

SOLVOLYSIS OF 4-TWISTYL AND 10-PROTOADAMANTYL TOSYLATES. THE RELATIONSHIP BETWEEN THESE SYSTEMS*

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Solvolysis of *exo*- and *endo*-4-twistyl tosylates and of *exo*-10-protoadamantyl tosylate in 70% aqueous acetone, ethanol and acetic acid has been shown to afford a mixture of *exo*-4-twistyl and *exo*-10-protoadamantyl derivatives, the latter predominating. Product composition, as well as deuterium distribution in the product, is compatible with the assumption of a common bridged carbonium ion which is stereospecifically opened by the solvent. From the reaction rates of the corresponding tosylates and the product composition, the energy difference between twistane and protoadamantane system has been calculated to be about 4.4 kcal mol⁻¹.

Like other adamantane isomers¹⁻⁴, twistane⁵⁻⁸ (tricyclo[4,4,0,0^{3,8}]decane)^{***} is known to be isomerised into adamantane by an indiscriminate generation of carbonium ions by Lewis acids⁵. In a solvolytic reaction, however, the behaviour of the twistane system depends on the position of the leaving group. Whitlock and Siefken⁵ found that acetolysis of 2-twistyl tosylate resulted in a mixture of six compounds of unknown structure, none of them being 2-twistyl acetate or 1- or 2-adamantyl acetate. On the other hand, 1-twistyl tosylate affords solely the unrearranged 1-twistyl derivative⁹. We decided to study the solvolysis of derivatives with the leaving group in the position 4 (4-twistyl tosylates) since it might reveal some interesting relations between this and other systems which could arise by rearrangement†.

SYNTHESIS

The tosylates *Ib* and *Iib* (Scheme 1) were prepared from the corresponding alcohols^{1,11} by the usual treatment with tosyl chloride in pyridine. Since the tosylate *Ib* was very

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*** We prefer to use the trivial names in order to avoid repetition of cumbersome systematic names; "twistane" is tricyclo[4,4,0,0^{3,8}]decane and "protoadamantane" is tricyclo[4,3,1,0^{3,8}]decane.

† Part of this work has been published in a preliminary form¹⁰.

reactive, the reaction and the subsequent rapid work-up procedure were in this case carried out at 0°C.

Attempts to crystallize the isomer *Ib* from methanol, or boiling its benzene solution, resulted in isolation of another tosylate which we identified as *exo*-10-protoadamantyl tosylate (*Vb*).

In order to prove that the tosylation products of twistanols *Ia* and *Ia* have the twistane skeleton, we reduced the tosylates *Ib* and *Iib* with lithium aluminium hydride. The tosylate *Iib* afforded pure twistane, whereas *Ib* gave a mixture of 70% of twistane and 30% of another hydrocarbon, different from protoadamantane or twistene (as shown by gas-liquid chromatography) which in the IR spectrum exhibits bands at 3010 and 3035 cm^{-1} ; indicative of a cyclopropane ring or a double bond. Obviously, the reduction of *Ib* proceeds partly with rearrangement; the situation may be analogous to that in the reduction of bicyclo-[2,2,2]oct-2-yl tosylate, described by Kraus¹². Also the reduction of 2-thia-7-oxatwistyl tosylate is reported¹³ to proceed with partial rearrangement.

We prepared the epimeric 10-protoadamantyl tosylates *IVb* and *Vb*, starting from 10-protoadamantanone (*III*) which was synthesised following the method of Cupas¹⁴. * Reduction of the ketone *III* with lithium aluminium hydride gave the almost pure *endo*-alcohol *IVa* (Scheme 1). This was converted into the *exo*-alcohol *Va*, m.p. 252–254°C by heating its tosylate *IVb* in molten tetra-*n*-butylammonium acetate¹⁵, followed by lithium aluminium hydride reduction of the formed acetate (Scheme 1). The *exo*-tosylate *Vb* was in every respect (IR-spectra, rate of solvolysis, mixture m.p.) identical with the tosylate obtained from the tosylate *Ib* by rearrangement. Equilibration of the alcohols *IVa* and *Va* at 90°C in the presence of aluminium isopropoxide gave a mixture of 60% of *IVa* and 40% of *Va*. The *endo*-alcohol *IVa* is thus by 0.3 kcal mol⁻¹ more stable than its epimer, contrary to the prediction, made on the basis of the molecular mechanics calculations for the methyl derivatives¹⁶ (according to these calculations, *endo*-10-methylprotoadamantane should be more stable by 0.7 kcal mol⁻¹ than its *exo*-epimer).

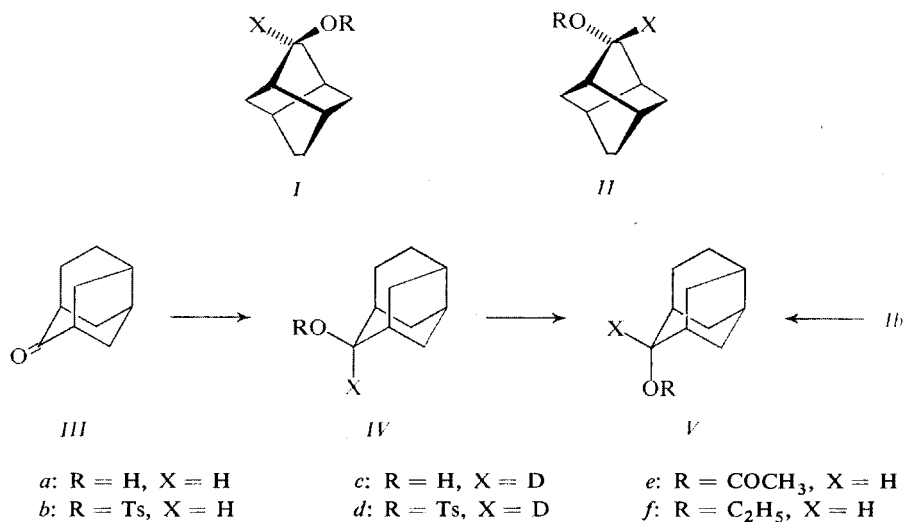
For the 10-protoadamantyl derivatives we use the notation suggested by Schleyer and coworkers¹⁶. According to this notation, a substituent is *endo* when it points toward the larger ring. Consequently, compounds of the type *IV* have *endo*-configuration whereas the configuration of compounds of the type *V* is *exo*. (Unfortunately, directly in the original paper dealing with this problem¹⁶ the configuration of the type *IV* is incorrectly given as *exo*.) The two isomeric 10-protoadamantanols were assigned configuration on the basis of comparison of their NMR spectra and chemical behaviour. As seen from models, the chair in the protoadamantane system is slightly distorted (ref.¹⁶). Therefore, the dihedral angles between the carbinol proton

* Although Cupas and coworkers report¹⁴ m.p. 240–242°C for *III*, this compound in our hands melted at 218–220°C (sealed capillary) and its melting point did not rise on further purification (preparative gas-liquid chromatography, crystallisation). The infrared spectrum of our ketone was superimposable with that kindly provided by Professor Cupas.

at $C_{(10)}$ and the neighbouring protons at $C_{(1)}$ and $C_{(6)}$ are somewhat different in the *exo* and *endo* isomer (Fig. 1). Under assumption that the Karplus relationship holds approximately, the order of the coupling constants should be: $J_{10\text{exo},6} > J_{10\text{endo},1} > J_{10\text{exo},1} > J_{10\text{endo},6}$. It is then obvious that the sum of the coupling constants for the *endo*-isomer *IVa* shall be greater than that for the *exo*-isomer *Va*: $(J_{10\text{exo},1} + J_{10\text{exo},6}) > (J_{10\text{endo},1} + J_{10\text{endo},6})$. The alcohol, which arises in the reduction of 10-protoadamantanone, exhibits a multiplet of the carbinol hydrogen, centered at 3.83 p.p.m., $\sum J = 8.5$ Hz (approximately $5 + 3.5$ Hz), whereas the corresponding signal of the epimeric alcohol at 3.65 p.p.m. has only $\sum J = 6.5$ Hz. Accordingly, we have ascribed *endo* configuration to the former and *exo* configuration to the latter compound. This assignment is also in agreement with the solvolytic behaviour of 4-twistyl and 10-protoadamantyl tosylates, since the 10-protoadamantyl product arising from the solvent attack of the supposed bridged ion should have the *exo*-configuration.

SOLVOLYSIS STUDIES

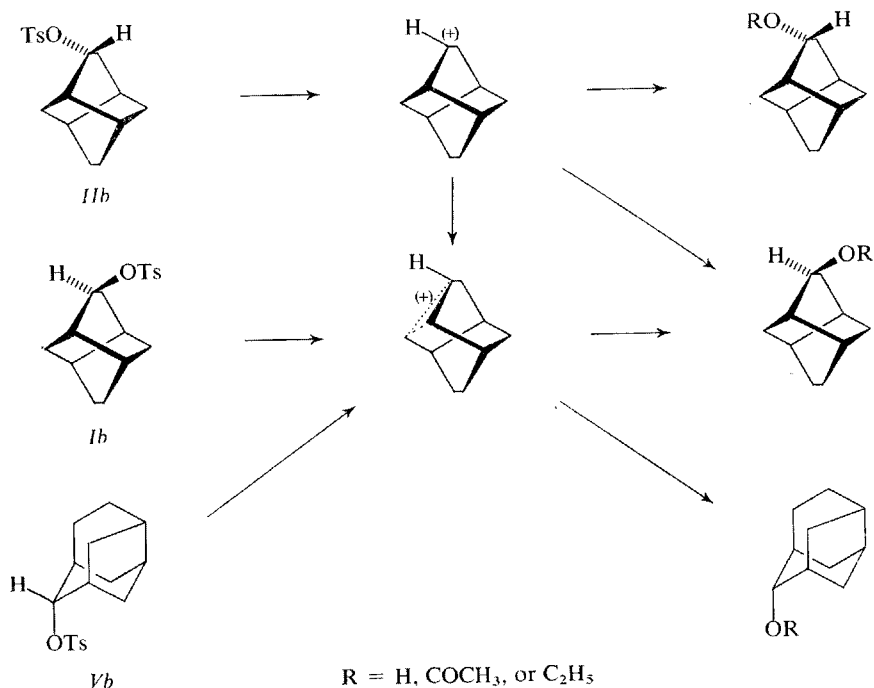
The ethanolysis rates of the tosylates *Ib*, *Ib* and *Vb* are summarised in Table I. When solvolysed in 70% ethanol at 50°C, the tosylate *Ib* afforded almost instantaneously about 50% of solvolysis products and 50% of rearranged tosylate *Vb* which then reacted by a constant slow rate. In our preliminary communication¹⁰, the reaction rate of *Ib* was reported to be $23.1 \cdot 10^{-5} \text{ s}^{-1}$ at 50°C in 70% ethanol. It is now evident that this rate is actually the rate of the rearranged tosylate *Vb*.



SCHEME 1

Since the solvolysis of *Ib* is simultaneously accompanied by the rearrangement of *Ib* to *Vb*, the kinetic measurements were corrected accordingly. The reaction of *Ib* is by more than 3 orders of magnitude faster than the solvolysis of the epimeric tosylate *IIb* (Table I). The extent of rearrangement $Ib \rightarrow Vb$ in anhydrous ethanol at 30°C was 66% and the rate of rearrangement was calculated to be $1.63 \cdot 10^{-4} \text{ s}^{-1}$.

The great difference between the two epimeric tosylates indicates that the solvolysis of *Ib* is probably anchimerically assisted. Further information was provided by the product study. The solvolyses were carried out in 70% aqueous acetone, acetic acid, and in ethanol, and their results are given in Table II. The alcohol mixtures from the reactions in the first two solvents (the acetolyses products were converted to alcohols by reduction with lithium aluminium hydride) were oxidised with Jones reagent to mixture of ketones in which we were able to detect only 4-twistanone and 10-protoadamantanone. The alcohols, arising in 70% acetone, were also transformed into the acetates, the composition of which agreed well with that of the ketones. The products of solvolysis of *Ib* and *Vb* in 70% acetone were chromatographically separated and the isolated alcohols shown to be identical with *Ia* and *Va*. Solvolysis of *Ib* in 70%



SCHEME 2

TABLE I
Solvolysis Data in Ethanol

Tosylate	Concentration of ethanol, %	Temperature °C	$10^{-5} k$ s^{-1}	ΔH^\ddagger kcal mol $^{-1}$	ΔS^\ddagger e.u.
<i>Ib</i>	100	30.0	8.64 ^a	—	—
<i>IIb</i>	70 ^b	50.0	4.14	—	—
	100	75.0	1.68	—	—
<i>Vb</i>	70 ^b	40.0	6.87	23.8 ± 0.1	-1.6 ± 0.3
		50.0	23.2		
		60.0	72.6		
	100	30.0 ^c	0.01	27.5 ± 0.5	-0.2 ± 1.5
		65.0	1.26		
		75.0	3.96		
	85.0 ^d	13.0			

^a Calculated as described on p. 3871; ^b by volume; ^c extrapolated from data at other temperatures; ^d measured in a sealed conductometric cell.

TABLE II
Percentage of Solvolysis Products of the Tosylates *Ib*, *IIb* and *Vb*

Tosylate	Conditions	4-X-Twistane ^a		<i>exo</i> -10-X-Protoadamantane
		<i>exo</i>	<i>endo</i>	
70% Aqueous acetone ^b (X = OH)				
<i>Ib</i>	20°C/20 min	28	0	72
<i>IIb</i>	95°C/12 h	32	6	62
<i>Vb</i>	95°C/5 h	29	0	71
Acetic acid (X = CH ₃ COO)				
<i>Ib</i>	20°C/2 h	18	0	82
<i>IIb</i>	100°C/15 h	21	2	77
<i>Vb</i>	100°C/8 h	18	0	82
Ethanol (X = C ₂ H ₅ O)				
<i>Ib</i>	50°C/30 min	36	0	64
<i>IIb</i>	110°C/24 h	42	2	56
<i>Vb</i>	110°C/8 h	36	0	64

^a In addition to the products mentioned in this Table, the solvolysis of *Ib* and *IIb* afforded about 2% of twistene as evidenced by gas-liquid chromatography, using n-pentadecane as internal standard; ^b by volume.

acetone under conditions which lead to the complete solvolysis of *Vb*, arising by rearrangement, gave a mixture of alcohols. These were oxidised and the ketones reduced to hydrocarbons. The IR spectra of the hydrocarbons exhibited also solely the bands corresponding to a 3 : 7 mixture of twistane and protoadamantane.

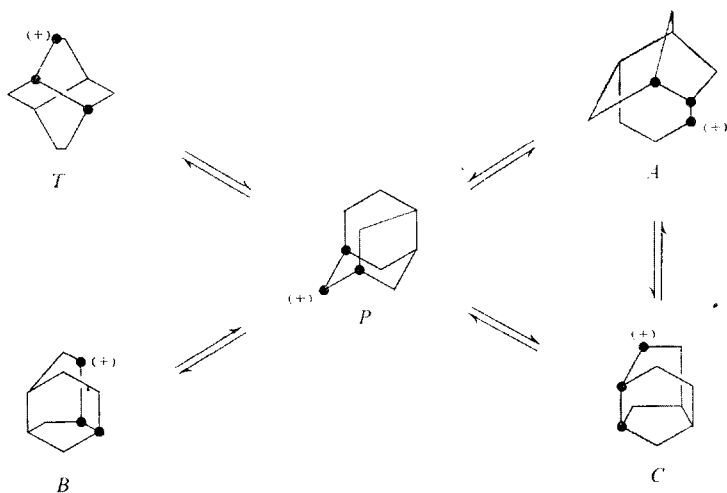
Thus, no experiment gave any indication of the presence of compounds other than 4-twistyl and 10-protoadamantyl derivatives. The presence of 1- and 2-adamantyl derivatives was positively excluded by gas-liquid chromatography.

Heteroanalogues of twistane with the *exo*-configuration of the leaving group were recently reported to yield also a mixture of the corresponding heterotwistane and heteroprotoadamantane derivatives of *exo*-configuration^{17,18} ("erythro"-5-chloro-1-azatwistane afforded 6-azaprotadamantane derivative even as the sole product¹⁸); no compounds with other isomeric skeleton were detected.

Spurlock and Clark¹⁹ have shown that acetolysis, formolysis and trifluoroacetolysis of 2-protoadamantyl brosylates lead to a mixture of rearranged products, including 4-twistyl and 2-adamantyl derivatives. It is interesting that, in spite of the presence of about 13% of the twistane derivatives, the authors did not find any 10-protoadamantyl derivative (although the 10-protoadamantyl cation is involved in their reaction scheme).

Whereas the *exo*-twistyl tosylate *Ib* and the protoadamantyl tosylate *Vb* gave (beside 1.5–3% olefin) the same mixture of products of exclusively *exo*-configuration (*I* and *V*), the epimeric *endo*-tosylate *Iib* afforded, in addition to these two products, a small amount of the corresponding *endo*-twistyl derivative *II*.

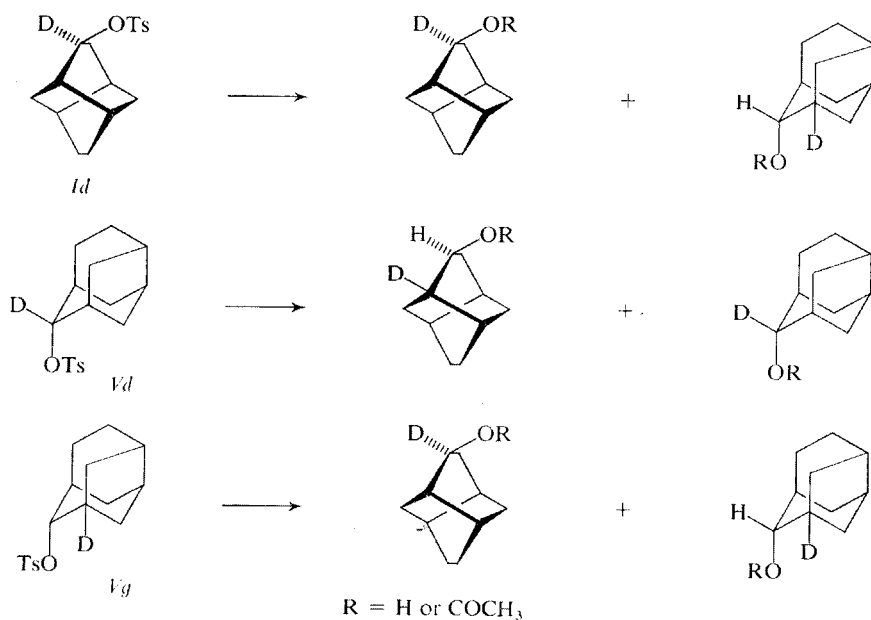
On the basis of the above data one can visualize a mechanistic scheme, involving a common bridged ion (Scheme 2) which arises directly from *Ib* and *Vb*, and by "leakage" from *Iib*; the latter moreover reacts to a certain extent *via* the classical



SCHEME 3

4-twistyl carbonium ion. The common intermediate ion is then stereospecifically opened by the solvent to give the products. Nevertheless, there might be another, though not very likely, alternative, namely an equilibrium between several classical ions, arising from each other by 1,2-shifts (Scheme 3).

A study of isotopically labelled compounds could decide between these alternatives. In solvolysis of deuterated tosylates *Id*, *IId*, *Vd* and *Vg*, the corresponding products arising in a stereospecific attack of the bridged ion should contain the deuterium atom in the positions denoted in Scheme 4. On the other hand, if an equilibrium of classical ions were involved, the deuterium should be statistically distributed in the three positions marked in Scheme 3 by large dots. Therefore, if one converts the solvolysis products of the α -deuterated tosylate *Id* into the corresponding ketones, then in the case of the bridged ion the arising twistanone should be deuterium-free and the 10-protoadamantanone should retain its deuterium content, whereas when a system of equilibria is operating, both ketones should contain the same amount (two thirds) of the original deuterium content. In actual fact, 4-twistanone, arising in acetolysis or hydrolysis of the α -deuterated tosylates *Id* and *IId*, contained no deuterium whereas the 10-protoadamantanone showed complete retention of deuterium. Also the hydrolysis of the tosylate *Vg* (Scheme 4) which was obtained by rearrangement of the α -deuterated *exo*-tosylate *Id* and is believed to contain all the deuterium in the



SCHEME 4

position 1, gave the same result. Conversely, as expected, the reaction of the α -deuterated protoadamantyl tosylate *Vd* (Scheme 4) resulted in retention of deuterium in 4-twistanone and its loss in 10-protoadamantanone. These results are fully consistent with the transformations depicted in Scheme 4 and thus with the bridged ion concept (Scheme 2).

TABLE III

Calculated and Found Deuterium Content in Various Mixtures of 4-Twistanone and 10-Protoadamantanone, Prepared by Oxidation of Fractions, Obtained by Chromatographic Separation of Solvolysis Products^a

Starting tosylate	Solvent	4-Twistanone ^b %	% d ₁	
			found	calculated
<i>Id</i> ^c	70% aqueous acetone ^d	100	0	0
		21	70	75.0
	CH ₃ COOH ^e	44	50	53.2
		10	82	85.5
		0.6	95	94.4
<i>IId</i> ^c	70% aqueous acetone ^f	86.3	10	13.0
		30.7	64	65.8
		22.6 ^g	71	73.5
		37.0 ^h	56	59.8
<i>Vd</i> ⁱ	70% aqueous acetone ^j	80.5	82	76.9
		30	38	28.6
		17	24	16.2
	CH ₃ COOH ^j	57	65	54.4
		18.6	22	17.7
		17.5	22	16.7
<i>Vg</i> ^c	70% aqueous acetone ^d	87.5	14	11.8
		19.0	76	76.9
		6.0	93	89.3

^a The reaction conditions were the same as given in Table II; the deuterium content is calculated on the basis of the percentage of twistanone, found by gas-liquid chromatographic analysis. The calculation is corrected for the actual deuterium content in the starting material, assuming complete retention or removal of the deuterium atom according to Scheme 4; ^b the rest is 10-protoadamantanone; ^c starting tosylate had 95.0% d₁; ^d the product alcohols had 94.5% d₁; ^e the product alcohols had 94.0% d₁; ^f the product alcohols contained 95.0% d₁; ^g the product contained 9.7% of *IIa*; ^h the product contained 34.1% of *IIa*; ⁱ the starting tosylate contained 95.5% d₁; ^j the product alcohols contained 95.5% d₁.

In most cases the alcohols *Ia* and *Va* were not completely separated by the chromatography and therefore in the deuterium content determinations various chromatographic fractions were oxidized to mixtures of ketones which were then analysed by gas-liquid chromatography and mass spectrometry. From the ketone ratio and the deuterium content of the starting tosylate (alcohol) the deuterium content, expected on the basis of the bridged ion mechanism (Scheme 2), was calculated and compared with that actually found by mass spectrometry. As seen from Table III, the agreement between the calculated and found values is satisfactory (and probably within the combined errors of the measurements) in the case of *Id*, *Ild* and *Vg*, whereas the differences found for *Vd* are probably significant, the found deuterium contents being larger than the calculated ones.

An explanation of this discrepancy may rest in the presence of a small amount of a ketone, arising from the species *B* and/or *C* (Scheme 3), which should retain all deuterium. If this ketone is inseparable on gas-liquid chromatography from 10-protoadamantanone, then the found deuterium contents in the 4-twistanone-10-protoadamantanone mixtures arising from *Vd* will be higher, whereas the ketone from *Vg* will give the calculated values. However, even if this ketone were present, its amount cannot be great, as indicated by the deuterium and infrared analyses (−5%). Its presence would show that also the C₍₅₎–C₍₆₎ bond of the protoadamantane system participates to a small extent; this would of course not be at variance with our conclusions.

ENERGY DIFFERENCE BETWEEN TWISTANE AND PROTOADAMANTANE SYSTEMS

In the case that *Ib* and *Vb* react *via* common intermediate, we can estimate the energy difference between twistyl and protoadamantyl systems using the Goering–Schewene energy diagram²⁰. This diagram, used successfully by several authors^{21–25}, is depicted in Fig. 2 and requires little comment. The difference between both the systems in the ground state $\Delta G = \Delta G_{\text{P}}^{\ddagger} + \Delta \Delta G_{\text{product}}^{\ddagger} - \Delta G_{\text{T}}^{\ddagger}$. The activation energies $\Delta G_{\text{T}}^{\ddagger}$ and $\Delta G_{\text{P}}^{\ddagger}$ are known from the reaction rates of *Ib* and *Vb*, respectively, and $\Delta \Delta G_{\text{product}}^{\ddagger}$ can readily be determined from the ratio of the protoadamantyl to twistyl product, P/T. Using the rate constants at 30°C in 100% ethanol (Table I) and the value of P/T = 64.3/35.7 we find that *exo*-4-twistyl tosylate is by 4.4 kcal mol^{−1} higher in energy than *exo*-10-protoadamantyl tosylate.

Molecular mechanics calculations predicted²⁵ that protoadamantane should be 7.83 kcal . mol^{−1} more stable than twistane, analogous calculations²⁶ using Allinger's force field²⁷ led to a difference of only 0.76 kcal . mol^{−1}. Better models for comparison with our result are *exo*-10-methylprotoadamantane¹⁶ and *exo*-4-methyltwistanone²⁸. * Here the differences are analogous, the Engler's force field giving 8.56 kcal . mol^{−1} whereas the Allinger's force field leads to 1.73 kcal . mol^{−1}. The experimental energy difference (4.4 kcal . mol^{−1}) lies thus nearer to the second value.

* We are greatly indebted to Professor P. von R. Schleyer for making available to us the results of these calculations.

CALCULATION OF RATE CONSTANTS

The solvolyses were followed conductometrically. The measured conductivity data (30–60 points) were fitted to the exponential curve of the type

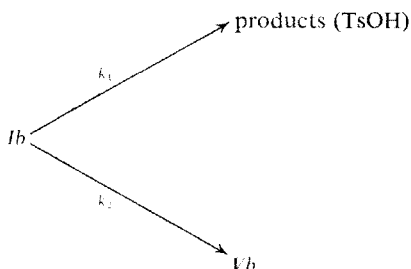
$$\lambda_t = a - b e^{-kt}, \quad (1)$$

where λ_t is the conductivity at the time t , $a = \lambda_\infty$, $b = \lambda_\infty - \lambda_0$, λ_∞ and λ_0 being the conductivity at the infinite and zero time, respectively. Späth's algorithm³⁰ was used and the transcendent equation in this algorithm was solved by the standard *regula falsi* procedure³¹.

Since the value of λ_0 was negligible in comparison with λ_∞ , the constants a and b were practically identical. Therefore, Eq. (1) can be written in the form

$$\lambda_t = a(1 - e^{-kt}), \quad (2)$$

The determination of the reaction rate of the *exo*-tosylate *Ib* was complicated by its simultaneous rearrangement. The solvolysis thus represents a system of two competitive reactions:



The tosylate *Vb* is practically unreactive under the conditions of the measurement (30°C) and therefore the measured conductivity reflects only the concentration of *p*-toluenesulphonic acid, formed by direct solvolysis of *Ib*.

The system can be described by the equation:

$$\lambda_t = \lambda_\infty \frac{k_1}{k_1 + k_2} (1 - e^{-(k_1 + k_2)t}) \quad (3)$$

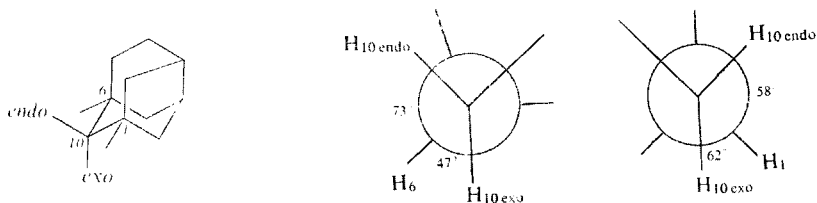


FIG. 1

Schematic Representation of the Torsion Angles in 10-Protoadamantyl Derivatives

where λ_t is the conductivity at the time t , λ_∞ is the infinite time conductivity, determined experimentally after complete solvolysis of both Ib and Vb (formed during the reaction by rearrangement), and k_1 and k_2 are the respective rate constants of the direct solvolysis of Ib and of its rearrangement to Vb . As evident, equation (3) is formally similar to equation (2). The solvolysis of Ib was therefore measured in a sealed conductometric cell at 30°C, at which temperature the reaction of Vb was practically not measurable. Then the cell was heated to 85°C for 20 hours (15 half-lives of the solvolysis of Vb), whereupon the infinite time conductivity λ_∞ was measured after cooling to 30°C. The data (λ_t and t) were fitted to the equation (1) and the parameters a , b and k were determined.

Since $a = b$ (*vide supra*), equation (1) was transformed into equation (2) which was compared with equation (3). From this comparison it follows that $a = \lambda_\infty k_1 / (k_1 + k_2)$ and $k = k_1 + k_2$. The values of k_1 and k_2 were therefore calculated from these relations, using the experimentally determined value of λ_∞ .

Thus, at 30°C, $k_1 = 8.64 \cdot 10^{-5}$, $k_2 = 1.63 \cdot 10^{-4}$, $k_1/k_2 = 0.529$; this corresponds to 65.8% of rearrangement of Ib to Vb . This result is close to the value $k_1/k_2 = 0.548$ (64.6% of rearrangement), found experimentally at 30°C (Ib in ethanol afforded after 10 half-lives 35.4% of solvolysis products I_f and V_f).

EXPERIMENTAL.

The gas-liquid chromatographic analyses were performed on a Carlo Erba Fractovap GT instrument with flame ionisation detector. The alcohols, ketones and acetates were analysed on a 50 m graphitized glass capillary with Carbowax 20 M at 140°C, for analysis of ethoxy derivatives a 50 m capillary with di-n-butyl tetrachlorophthalate (at 100°C) was used. The mass spectra were taken on a MS-902 (AEI — England) spectrometer, the deuterium analyses were carried out on a MCH-1303 (USSR) spectrometer. The NMR spectra were measured on a Varian HA-100 instrument and the IR-spectral measurements were performed on a Perkin-Elmer 621 model.

exo-4-*p*-Toluenesulphonyloxytricyclo[4,4,0,0^{3,8}]decane (*Ib*)

A mixture of *Ia* (240.1 mg)¹¹ and *p*-toluenesulphonyl chloride (750 mg) in pyridine (2 ml) was allowed to stand overnight at 0°C. The excess of *p*-toluenesulphonyl chloride was destroyed by a careful addition of few drops of water under cooling, the product was taken into ether,

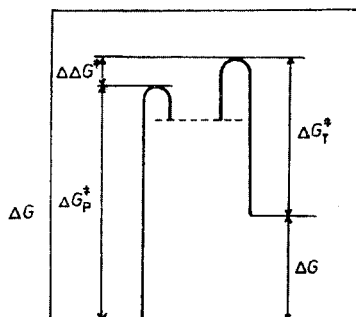


FIG. 2
Free Energy Relationship between Twistane
and Protoadamantane Systems

washed with dilute ice-cold hydrochloric acid (1 : 5), water and a sodium bicarbonate solution, and dried. Evaporation of the solvent at 0°C afforded 460 mg (85.6%) of the tosylate, m.p. 56–58°C, which still contained about 3% of the starting alcohol. The whole work-up procedure was carried out at 0°C as rapidly as possible. Chromatography of the crude tosylate on a silica gel column (50 g) cooled to –10°C, using ether–pentane (2 : 1) as eluant, afforded 365 mg of pure *Ib*, m.p. 60–62°C. For $C_{17}H_{22}O_3S$ (306.4) calculated: 66.65% C, 7.24% H; found: 66.67% C, 7.22% H. NMR spectrum ($CDCl_3$; δ , p.p.m.): 4.69 d of ds, 1 H (—O—CH—), J_{vic} (Hz) $\sim 7.5 + 5.0 \div <1$.

endo-4-*p*-Toluenesulphonyloxytricyclo[4,4,0,0^{3,8}]decane (*Iib*)

Treatment of the alcohol *Iia* (205 mg)¹¹ with *p*-toluenesulphonyl chloride in pyridine (15 hours, room temperature) afforded 200 mg of *Iib*, m.p. 61–62°C (methanol); on admixture with *Ib* it melts at 47–56°C. For $C_{17}H_{22}O_3S$ (306.4) calculated: 66.65% C, 7.24% H; found: 66.88% C, 7.38% H. NMR spectrum: ($CDCl_3$; δ , p.p.m.): 4.77 t with fine splitting, 1 H (—O—CH—), J_{vic} (Hz) $- 7.5 + 7.5 + \sim 1$.

Reduction of the Tosylates *Ib* and *Iib* with Lithium Aluminium Hydride

A solution of *Ib* (300 mg) in ether (2 ml) was added to an ethereal solution (5 ml) of lithium aluminium hydride (150 mg) and the mixture was stirred for 5 hours. After standing overnight the mixture was decomposed with a sodium hydroxide solution, filtered and the filtrate was taken down. The residue was dissolved in pentane, allowed to pass through an alumina column (activity II) and the eluate was taken down. Sublimation of the residue gave 52 mg of a hydrocarbon mixture. Gas-liquid chromatography shows two peaks in the ratio 3 : 7, the larger peak having retention time identical with twistane. No twistene was observed. The IR spectrum is consistent with twistane, contaminated with another compound (bands at 3010 and 3035 cm^{-1}).

The reduction of *Iib* (300 mg) was performed as described for *Ib* and afforded 60 mg of pure twistane, identified by its IR spectrum, gas-liquid chromatography and mixture melting point with the authentic sample.

exo-10-*p*-Toluenesulphonyloxytricyclo[4,3,1,0^{3,8}]decane (*Ivb*)

Reduction of the ketone *III* (1.1 g)¹⁴ in ether (20 ml) with lithium aluminium hydride (0.6 g in 30 ml) afforded 1.0 g of the alcohol *IVa*, which was purified by crystallisation from methylcyclohexane, m.p. 265–267°C (sealed capillary). For $C_{10}H_{16}O$ (152.2) calculated: 78.89% C, 10.59% H; found: 79.33% C, 10.85% H.

Tosylate *IVb*, m.p. 92.5–93.5°C (methylcyclohexane). For $C_{17}H_{22}O_3S$ (306.4) calculated: 66.65% C, 7.24% H; found: 66.76% C, 7.38% H.

A mixture of *IVb* (1.1 g), tetra-*n*-butylammonium acetate (6 g) and dimethylformamide (0.2 g) was heated to 135–140°C for 12 hours. The cooled reaction mixture was dissolved in water, extracted three times with pentane, the organic layer was washed with water, dried and the solvent evaporated (column). The residue was dissolved in ether (15 ml) and added to an ethereal solution of lithium aluminium hydride (800 mg in 25 ml). The reaction mixture was worked up in the usual manner, giving 430 mg of crude *Va* which was further purified by chromatography on silica gel (45 g), using pentane–ether (2 : 1) as eluant, and by crystallisation from ligroin. The yield of pure *Va* was 200 mg (36.6%), m.p. 252–254°C (sealed capillary). Mass spectrum: calculated for $C_{10}H_{16}O$: 152.1201, found: 152.1203. The substance exhibited no melting

point depression on admixture with its epimer *IVa*, whereas gas-liquid chromatography showed a single peak with a retention time distinctly different from that of *IVa*. Tosylate *Vb*, m.p. 77.5 to 78°C (methanol), is in all respects identical with the tosylate obtained by rearrangement of *Ib*; on admixture with the epimeric *IVb* it melts at 65–69°C. For $C_{17}H_{22}O_3S$ (306.4) calculated: 66.65% C, 7.24% H; found: 66.87% C, 7.18% H.

exo- and *endo*-4-Hydroxy[4-D]tricyclo[4,4,0,0^{3,8}]decane (*Ic* and *Ile*)

A solution of tricyclo[4,4,0,0^{3,8}]decan-4-one⁶ (1.0 g) in ether (20 ml) was added to a stirred suspension of lithium aluminium deuteride (0.4 g) in ether (20 ml). After 1 hour the mixture was worked up in the usual manner and the alcohols were chromatographed on silica gel (120 g, pentane-ether 4 : 1) affording 312 mg of pure *Ic* and 98 mg of pure *Ile*, and a large middle fraction. The deuterium content of both isomers was 95% d₁.

exo-10-Hydroxy[10-D]tricyclo[4,3,1,0^{3,8}]decane (*Vc*)

Reduction of *III* (1.0 g) with lithium aluminium deuteride (0.4 g) suspension in ether (40 ml) followed by crystallisation of the product from ligroin afforded 850 mg of pure *IVc*, m.p. 266 to 268°C (sealed capillary); *m/e* = 153, deuterium content: 96% d₁.

Tosylate *IVd*, m.p. 92.5–93.5°C (methanol). The conversion of the tosylate *IVd* (1.1 g) into *Vc* was carried out exactly as described for the non-deuterated compound *IVb* and afforded 205 mg of *Vc*, m.p. 265–267°C (sealed capillary); *m/e* = 153, deuterium content 95.5% d₁.

exo-4-Ethoxytricyclo[4,4,0,0^{3,8}]decane (*If*)

A mixture of *Ia* (103 mg), hexamethylphosphoric triamide (1 ml) and 1M ethereal phenyllithium (1.5 ml) was stirred for 1 hour under nitrogen, then ethyl iodide (2 ml) was added and the solution was allowed to stand for two days. The reaction mixture was shaken between water and pentane, the organic layer washed with water, dried and taken down. The residue was chromatographed on a silica gel column (50 mg), yielding 21 mg of the pure product. Mass spectrum: for $C_{12}H_{20}O$ M^+ calculated: 180.1514, found: 180.1511; 134 ($M-C_2H_5OH$), 119, 107, 105, 92, 91, 80, 79. The ethoxy derivatives *If* and *Vf* were prepared in the same manner but they were used only as standards for chromatography without being isolated in the pure state.

Preparation of the Acatates *Ie*, *Ile* and *Ve*

The compounds were prepared by acetylation of the corresponding alcohols with an excess of acetic anhydride in pyridine (room temperature, 2 days). The products have different retention times on gas-liquid chromatography and they were identified by mass spectroscopy, (*m/e*): for *Ie* 194 (M^+ , very small), 152, 151, 134 ($M-CH_3COOH$), calculated for $C_{10}H_{14}$ ($M - 60$): 134.1095, found: 134.1097; for *Ile*: 194 (M^+), calculated for $C_{12}H_{18}O_2$: 194.1307, found: 194.1305, 152, 151, 134 ($M-CH_3COOH$); for *Ve*: 194 (M^+) not discernible, 152, 151, 134 ($M-CH_3COOH$), calculated for $C_{10}H_{14}$: 134.1095, found: 134.1095.

Solvolysis of *Ib* in 70% Acetone

A) A mixture of *Ib* (1000 g) and sodium hydrogen carbonate (2.0 g) in 70% acetone (100 ml) was stirred at room temperature for 20 minutes. The mixture was diluted with water and extracted four times with ether. The combined ethereal extracts were washed with water, dried and evapo-

rated. Chromatography of the residue (835 mg) on a silica gel column (40 g, pentane-ether 2 : 1) afforded 520 mg (53%) of the rearranged tosylate and 245 mg of a mixture of alcohols. Crystallisation of the tosylate from methanol (-20°C) gave 500 mg of *Vb*, m.p. $78-79^{\circ}\text{C}$, undepressed on admixture with an authentic sample.

Since the alcohols *Ia* and *Va* have very similar retention times and an accurate analysis was therefore not possible, a sample of the alcohol mixture was oxidised with Jones reagent in acetone: according to gas-liquid chromatography and IR-spectra the product consisted of 28% 4-twistanone and 72% 10-protoadamantanone. The alcohols (which, as shown by gas-liquid chromatography, did not contain any *Ila*) were chromatographed on silica gel (120 g, pentane-ether 4 : 1). The first fraction (11.2 mg) consisted of the almost pure *Ia*, as proved by its melting point, gas-liquid chromatography and IR-spectrum, the last fractions (76.0 mg) contained pure protoadamantanol *Va*, m.p. $260-261^{\circ}\text{C}$ (sealed capillary), also identified by its spectrum and retention time.

B) A stirred mixture of *Ib* (155 mg) and sodium hydrogen carbonate (0.3 g) in 70% aqueous acetone (15 ml) was heated to 95°C in a sealed ampoule for 5 hours. The reaction mixture was shaken between water and ether, the ethereal layer washed with water, dried and taken down. The residue (70 mg) was dissolved in acetone (1 ml) and titrated with Jones solution (0.17 ml) at 0°C . After one hour's stirring the mixture of ketones was isolated in the usual manner and sublimed. The product consisted of 4-twistanone and *III* in the ratio 3 : 7 (IR-spectrum, gas-liquid chromatography). This ketone mixture (24 mg) was heated under nitrogen with triethylene glycol (2 ml), hydrazine hydrate (0.6 ml) and 2 drops of acetic acid to $90-100^{\circ}\text{C}$ for 18 hours. Potassium hydroxide (0.4 g) was then added and the mixture was heated to $190-200^{\circ}\text{C}$ for 5 hours. The compound which sublimed from the reaction mixture was taken into pentane, the reaction mixture was diluted with water, extracted with pentane, the combined pentane solutions were washed with water and allowed to pass through a silica gel column (25 g). The eluate was evaporated (column) and sublimed at 20 Torr, yield 15.4 mg. The IR-spectrum exhibits only bands attributable to protoadamantane and twistane in the ratio of about 3 : 7.

Solvolysis of *Ib* in 70% Acetone

A stirred (magnetic stirrer) mixture of *Ib* (300 mg) and sodium hydrogen carbonate (600 mg) in 70% aqueous acetone (30 ml) was heated to 95°C in a sealed ampoule for 12 hours. The mixture was diluted with water, extracted with ether, the ethereal extracts washed with water, dried and taken down, affording a mixture of alcohols (130 mg) which contained 6.5% of *Ila* (analysed as alcohols). Analysis of the corresponding acetates (prepared by treatment with acetic anhydride in pyridine) showed that the product consisted of 62% *Va*, 32% of *Ia* and 6% of *Ila*. Oxidation of the alcohols to ketones (Jones reagent) afforded a mixture of 38% of 4-twistanone and 62% of *III* (gas-liquid chromatography, IR-spectra).

Solvolysis of *Vb* in 70% Acetone

A stirred mixture of *Vb* (450 mg) and sodium hydrogen carbonate (1.0 g) in 70% aqueous acetone (50 ml) was heated in an ampoule to 95°C for 5 hours. The usual work-up procedure afforded 210 mg of an alcohol mixture, containing 29% of *Ia* and 71% of *Va* (determined as ketones). Acetylation of a sample of the alcohols gave a mixture of acetates, containing 33% of *Ie*; no *Ile* was detected. The original alcohol mixture was chromatographed on silica gel (120 g, pentane-ether 4 : 1), affording almost pure *Ia* in the first fractions and pure *Va* in the last fractions. Both compounds were identified by their melting points, IR-spectra and gas-liquid chromatography.

Acetolysis of *Ib*

A solution of *Ib* (396 mg) and freshly fused potassium acetate (400 mg) in acetic acid (20 ml) was allowed to stand 2 hours at 20°C. The mixture was diluted with water and extracted three times with ether, the ethereal layers washed with water (2 x), sodium carbonate solution (3 x), again with water and the dried extracts were taken down (column). The residue (350 mg) was chromatographed on silica gel (40 g, pentane-ether 4 : 1) affording 49 mg of acetates and 218 mg of the rearranged tosylate *Vb*, m.p. 79–80°C, identical with an authentic sample, prepared from *Va*. The acetates proved to be a mixture of *Ie* and *Ve* in the ratio 18 : 82. A direct gas-liquid chromatographic analysis of the crude acetolysis mixture showed 18.5% of *Ie*.

Acetolysis of *I Ib*

A solution of *I Ib* (363 mg) and of freshly fused potassium acetate (300 mg) in acetic acid (15 ml) was heated to 100°C for 12 hours. The mixture was diluted with water, extracted with ether, the organic layer washed successively with water, sodium hydrogen carbonate and water, dried and taken down (column). The product (226 mg) contained 21% of *Ie*, 2% of *I Ie* and 77% of *Ve*.

Acetolysis of *Vb*

A solution of *Vb* (200 mg) and fused potassium acetate (200 mg) in acetic acid (10 ml) was heated to 100°C for 8 hours. The work-up procedure was the same as in the case of *I Ib* and afforded 120 mg of a mixture containing 18% *Ie*, 82% *Ve*, and no *I Ie*. Reduction with lithium aluminium hydride and oxidation gave a mixture of 18% 4-twistanone and 82% *III* (gas-liquid chromatography).

Ethanolysis of *Ib*

A) A solution of *Ib* (30.6 mg) and fused potassium acetate (12 mg) in ethanol (5 ml) was kept at 50°C for 30 minutes, the cold mixture was diluted with water, extracted with pentane and directly injected into the gas-liquid chromatograph. The chromatogram showed product contained 35.8% of *If*, the remainder being *Vf*.

B) Solvolysis of *Ib* in ethanol at 30°C for 20 hours (10 half-lives) gave 35.4% of a mixture of *If* and *Vf* as determined by gas-liquid chromatography, using 2 α -methoxy-*trans*-decalin as the internal standard.

Ethanolysis of *I Ib*

A solution of *I Ib* (30.2 mg) and fused potassium acetate (12 mg) in anhydrous ethanol (5 ml) was heated in a glass ampoule to 110°C for 24 hours. The reaction mixture was worked up as described for *Ib*. The product contained 41.8% of *If*, 2.1% of *I If* and 56.1% of *Vf*.

Ethanolysis of *Vb*

A solution of *Vb* (31.1 mg) and fused potassium acetate (12.5 mg) in ethanol (5 ml) was kept at 110°C for 8 hours. The reaction mixture contained 35.6% *If* and 64.4% *Vf*.

Solvolysis of Deuterated Tosylates *Id*, *IId*, *Vd*, and *Vg*

The α -deuterated tosylates *Id*, *IId* and *Vd* were prepared from the corresponding deuterated alcohols exactly as described for the non-deuterated compounds. All were purified by chromatography on silica gel and did not contain the starting alcohols (in the case of *Id* the chromatography was carried out at -10°C) and their m.p. was identical with that of the non-deuterated tosylates. β -Deuterated tosylate *Vg* was obtained by rearrangement of *Id* (see the solvolysis of *Ib*). The deuterium content of these tosylates is given in Table III, footnotes *c* and *i*, and is assumed to be the same as that of the starting alcohols. The solvolyses were carried out as described for the non-deuterated tosylates. In acetolysis experiments, the acetates were converted into alcohols by lithium aluminium hydride reduction (the deuterium content of the alcohol mixtures is given in Table III). The alcohols were partially separated by chromatography on silica gel (500-fold excess) with pentane-ether (4:1) as eluant, the fractions were oxidized with Jones reagent, and the mixture of ketones was analysed by gas-liquid chromatography. The deuterium content was determined by mass spectrometry; for a given ratio of ketones a mixture of non-deuterated ketones of the same composition was used as standard. The compositions of the ketone mixtures and their deuterium content are given in Table III.

Kinetic Measurements

The solvolysis rates were measured conductometrically in 50 ml cells with bright platinum electrodes²⁹. The initial concentration of the tosylates was approximately $2 \cdot 10^{-4}$ and the reaction was followed for three half-lives.

At least two measurements at each temperature were carried out, the reproducibility of the rate constants being 0.2% or better in 70% ethanol and 0.5% or better in 100% ethanol. The values of the rate constants are listed in Table I.

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REFERENCES

1. Lenoir D., Schleyer P. von R.: Chem. Commun. 1970, 941.
2. Paquette L. A., Meehan G. V., Marshall S. L.: J. Amer. Chem. Soc. 91, 6779 (1969).
3. Pozdnikina S. G., Morozova O. E., Petrov A. A.: Neftekhimiya 13, 21 (1973).
4. Engler E. M., Farcasiu M., Sevin A., Cense J. M., Schleyer P. von R.: J. Amer. Chem. Soc. 95, 5769 (1973).
5. Whitlock H. W. jr, Siefken M. W.: J. Amer. Chem. Soc. 90, 4929 (1968).
6. Gauthier J., Deslongchamps P.: Can. J. Chem. 45, 297 (1967).
7. Tichý M., Sicher J.: This Journal 37, 3106 (1972).
8. Bélanger A., Lambert Y., Deslongchamps P.: Can. J. Chem. 47, 795 (1969).
9. Bingham R. C., Schleyer P. von R., Lambert Y., Deslongchamps P.: Can. J. Chem. 48, 3739 (1970).
10. Tichý M., Kniežo L., Hapala J.: Tetrahedron Lett. 1972, 699.
11. Tichý M., Kniežo L.: This Journal 38, 1537 (1973).
12. Kraus W., Chassin C.: Tetrahedron Lett. 1970, 1443.

13. Wigger N., Ganter C.: *Helv. Chim. Acta* 55, 2769 (1972).
14. Cupas C., Schumann W., Heyd W. E.: *J. Amer. Chem. Soc.* 92, 3237 (1970).
15. Tichý M., Sicher J.: *This Journal* 36, 1426 (1971).
16. Lenoir D., Hall R. E., Schleyer P. von R.: *J. Amer. Chem. Soc.* 96, 2138 (1974).
17. Wicker K., Ackermann P., Ganter C.: *Helv. Chim. Acta* 55, 2744 (1972).
18. Teufel H., Jenny E. F., Heusler K.: *Tetrahedron Lett.* 1973, 3413.
19. Spurlock L. A., Clark K. P.: *J. Amer. Soc.* 94, 5349 (1972).
20. Goering H. L., Schewene C. B.: *J. Amer. Chem. Soc.* 87, 3516 (1965).
21. Brown H. C., Liu K.-T.: *J. Amer. Chem. Soc.* 89, 466 (1967).
22. Brown H. C., Rei M. H.: *J. Amer. Chem. Soc.* 90, 6216 (1968).
23. Goering H. L., Humski K.: *J. Amer. Chem. Soc.* 90, 6213 (1968).
24. Goering H. L., Brown C., Schewene C. B.: *J. Amer. Chem. Soc.* 90, 6214 (1968).
25. Lenoir D., Raber D. J., Schleyer P. von R.: *J. Amer. Chem. Soc.* 96, 2149 (1974).
26. Engler E. M., Andose J. D., Schleyer P. von R.: *J. Amer. Chem. Soc.* 95, 8005 (1973).
27. Allinger N. L., Tribble M. T., Miller M. A., Wertz D. W.: *J. Amer. Chem. Soc.* 93, 1637 (1971).
28. Schleyer P. von R.: Unpublished results.
29. Hapala J.: *Thesis*. Czechoslovak Academy of Sciences, Prague 1971.
30. Späth H.: *Algorithm* 295, *Commun. ACM* 10, 87 (1967).
31. Mossin E.: *Gier System Library*, *Algorithm* 127. A/S Regnecentralen, Copenhagen 1962.

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