforded 56 g (37%) of dimethyl *endo, endo*-bicyclo[2,2,2]octane-2,5-dicarboxylate (*II*), m.p. 41−41·5°C. For $C_{12}H_{18}O_4$ (226·3) calculated: 63·70% C, 8·02% H; found: 63·58% C, 8·02% H. The position isomeric dimethyl *endo,endo*-bicyclo[2,2,2]octane-2,6-dicarboxylate (*IX*), m.p. 47−48°C, was obtained by fractio-

nal crystallisation of the mother liquors. For $C_{12}H_{18}O_4$ (226·3) calculated: 63·70% C, 8·02% H; found: 63·73% C, 8·10% H.

cis-Tricyclo[4,4,0,0^{3,8}]decane-4,5-diol (Twistane-4,5-diol) (*V*)

To a solution of sodium (12·3 g; 0·533 mol) in anhydrous liquid ammonia (900 ml) ether (250 ml) was added. A solution of the pure diester *II* (26·7 g; 0·118 mol) in ether (300 ml) was added dropwise under nitrogen to this mixture under vigorous stirring, in the course of 1 h. Ammonia was evaporated, 300 ml of ether added and approximately the same amount again distilled off to remove traces of ammonia. The mixture was carefully acidified with ice-cold dilute HCl (100 ml; 1 : 1) under efficient cooling and stirring, the ethereal layer was separated and the aqueous layer saturated with sodium chloride and extracted three times with ether. The combined ethereal layers were washed thoroughly with sodium hydrogen carbonate solution, dried and taken down. The whole isolation procedure was carried out as rapidly as possible. Distillation of the residue afforded the crude product as a waxy mass (10·9 g), boiling at 110—120°C/0·5 Torr. Redistillation of a sample at 110°C/0·5 Torr gave the pure acyloin *IV*. IR-spectrum (CCl_4): 1 732 cm^{-1} (C=O); 3 525, 3 445 cm^{-1} (bonded OH). For $C_{10}H_{14}O_2$ (166·2) calculated: 72·26% C, 8·49% H; found: 72·23% C, 8·61% H. The crude acyloin was hydrogenated in methanol (70 ml) in the presence of Adams catalyst (0·8 g). After 1 700 ml of hydrogen had been consumed and the uptake stopped, the catalyst was filtered off and the filtrate boiled with an aqueous solution (30 ml) of NaOH (5 g) for 1 h in order to remove the unreacted ester. The mixture was partially evaporated, diluted with water and the product taken up in ether. The ethereal extract was dried, taken down and the residue crystallized from ligroin and then from ethyl acetate affording 8·9 g (45%) of the pure diol *V*, m.p. 173·5—174°C. IR-spectrum (CCl_4; 5 . 10^{-3}M): 3 554 cm^{-1} (bonded OH), 3 635 cm^{-1} (free OH). Rate of periodic acid oxidation (pH 6·8, phosphate buffer–10% tert.butanol, *c* 1 . 10^{-4}M) $k_2^{23°} = 111·5$ l mol^{-1} s^{-1}. For $C_{10}H_{16}O_2$ (168·2) calculated: 71·39% C, 9·59% H; found: 71·44% C, 9·44% H.

endo-Bicyclo[2,2,2]octane-2,5-dicarboxylic Acid (*III*)

A) *From the ester* II: A solution of dimethyl *endo,endo*-bicyclo[2,2,2]octane-2,5-dicarboxylate (*II*) (66 g) in methanol (300 ml) was mixed with 15% aqueous KOH (300 ml) and the resulting mixture was refluxed for 45 min. Methanol was distilled off under diminished pressure, the residue extracted with ether, the aqueous layer acidified with hydrochloric acid and the product filtered off. Concentration of the filtrate *in vacuo* followed by several extractions with ether gave further portion of the diacid. Crystallisation from water gave 52·5 g (92%) of the product *III*, m.p. 234·5—235°C. For $C_{10}H_{14}O_4$ (198·2) calculated: 60·59% C, 7·12% H; found: 60·50% C, 7·09% H.

B) *From the diol* V.: The diol *V* (100 mg) was shaken with a solution of sodium periodate (500 mg) in water (5 ml) for 5 min. The clear solution was extracted with ether, the ethereal layer dried and taken down. The residue was dissolved in acetic acid and oxidized with saturated potassium permanganate solution till the colour persisted. The excess of permanganate was destroyed by addition of sodium sulphite, the mixture diluted with water and the product taken into ether. After drying and evaporation of ether the crystalline residue (90 mg) melted at 231 to 233°C and was identical with the acid, m.p. 234°C, obtained from the pure ester *II*.

(—)-*endo,endo*-Bicyclo[2,2,2]octane-2,5-dicarboxylic Acid

To a warm saturated ethanolic solution of the racemic *endo,endo*-bicyclo[2,2,2]octane-2,5-dicarboxylic acid (50 g) warm saturated ethanolic solution of brucine (100 g) was added. After

cooling, the precipitated salt was filtered off, washed with cold ethanol and ether and dried. Two crystallisations from water (about 5 l) gave 41.5 g of the pure brucine salt, $[\alpha]_D^{25}$ −118·3° (0·5, dimethylformamide). The mother liquors afforded further 1·5 g of the pure salt, increasing thus the yield to 55%. For $C_{33}H_{40}N_2O_8.2\,H_2O$ (624·7) calculated: 63·04% C, 7·05% H, 4·46% N; found: 63·11% C, 7·27% H, 4·61% N. The salt (42·9 g) was decomposed with dilute hydrochloric acid, the product was extracted repeatedly with ether, the ethereal layer was washed several times with small amount of water and dried. Evaporation of the solvent afforded 13·0 g of the desired acid, m.p. 198—199°C (water), $[\alpha]_D^{25}$ −125° (*c* 0·50, methanol). For $C_{10}H_{14}O_4$ (198·2) calculated: 60·59% C, 7·12% H; found: 60·32% C, 7·07% H.

Tricyclo[4,4,0,$0^{3,8}$]dec-4-ene (*VI*)

A mixture of *cis*-tricyclo(4,4,0,$0^{3,8}$)decane-4,5-diol (*V*) (8·0 g) and N,N′-thiocarbonyldiimidazole[23] (9·8 g) in dry toluene (150 ml) was refluxed for 45 min, cooled, diluted with benzene, washed three times with water to remove the imidazole, dried, evaporated and the residue crystallized twice from ethyl acetate, affording thus 8·5 g (85%) of the thiocarbonyl derivative, m.p. 228—229°C. For $C_{11}H_{14}O_2S$ (210·2) calculated: 62·85% C, 6·71% H; found: 63·11% C, 6·73% H. A solution of the above thiocarbonyl derivative (6·0 g) in trimethyl phosphite (50 ml) was heated in an autoclave to 135°C for 110 h under nitrogen. The reaction mixture was cooled to −20°C, the unreacted compound (1·6 g) filtered off and washed with few milliliters of pentane. The trimethyl phosphite was decomposed by shaking with 20% NaOH (200 ml), and the product was taken up in pentane. After passing of the solution through a column (60 g) on activated silica gel, the solvent was distilled off and the residue after sublimation at 10 Torr yielded 1·6 g (56%) of the product *VI*, m.p. 128·5—129°C (methanol), pure according to vapour phase chromatography. NMR-spectrum: δ (p.p.m.) 0·8—1·1 (2 H, m, CH), 1·35—1·90 (8 H, m, CH_2), 2·40—2·70 (2 H, m, CH═CH—CH_2), 6·25 (2 H, m, CH═CH); mass spectrum: 134 (molecular peak). For $C_{10}H_{14}$ (134·2) calculated: 89·49% C, 10·51% H; found: 89·31% C, 10·42% H. Preparations carried out at temperatures higher than 140°C resulted in formation of variable amounts of another compound, as evidenced by appearance of a second peak in the gas chromatogram. This compound may be a rearrangement product and was not studied.

Tricyclo[4,4,0,$0^{3,8}$]decane (Twistane) (*VII*)

Catalytic reduction of tricyclo[4,4,0,$0^{3,8}$]dec-4-ene (*VI*) in methanol in the presence of Adams' catalyst afforded in nearly quantitative yield twistane, m.p. 160—163°C, raised to 163—165°C after crystallisation from methanol; this compound was identical in all respects with an authentic sample of twistane prepared from 4-twistanone[4].

endo,endo-(or *exo,exo*)-Tricyclo[4,3,1,$0^{3,7}$]decane-4,5-diol (*XI*)

The position isomeric diester *IX* (3·1 g) was cyclized to the acyloin and converted to the diol *XI* using the same procedure as described for the reaction of *II*; yield 0·9 g (39%) of pure diol *XI*, m.p. 102—103°C. IR-spectrum (CCl_4 5 . 10^{-3}M): 3 544 cm^{-1} (bonded OH), 3 636 cm^{-1} (free OH). Rate of oxidation with periodic acid (pH 6·8, phosphate buffer–10% tert-butanol) $k_2^{23°}$ = = 74·7 l mol^{-1} s^{-1}. For $C_{10}H_{16}O_2$ (168·2) calculated: 71·39% C, 9·59% H; found: 71·26% C, 9·36% H.

endo,endo-Bicyclo[2,2,2]octane-2,6-dicarboxylic Acid (*X*)

This compound was prepared by periodate oxidation of the diol *XI* analogously as described for the preparation of the acid *III* from the diol *V*. It melts at 227—229°C, mixed melting point

with the acid *III* shows depression. For $C_{10}H_{14}O_4$ (198·2) calculated: 60·59% C, 7·12% H; found: 60·80% C, 7·18% H. The dimethyl ester was prepared by treatment with diazomethane, m.p. 47—48°C, undepressed on admixture with the ester *IX* obtained from the hydrogenation of the Diels–Alder product.

Tricyclo[4,3,1,$0^{3,7}$]dec-4-ene (*XII*)

A) The diol *XI* (3·5 g) was transformed into the olefin *via* the thiocarbonyl derivative, m.p. 160 to 161°C, in exactly the same way as described for the twistane series. Sublimation of the product gave 1·1 g (40%) of the olefin, m.p. 95—96°C. Mass spectrum: 134 (mol. peak). NMR-spectrum ($CDCi_3$, δ-scale): 1·25—2·30 overlapping m's, (10 H); 2·28 m, (2 H) allylic CH; 6·07 m (2 H) sp^2-H. For $C_{10}H_{14}$ (134·2) calculated: 89·49% C, 10·51% H; found: 89·38% C, 10·35% H. *B*) The diol *XI* on usual treatment with *p*-bromobenzenesulphonyl chloride in pyridine afforded the corresponding di-*p*-bromobenzenesulphonate, m.p. 166—167·5°C (ethyl acetate), in 72% yield. For $C_{22}H_{22}Br_2O_6S_2$ (606·4) calculated: 43·57% C, 3·66% H; found: 43·73% C, 3·73% H. A mixture of this di-*p*-bromobenzenesulphonyl derivative (0·80 g) and sodium iodide (5·0 g) in diglym (20 ml) was refluxed for 30 min under nitrogen. The mixture was diluted with water and titrated with sodium thiosulphate solution (the consumption corresponded to 307 mg I_2; theory 335 mg I_2). The colourless mixture was extracted with pentane and the organic layer washed several times with water and passed through activated silica gel column (30 g). Evaporation of the solvent and sublimation of the residue gave 135 mg of the olefin *XII*, m.p. 94—95°C, identical with the sample prepared under *A*).

Tricyclo[4,3,1,$0^{3,7}$]decane (*XIII*)

A) *From the olefin* XII: Catalytic hydrogenation of the olefin *XII* from the preceding experiment afforded in quantitative yield hydrocarbon *XIII*, m. p. 91 °C (methanol). For $C_{10}H_{16}$ (136·2) calculated: 88·16% C, 11·84% H; found: 88·11% C, 11·92% H. B) *From the ketone* XIX: The ketone *XIX* was subjected to Wolf–Kishner reduction essentially as described by Whitlock[1]. The ketone (0·30 g) was heated with triethylene glycol (8 ml), 100% hydrazine hydrate (1·5 ml) and 6 drops of acetic acid at 90°C for 6 h. Then KOH (1·0 g) was added and the mixture was heated to 190—210°C for 8 h. After cooling, the condenser was washed with pentane. The reaction mixture was diluted with water, extracted with pentane, the pentane layers were combined, filtered through a silica gel column and the solvent evaporated through a column. The residue after sublimation afforded 0·22 g (81%) of product, m.p. 89—91°C identical with the hydrocarbon obtained by the reduction of *XII*.

Tetracyclo[4,4,0,$0^{2,4}$,$0^{3,8}$]decan-5-one (*XVII*)

A solution of *endo*-bicyclo[2,2,2]oct-5-ene-2-carboxylic acid[18] (5·0 g) in thionyl chloride (7·0 g) was stirred at 20°C for 2 h. The unreacted thionyl chloride was removed by stirring at 0·5 Torr for 1 h. The remaining crude acid chloride was dissolved in ether (50 ml) and this solution was added dropwise to a stirred ethereal solution of diazomethane (3·8 g in 135 ml) at 0°C during 30 min. After addition, the mixture was allowed to stand for 1 h, the solvent taken down under diminished pressure and the residue crystallized from ligroin, affording 4·5 g (78%) of yellow crystals of the diazo ketone *XVI*, m.p. 49—50°C. For $C_{10}H_{12}N_2O$ (176·2) calculated: 68·16% C, 6·86% H, 15·90% N; found: 67·76% C, 6·90% H, 14·87% N. A solution of the above diazo ketone *XVI* (3·5 g) in cyclohexane (170 ml) was refluxed with copper bronze (0·7 g) for 1 h, filtered, the solvent distilled off and the residue chromatographed on silica gel (200 g). Elution with pentane–ether (4 : 1) gave the pure ketone *XVII* (2·3 g, 78%) which after sublimation *in*

vacuo melted at 107—108·5°C. IR-spectrum (CCl_4, 5%): 3020, 3035, 3060 cm^{-1} (cyclopropane ring); 1732 cm^{-1} (C=O). For $C_{10}H_{12}O$ (148·2) calculated: 81·04% C, 8·16% H; found: 81·13% C, 8·13% H.

Hydrogenation of Tetracyclo[4,4,0,$0^{2,4}$,$0^{3,8}$]decan-5-one (*XVII*)

The ketone *XVII* (500 mg) was hydrogenated in ethanol (5 ml) on 5% Pd/$CaCO_3$ (1·5 g). After 10 h the consumption of hydrogen ceased (total 122 ml). The usual work-up procedure afforded 450 mg of product, m.p. 118—122°C, which, according to vapour phase chromatography and IR-spectra contained only 10% of twistanone *XVIII*, the remaining compound being the isomeric ketone *XIX*.

Tricyclo[4,3,1,$0^{3,7}$]decan-4-one (*XIX*)

To a stirred solution of the ketone *XVII* (2·0 g) in anhydrous liquid ammonia (120 ml) lithium (0·8 g) was added. The mixture was stirred for 2 h, the excess of lithium destroyed with ammonium chloride, and the ammonia evaporated. The residue was taken between ether and water, the ethereal layer washed three times with water, dried and taken down. Because the residue contained still about 20% of the starting material the whole procedure was repeated. The reaction product then did not contain the starting ketone and was treated with Jones reagent[22] to oxidize some alcohols formed during the reduction, and the crude product was purified by chromatography on silica gel (300 g) with pentane–ether (5 : 1) as eluent, yielding 1·3 g (65%) of the pure ketone, m.p. 114—116°C. IR-spectrum (CCl_4): 1742 cm^{-1}. For $C_{10}H_{14}O$ (150·2) calculated: 79·96% C, 9·39% H; found: 80·13% C, 9·36% H.

Tetracyclo[4,4,0,$0^{2,4}$,$0^{3,8}$]decan-5-ol (*XXIa*)

The tetracyclic ketone *XVII* (2·0 g) was reduced with lithium aluminium hydride in ether. The usual work-up procedure and crystallisation from pentane gave 1·7 g of an alcohol, m.p. 88—89°C. For $C_{10}H_{14}O$ (150·2) calculated: 79·96% C, 9·39% H; found: 80·08% C, 9·41% H. Oxidation of a sample with chromium trioxide afforded pure starting ketone *XVII*. Equilibration of a sample of this alcohol *XXIa* under Meerwein–Ponndorf reaction conditions gave a second compound in an approximately equal amount, as evidenced by vapour phase chromatography. 2,4-*Dinitrobenzoate* (XXIb), m.p. 133—136°C (methanol). For $C_{17}H_{16}N_2O_6$ (344·3) calculated: 59·30% C, 4·68% H, 8·14% N; found: 59·39% C, 4·62% H, 8·20% N.

Solvolysis of the 2,4-Dinitrobenzoate *XXIb*

A mixture of the above dinitrobenzoate (599 mg) and anhydrous potassium acetate (500 mg) in acetic acid (15 ml) was heated in a sealed ampoule to 100°C for 20 h, cooled, diluted with water and extracted with pentane. The organic layer was washed with sodium hydrogen carbonate, dried, and taken down. NMR spectrum of the residue (345 mg) shows bands δ 1·92 (CH_3) and 4·70 (CH—OAc) but no bands attributable to a double bond. Reduction of the product with lithium aluminium hydride gave an alcohol (241 mg) which upon oxidation with Jones reagent afforded the ketone, *XVII* m.p. 106—108°C.

Tetracyclo[4,4,0,$0^{2,4}$,$0^{3,8}$]decane (*XX*)

A mixture of the ketone *XVII* (1·0 g), hydrazine hydrate 100% (6·0 ml), and ethanol (2 ml) was heated to 100°C for 15 h. After cooling, the mixture was taken to dryness *in vacuo* and the residue was heated with potassium hydroxide (10 g) in triethylene glycol (30 ml) to 200—210°C for 8 hours. The reaction mixture was diluted, taken between pentane and water and the pentane

solution passed through activated silica gel (10 g). After careful evaporation of pentane (column) and sublimation *in vacuo* at 60°C, the hydrocarbon *XX* (0·343 g) was obtained, m.p. 118–119°C. IR-spectrum (carbon disulphide): 3030 cm^{-1} (cyclopropane C—H). For $C_{10}H_{14}$ (134·2) calculated: 89·49% C, 10·51% H; found: 89·50% C, 10·42% H. The hydrocarbon (140 mg) was hydrogenated over Adams catalyst (149 mg) in acetic acid (5 ml). After the end of hydrogen absorption, (1 h) the catalyst was filtered off, the mixture shaken between pentane and water, and the organic layer was washed with water and sodium hydrogen carbonate solution. Evaporation gave 109 mg of the product which was — according to vapour phase chromatography and IR-spectra — almost pure *XIII*, and contained only about 3% of other compounds.

Equilibration of Esters *II* and *IX*

A solution of the ester (180 mg) in methanolic 0·25M sodium methoxide (10 ml) was kept at 55·4°C and in given time intervals the samples (0·5 ml) were taken by means of a syringe. The sample was shaken between ice-cold water and pentane, the pentane layer washed once with water and analysed on a Carlo Erba Fractovap GT-207 gas chromatograph; 50 m capillary column, diameter 0·25 mm, Carbowax 20 M, 170°C). The retention times were: *II* 1·000, *XXII* 0·867, *XXIII* 0·952 (relative to *II*); *IX* 1·000, *XXIV* 0·863, *XXV* 1·032 (relative to *IX*).

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