141. Synthesis of Potential Ambra Odorants: 5,5,9-Trimethyldecalyl Derivatives

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Summary. The synthesis of racemic stercoisomeric compounds with the 5,5,9-trimethyldecalin skeleton and an oxygen function at C(1), C(2) or C(3) is described[1]). A novel general one-step synthesis of 2-decalones by means of acid catalyzed cyclization of acyclic or monocyclic precursors has been developed.

Introduction. – It has been shown that a large number of *trans*-decalins containing oxygen functions exhibit a typical ambra odour [1a]. They are chemically similar to the triterpene ambreine [2] [3], and the diterpenes sclareol [4] [5] and manool [6]. The fusion (*cis* or *trans*) of the rings and the configuration of the substituent at C(2) are the common structural properties thought to be responsible for specifically stimulating the human olfactory system and generating the impression of ambra odour [1b]. The chemical nature of the oxygen-containing group is less important.

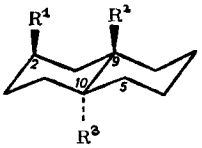


Fig. 1. *Triaxial rule of odour sensation*

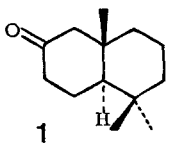
2,9,10-Triaxial arrangement of the substituents R in the *trans*-decalin ring system, one of these axial groups R being an oxygen function, is the geometrical requirement for a molecule in order to exhibit an ambra type odour [1a].

The triaxial rule of odour sensation [1a] (see Fig. 1) is based upon these observations. The high specificity of odour sensation has led to various speculations concerning the molecular mechanism on the receptor site of the human olfactory system [7] [8] [9]. Systematic investigation of the stereochemistry of odour stimuli should establish the scope and limitation of odour theories based on the nature and spacial

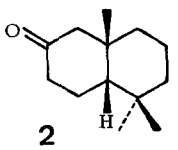
[1]) Although racemic decalins are described, only the enantiomer related to steroids is drawn. The projection of the decalins was chosen so as to place the angular methyl group above the plane of the molecule and the oxygen function at C(1), C(2) or C(3) on the left side, as represented by formula **1–6**. The relative configuration of the substituents in decalins is designated by using the convention of the steroid series: β, meaning on the same side as the angular methyl group at C(9) and α, meaning on the side opposite from the angular methyl group. The prefix *cis* or *trans* refers to the fusion of the decalin ring system, not to the position of the substituents.

arrangement of molecular odorants. The present paper attempts to supply the experimental basis for a defined group of odorants, the ambra group; their olfactive properties will be discussed in a future publication. The synthesis of racemic, stereoisomeric compounds having the 5,5,9-trimethyldecalinskeleton and possessing an oxygen function (ketone, alcohol, ester, epoxide) at C(1), C(2) or C(3) is described.

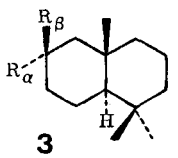
Scheme 1



1

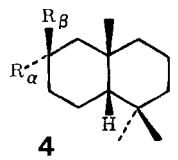


2



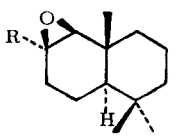
3

a R_α = H ; R_β = OH
a' R_α = OH ; R_β = H
b R_α = H ; R_β = OAc
b' R_α = OAc; R_β = H
c R_α = CH_3; R_β = OH
c' R_α = OH ; R_β = CH_3
d R_α = CH_3; R_β = OAc
d' R_α = OAc; R_β = CH_3

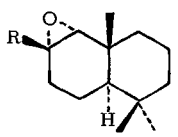


4

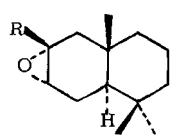
a R_α = H ; R_β = OH
a' R_α = OH ; R_β = H
b R_α = H ; R_β = OAc
b' R_α = OAc; R_β = H



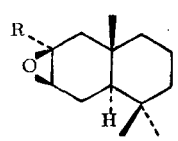
5a R = H
a' R = CH_3



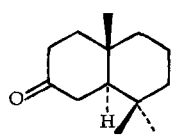
5b R = H
b' R = CH_3



6a R = H
a' R = CH_3



6b R = H
b' R = CH_3



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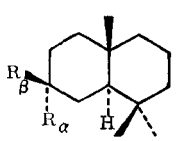


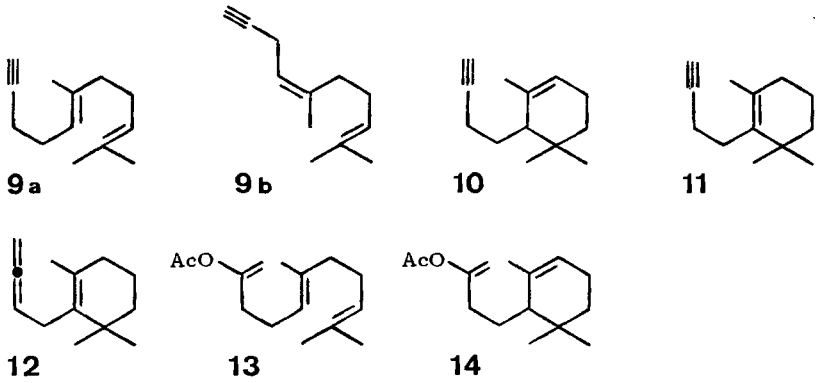
8

a R_β = OH ; R_α = H
a' R_β = H ; R_α = OH
b R_β = OAc; R_α = H
b' R_β = H ; R_α = OAc

The synthetic routes chosen. – *Preparation of the key intermediates* **1** *and* **2.** Diastereomeric ketones **1** [10] and **2**, used as key intermediates, afford sure and easy access to this group of compounds. Several synthetic approaches were considered for

the preparation of the diastereomeric ketones. Biogenetic type cyclizations [11] [12], as used in sesquiterpene chemistry, were especially appealing; *e.g.* the well known transformations of acyclic 1,5,9-trienes or monocyclic 1,5-dienes to bicyclic compounds [13].

Scheme 2



It was hoped to obtain the ketones **1** and/or **2** directly by acid catalyzed cyclization of a suitable acyclic (**9a**, **9b**, **13**) or monocyclic (**10**, **11**, **12**, **14**) precursor[2]). Indeed, cyclization of the acyclic *trans*-dienyne **9a** with conc. sulfuric acid in hexane at 0° gave 64% yield of diastereomeric decalins consisting mainly of **1** (93%) and a little **2** (7%) (Table 1, Exp. 6a). On the other hand the *cis*-dienyne **9b** (~80% pure *cis*) yie ded predominantly the *cis*-decalone **2** (~80% pure *cis*), the cyclization of **9a** and **9b** in H_2SO_4/hexane being therefore *highly stereospecific*.

In clear contrast to the acyclic case, cyclization of the monocyclic alkynes **10** and **11** (1:1 mixture) is scarcely stereospecific as the product ratio **1**/**2** is close to unity (Table 1, Exp. 6f and g).

With precursors other than alkynes, *i.e.* with enol acetate mixtures **13**/**21** and **14**/**22**, and with the allene **12**, yields (Table 1, Exp. 6e, h, k) and stereoselectivity (Exp. 6e, k) are definitely lower. It should be pointed out, however, that only the terminal enol acetates **13** and **14** can undergo the desired cyclization to give **1** and/or **2**, whereas the non-terminal enol acetates **21** and **22** are expected to yield some structurally isomeric cyclization product(s). Indeed, cyclization of the relatively pure **14** (containing less than 20% of its isomer **22**) exclusively led to the decalones **1**/**2**, and cyclization of a 1:1 mixture of **13** and **21** gave the decalones **1**/**2** *together with* two by-products of the same molecular weight (194)[3]). Unfortunately it was not possible to synthesize pure **13** and **14** by the method used (*vide infra*). For the strong solvent dependence of all the cyclization reactions listed in Table 1 see Discussion.

The structures of **1** and **2** are in accordance with their spectra (IR., NMR., MS., see p. 1421 and Exp. Part) and were further proved by correlating them chemically *via*

[2]) Participation of the triple bond in cyclization has been reported by *Hanack et al.* [14], *Peterson & Kamak* [15], and very recently by *Johnson* (→ steroid synthesis) [16].

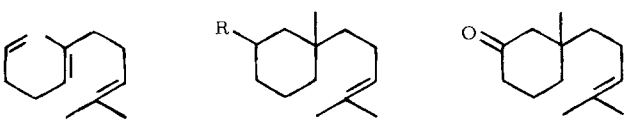
[3]) The determination of their structure is at present under investigation and will be the subject of a future publication.

Table 1. *Decalones* **1** *and* **2** via *acid catalyzed cyclization of acyclic* (**9**, **13**) *or monocyclic* (**10**, **11**, **12**, **14**) *precursors*

Experiment no corresp. to the Experimental Part	Starting material		Reaction conditions	Product ratio % **1** (*trans*)	% **2** (*cis*)	Yield % (**1**+**2**)
	precursors:					
6a	acyclic	**9a**	H_2SO_4/hexane/0–5°/½ h	93	7	65
6b		**9a**	H_2SO_4/AcOH/35–40°/3 h	84	16	50
6c		**9b**	H_2SO_4/hexane/0–5°/½ h	20	80	46
6d		**9b**	H_2SO_4/AcOH/35–40°/3 h	45	55	38
6e		**13**+**21** (42:58)	H_2SO_4/hexane/0–5°/½ h	84	16	30
6f	monocyclic	**10**+**11** (1:1)	H_2SO_4/hexane/0–5°/50 min	34	66	77
6g		**10**+**11** (1:1)	H_2SO_4/AcOH/35–40°/4½ h	49	51	60
6h		**12**	H_2SO_4/hexane/0–5°/45 min	30	70	~2
6i		**12**	H_2SO_4/AcOH/H_2O/50°/15 h	51	49	~2
6k		**14**+**22** (4:1)	H_2SO_4/hexane/0–5°/35 min	39	61	30

unambiguous transformations with known compounds: 1-carbomethoxy-5,5,9-trimethyl-*trans*-decal-2-one [17] with KI/DMF/5h at reflux gave pure **1**[4]), while 5,5-dimethyl-$\Delta^{1,9}$-octal-2-one [18], treated with dimethylcopperlithium[5]), formed **2**.

Scheme 3



15 **16a** R = OAc **b** R = OH **17**

A slightly different and more classical approach to the key intermediates **1** and **2** was offered by the acid catalyzed cyclization of triene **15** *via* decalyl alcohols **3a'** and **4a'** and subsequent chromic acid oxidation. It is evident from Table 2 that the *trans*-equatorial isomer **3a'** is formed preferentially (61–73% of the reaction mixture, depending on the reaction conditions), and the *cis*-equatorial isomer **4a'** is only a minor (18–7%) reaction product. Apart from these two desired decalins there is considerable formation of two by-products; namely cyclization in AcOH/H_2SO_4 at

[4]) For a further synthesis of **1** see [10].

[5]) Addition of methylcopper(I) derivatives to $\Delta^{1,9}$-octal-2-one systems are known to form the 9-methyl-*cis*-decalin derivatives stereoselectively; see [19] and footnote 5 therein.

35–40° gives, after saponification, the diastereomeric monocyclic alcohols **16b**[6]) (21% of the reaction mixture) and cyclization in dioxane/HCOOH/H_2SO_4 at 50–60° with subsequent hydrolysis forms the decalol **8a'**[7]) (20% of the reaction mixture), structurally isomeric to **4a'**.

Table 2. *Compounds* **3a'**, **4a'**, **8a'**, *and* **16b** via *acid catalyzed cyclization of triene* **15** *and subsequent saponification of the intermediate decalyl groups*

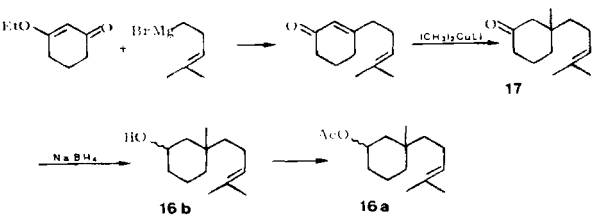
Experiment no	Starting material	Reaction conditions	Product distribution after cyclization (esters)	Product distribution after subsequent saponification (alcohols)
9, 10	**15**	AcOH/H_2SO_4/35–40°/3½ h	**3b'** (57%) **4b'** (22%) **16a** (21%)	**3a'** (61%) **4a'** (18%) **16b** (21%)
12, 13	**15**	Dioxane/HCOOH/H_2SO_4/ 50–60°/3½ h	not determined	**3a'** (73%) **4a'** (7%) **8a'** (20%)

The choice of ketones **1** and **2** as key intermediates proved fortunate because the alcohols **3a'** and **4a'** are difficult to purify on a preparative scale.

Chromic acid oxidation of the mixture of alcohols obtained *via* the triene **15** cyclization gave a mixture of ketones from which the main product, *trans*-decalone **1**, was readily isolated in pure form by crystallization from hexane. The minor products were, as expected, **2** and **17**[6]) or **2** and **7** [21].

Preparation of the acyclic (**9a** [22], **9b**, **13/21**) *and monocyclic* (**10/11**, **12**, **14/22**) *precursors.* The acyclic acetylenic *trans*-precursor **9a** (~95% isomerically pure) was readily accessible from geranyl bromide as described by *Corey & Kirst* [22c], while the *cis*-isomer **9b** (~80% isomerically pure) was prepared analogously from neryl chloride which had been obtained from nerol by the chlorination method of *Stork* [23]. The monocyclic alkynes **10** and **11** together with the allene **12** were available from dihydro-α-ionone **19** *via* the known chlorination (with PCl_5 to give **20**) -dehydrochlorination (with $NaNH_2$ in paraffin oil) sequence[8]). The alkynes **10** and **11** thus formed as solid sodium derivatives can be selectively removed from the reaction mixture by filtration, leaving the liquid allene **12** in the filtrate. Subsequent hydrolysis of the precipitate gives a 1:1 mixture of **10** and **11**, and distillation of the filtrate yields pure **12**.

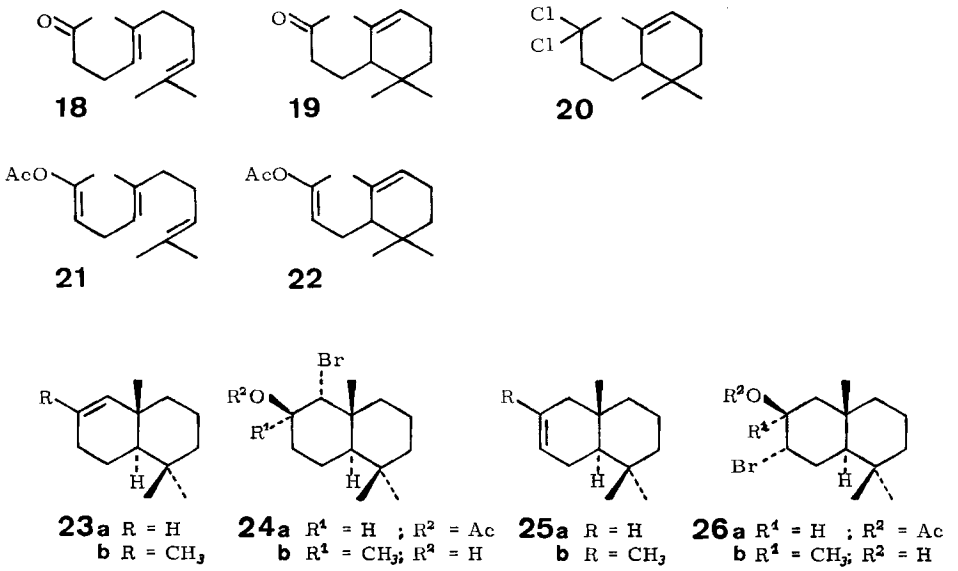
[6]) Product independantly obtained during the following transformations [20]:



[7]) Unambiguously prepared from ketone **7** [21], see Exp. Part 36.

[8]) Following the method given by [24].

Scheme 4



The terminal enol acetates **13** and **14** (contaminated with the non-terminal enol acetates **21** and **22** respectively) were prepared from the corresponding ketones dihydro-α-ionone **19** and *trans*-geranylacetone **18** [25] by the method of *House et al.* [26]: *i.e.* formation of the enolate with triphenylmethylpotassium of triphenylmethyllithium and its subsequent trapping with acetic anhydride. Despite the fact that this procedure is laborious and gives an isomeric mixture of acetate in moderate yields it is nontheless the best available at present. An isomeric mixture with at least 80% of the desired terminal isomer **14** was obtained from dihydro-α-ionone **19**/triphenylmethyllithium/Ac_2O whereas only a 42:58 mixture of **13** and **21** resulted from *trans*-geranylacetone **18**/triphenylmethylpotassium/Ac_2O.

The *trans*-triene **15** [27] was prepared *via* a *Wurtz*-type reaction using a mixture of geranyl bromide and allyl bromide with magnesium.

Decalyl derivatives of the trans-*ketone* **1**. Reduction (see Table 3) of **1** by Na/NH_3 gave pure equatorial alcohol **3a'** (mp. 48–51°), while $NaBH_4$ in methanol produced a mixture of equatorial (**3a'**, 37%) and axial (**3a**, 63%) alcohol. Acetylation with Ac_2O/Py led to the corresponding acetates: pure **3b'**, and a 2:1 mixture of **3b** and **3b'**. In order to obtain, in addition, the pure alcohol **3a** and its acetate **3b**, both of which are difficult to separate from their epimers **3a'** and **3b'**, a stereoselective method of preparation was needed.

Steroid chemistry shows that acetoxy groups can be introduced by bromoacetate addition to unsaturated steroids[9]). When a 1:2 mixture of octalins **23a** and **25a** (from a mixture of acetates **3b** (63%) and **3b'** (37%) *via* pyrolysis at 450°) was shaken with bromoacetamine in acetic acid, two isomeric diaxial bromoacetates **24a** (mp. 153–154,5°) and **26a** (mp. 81–83°), separable by fractional crystallization, were

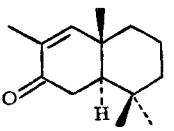
[9]) See *e.g.* ref. [28], page 606ff.

Table 3. *Decylyl alcohols* **3a**, **3a'**, **4a**, **4a'**, **8a**, *and* **8a'** *by means of reduction of the corresponding ketones*

Experiment no	Starting ketone	Reaction conditions	Product distribution	Yield of isomeric mixture
15	**1**	Na/NH_3	**3a'** (100%)	87%
17	**1**	$NaBH_4$	**3a** (63%) **3a'** (37%)	~ quant.
33	**2**	Na/*i*-PrOH	**4a'** (77%) **4a** (23%)	~ quant.
34	**2**	$NaBH_4$	**4a'** (55%) **4a** (45%)	~ quant.
36	**7**	$NaBH_4$	**8a** (88%) **8a'** (12%)	87%

formed. Reductive elimination of bromide from **24a** (or **26a**) with triphenyltin hydride [29] afforded pure acetate **3b** and, after subsequent saponification, pure alcohol **3a**.

Reactions of ketone **1** with methyllithium or methylmagnesium bromide led to only one isomer, the axial alcohol **3c**, which was acetylated to **3d** and dehydrated (by $KHSO_4$) to give a mixture of tetramethyloctalins **23b** (14%) and **25b** (86%). The equatorial alcohol **3c'** was obtained from octalin mixture **23b**/**25b** *via* epoxidation with peracetic acid (to give **5b'**, 18%, and **6a'**, 36%) and subsequent $LiAlH_4$ reduction. The epoxides **5a'** and **6b'** were formed by treatment of **23b** and **25b** with NBS/AcOH followed by potassium *t*-butoxide. Formation of epoxide **5a'**, however, was very sluggish, and a side-reaction, a formal allylic oxidation of **23b** to give the α,β-unsaturated ketone **27**, was observed.



27

Epoxidation of the octalins **23a** and **25a** with peracetic acid gave **5b** and **6a**, while their epimers **5a** and **6b** were available from the corresponding bromoacetates **24a** and **26a** by treatment with methanolic KOH.

Decalyl derivatives derived from the cis-*fused ketone* **2**. Reduction with either Na or $NaBH_4$ gave an isomeric mixture of **4a'** and **4a** (Table 3, Exp. 33 and 34), which was acetylated (Ac_2O/Py) to give the corresponding acetates **4b'** and **4b**, the pure isomers being obtained by GLPC.

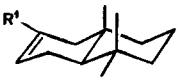
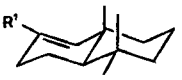
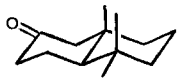
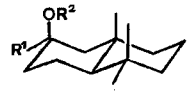
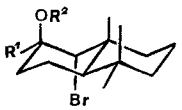
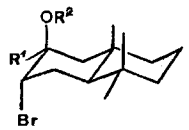
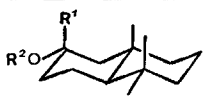
Decalyl derivatives derived from the trans-*ketone* **7**. $NaBH_4$ reduction of ketone **7** gave an isomeric mixture of **8a** (88%) and **8a'** (12%) which was separated by chromatography and crystallization. The pure alcohols were then acetylated yielding the pure acetates **8b** and **8b'**.

NMR. spectra[10]) *of the decalins.* Table 4 summarizes some typical chemical shifts of all decalins obtained in the present work. The structures of most compounds of the *trans*-series were evident from their mode of preparation and have been further corroborated by their NMR. spectra.

The three *t*-CH_3-groups of **1**, which resonate very close together, were *tentatively* assigned using $Eu(fod)_3$ [31] as a chemical shift agent[11]) in conjunction with a qualitative estimate of the expected shifts. Both angle and distance dependence of the shift induced were considered using the pseudo-contact equation of *McConnell & Robertson* [33].

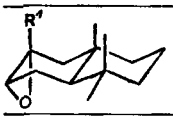
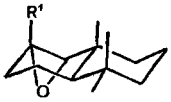
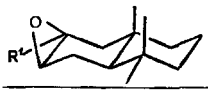
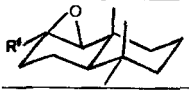
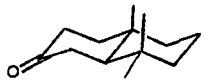
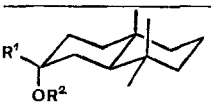
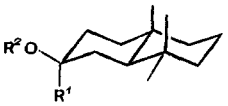
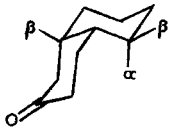
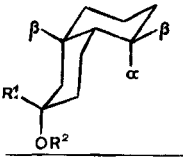
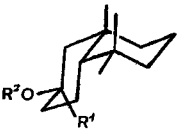
Table 4. *NMR. spectra of the* trans- *and* cis-*5,5,9-trimethyldecalin derivatives: chemical shift values* (δ) *of some typical groups at 25° with TMS as an internal standard*

A: trans-*Decalyl derivatives*

Structure	R^1	R^2	No	Chemical shifts (δ) of typical protons R^1	R^2	C(5)-$(CH_3)_2$		C(9)-CH_3	Remarks
	H		**25a**			0.87	0.87	0.88	a
	CH_3		**25b**	1.55		0.86	0.86	0.86	a
	H		**23a**			0.85	0.88	0.97	a
	CH_3		**23b**	1.57		0.84	0.88	0.92	a
			**1**			0.87**	0.98*	0.91	b, c
						0.86**	0.96*	0.86	a
	H	H	**3a**	4.1		0.84	0.88	1.16	b
						0.85	0.85	1.12	a
	H	Ac	**3b**	4.94	1.93	0.85	0.88	1.04	a
	CH_3	H	**3c**	1.09		0.82	0.85	1.05	a
	CH_3	Ac	**3d**	1.4	1.92	0.83	0.87	0.98	a
	H	Ac	**24a**	5.21	1.97	0.85	0.9	1.22	C_6D_6/ acetone-d_6
	H	Ac	**26a**	4.95	2.03	0.85	0.85	1.05	CCl_4/ DMSO-d_6
	H	H	**3a'**	3.82		0.79	0.88	0.94	b
	H	Ac	**3b'**	4.8	1.89	0.81	0.88	1.0	a
	CH_3	H	**3c'**	1.25		0.77	0.85	0.95	a
	CH_3	Ac	**3d'**			0.78	0.87	0.98	a

[10]) For a comprehensive source of references see [30].

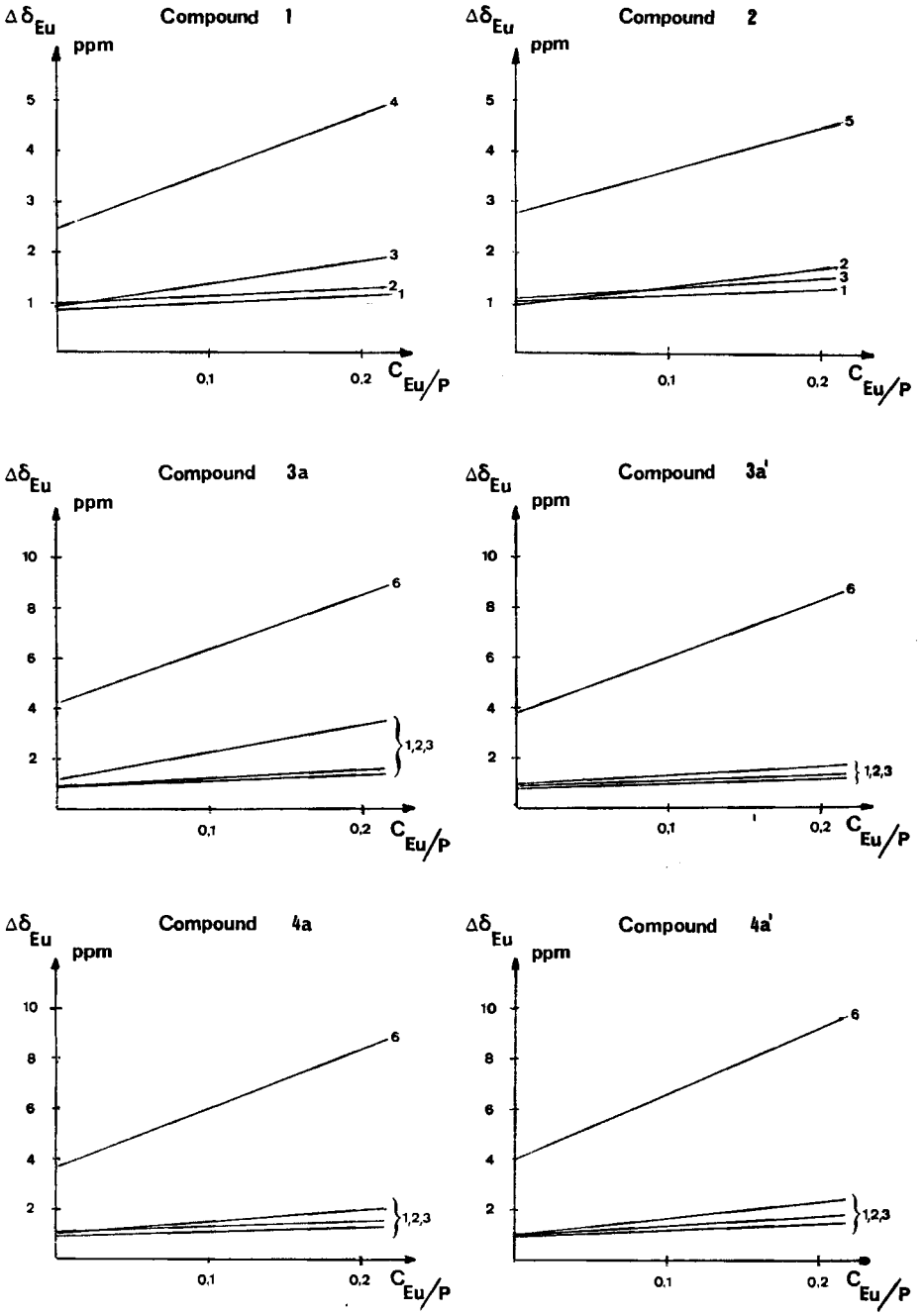
[11]) For a recent survey on shift agents in NMR. spectroscopy see [32]. Following a suggestion given by Prof. *E. Wenkert,* Indiana University, we use the term shift *agent* instead of shift reagent.

Structure	R^1	R^2	No	Chemical shifts (δ) of typical protons R^1	R^2	C(5)-$(CH_3)_2$		C(9)-CH_3	Remarks
	H		**6a**			0.84	0.84	0.88	a
	CH_3		**6a'**	1.18		0.84	0.84	0.84	a
	H		**5b**			0.78	0.83	1.02	a
	CH_3		**5b'**	1.18		0.79	0.83	0.97	a
	H		**6b**			0.81	0.85	0.95	a
	CH_3		**6b'**	1.18		0.81	0.85	0.95	a
	H		**5a**			0.78	0.82	1.02	a
	CH_3		**5a'**			0.8	0.86	1.05	b
			**7**			0.85	0.85	1.12	a
	H	H	**8a'**	4.1		0.8	0.85	0.93	a
	H	Ac	**8b'**	5.06	1.96	0.8	0.8	0.94	a
	H	H	**8a**	3.5		0.84	0.87	0.96	a
	H	Ac	**8b**	4.55	1.94	0.82	0.88	0.98	a
B: cis-*Decalyl derivatives*									
			**2**			1.06**	0.98*	1.11	b, c
	H	H	**4a'**	3.78		1.04	0.98	0.93	b
	H	Ac	**4b'**	4.9	1.92	1.08	1.08	0.98	a
	H	H	**4a**	3.72		0.87	1.12	1.12	b
	H	Ac	**4b**	4.7	1.9	0.88	1.11	1.11	a

a) 60-MHz spectra in CCl_4.
b) 90-MHz spectra in $CDCl_3$.
c) Tentativc assignment of the CH_3-signals by means of Eu(fod)$_3$.
d) Tentative assignment of the CH_3-signals by analogy.

* α-CH_3
** β-CH_3

Fig. 2. *Chemical shift induced by Eu(fod)$_3$ ($\Delta\delta_{Eu}$) versus ratio of Eu(fod)$_3$/product* ($C_{Eu/P}$)



1) C(5)-CH_3 (β) 2) C(5)-CH_3 (α) 3) C(9)-CH_3 (β)
4) C(3)-CH< (β) 5) C(1)-CH< (β) 6) C(2)-CH<

In the case of the decalones Eu was located 0.6 Å below (α side) the C=O axis at a distance of 2.5 Å from oxygen; because of the uncertainty encountered with chemical Eu-shift calculations in general[12]) and because of the rather rough estimate used in our case, we emphasize that the assignment of the C(5) methyl groups is only tentative.

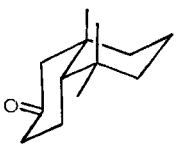
The chemical shift dependence of the angular C(9) methyl group on substitution at C(2) was found to be in excellent agreement with C(2) substituted 5 α-steroids (see Table 5).

Table 5. trans-*5,5,9-Trimethyl-2-decalyl derivatives, and 5α-steroids substituted at C(2): effect of substituents on the chemical shift of the angular methyl group*

5α-Steroids[13])	Downfield shift (Hz) of the ang. CH_3-group at 60-MHz	*trans*-Decalins		Downfield shift (Hz) of the ang. CH_3-group at 60-MHz
Δ^2	0	Δ^2	**25a**	0
2-Oxo	−1.5	2-Oxo	**1**	−1.2
2β-OH	15.0	2-OHβ	**3a**	14.4
2β-OAc	9.0	2-OAcβ	**3b**	9.6

The structure and configuration of *cis*-ketone **2** are evident from its mode of preparation and further supported, but not proved, by the NMR. spectrum.

As **2** might exist in either the stable steroid ($\mathbf{2_x}$) or the stable nonsteroid ($\mathbf{2_y}$) conformation or might also exhibit a rapidly equilibrating mixture of the steroid and non-steroid conformer, temperature NMR. measurements were made. There was no characteristic change in the NMR. spectrum from −90° to +120°[14]) and therefore **2** exists in one stable conformation. On the basis of Eu shift experiments we *tentatively* prefer the non-steroid conformation $\mathbf{2_y}$.



2_x
steroid conformation

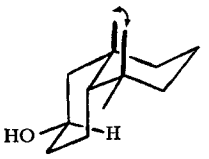
2_y
non-steroid conformation,
preferred

The configurational assignment of the two *cis*-decalols **4a** and **4a'** was, however, not feasible on the basis of their mode of preparation. The NMR. spectra of both conformers showed typical axial hydrogens at 3.72 and 3.78 ppm respectively, and temperature NMR. experiments (−100° to +140°) revealed the prevalence of one stable conformation for the *cis*-decalols. The findings are well understood in the light of conformational analysis considering unfavourable 1,3-diaxial interactions:

[12]) For a recent paper dealing with these difficulties see [34].

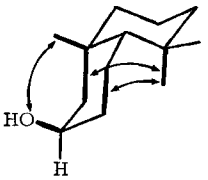
[13]) Values taken from [35], p. 19.

[14]) Contrary to the *cis*-decalin derivatives **2**, **4a'** and **4a**, 10-methyl-*cis*-2-decalone is known to exist as a rapidly equilibrating mixture of conformers at room temperature; it exhibited a spectrum with band broadening at −20° to −30° and an increase in the fine structure at −65° to −70° as described earlier [36].



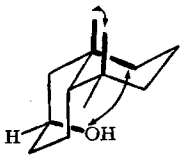
4a$_x$

steroid conformation, ***preferred***



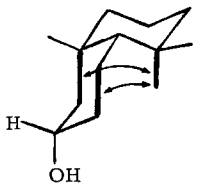
4a$_y$

non-steroid conformation



4a'$_x$

steroid conformation

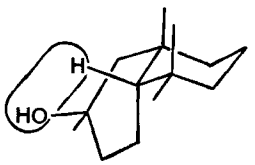


4a'$_y$

non-steroid conformation, ***preferred***

$Eu(fod)_3$ experiments with both *cis*-decalols, however, did not allow us to make a configurational assignment. This is not surprising as the theory describing the lanthanide pseudo-contact shifts, when applied to our rather complex decalols, contains too many unknown variables.

Fortunately mass spectrometry offered an elegant configurational assignment of the two decalols by observation of the intensity of the M-H_2O peak. *Green & Roy* [37] have shown by means of deuterium labelling that cyclohexanols lose their water preferentially in a 1,4-fashion *via* a boat transition state. Compound **4a** in its boat conformation **4a$_z$** is therefore expected to lose water more easily than compound



4a$_z$

4a', and indeed the M-18 fragments observed are 23% of the total ionization ε_{29} for **4a**, and 10% of the total ionization ε_{29} for **4a'** *).

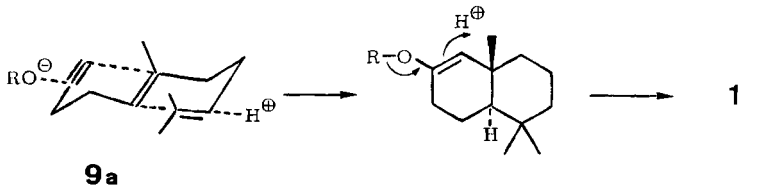
An investigation of these decalin derivatives by means of ^{13}C-NMR. spectroscopy is being conducted by *Wenkert* [38].

*) We like to thank Prof. Dr. *J. J. Uebel* and Miss *S. Story* (University of New Hampshire) for the configurational assignment of **4a** and **4a'** using a computer program to find the best least squares fit of our measured $Eu(fod)_3$ shift effect. Their result corroborates our assignment based on mass spectrometry.

Discussion of the syntheses. – A short survey on the synthetic routes chosen and the compounds obtained was given in the preceding section. Here the reactions carried out (*i.e.* acid catalyzed cyclization, reduction of decalones, *Grignard* addition to decalones, electrophilic addition of bromoacetate and peracid to octalins, reductive opening of epoxydecalins) are discussed in detail with special emphasis on the stereochemistry.

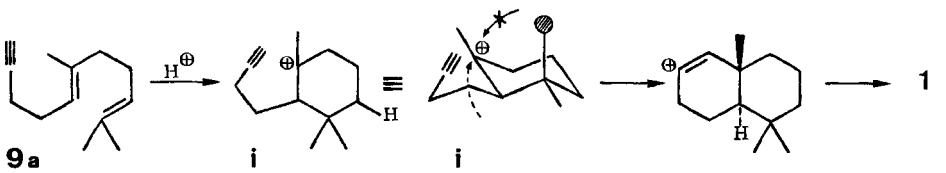
1. *Acid catalyzed cyclizations. Eschenmoser* [17] [39] and *Stork* [40] were the first to establish rules about the stereochemistry of completely synchronous polyene cyclizations. They soon recognized that many cases, such as the acid catalyzed cyclization of farnesic and desmethylfarnesic acid, are non-stereospecific; the preferential formation of the *trans*-decalin skeleton depends on factors other than the geometry of the original olefinic bond [41]. On the other hand *Johnson* [11a] reported some highly stereospecific cyclizations with dienoic acetals, sulfonate esters, and allyl alcohols, giving either *trans*- or *cis*-decalins, depending on the configuration of the starting material. Similar stereospecificity has been obtained by Russian workers [42] on cyclizing *cis*- and *trans*-geranylacetone to bicyclic *cis*- or *trans*-hexahydrochromenes. They pointed out that the stereospecificity of such an electrophilic addition of AB to a central double bond is mainly governed by both the electrophilicity of A and the nucleophilicity of B, which explains the lack of specificity with a poor nucleophile B such as –CH=CH–COOR in the case of farnesic acid [41], and the high specificity with a strong nucleophile B such as >C=O in the geranylacetone cyclization [42].

The cyclization of the acyclic *trans*-dienyne **9a** (see Table 1, Exp. 6a/b) gives a high proportion of the *trans*-decalone **1**. Mechanistic pathways which account for this result are: (1) concerted addition to the Δ^5-double bond, (2) stepwise addition



9a

via a monocyclic cationic intermediate **i** during which the attack of the alkyne is sterically controlled by the axial methyl group[15]), (3) stepwise addition *via* a cationic intermediate which reacts faster than it equilibrates (see [41]).



9a **i** **i**

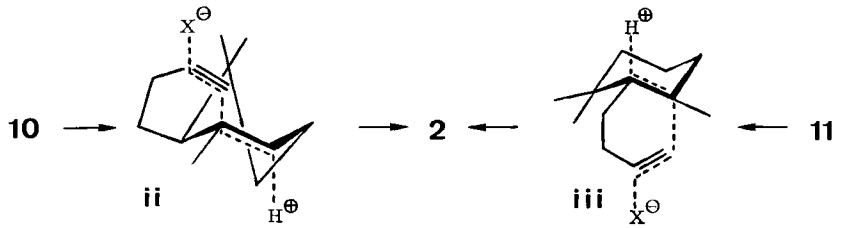
The actual mechanism cannot be decided from our results; a variety of competing pathways with similar energy of activation may also be considered.

[15]) For arguments explaining the preferential formation of a *trans*-decalin system without steric control of the above mentioned methyl group see [12a].

The cyclization of the acyclic *cis*-dienyne **9b** in H_2SO_4/hexane at 0° (see Table 1, Exp. 6c) gives a high proportion of the *cis*-decalone **2**. This remarkable stereospecificity can be accounted for by (1) concerted addition to the Δ^5-double bond or (2) a stepwise addition *via* a shortlived non-equilibrating cationic intermediate. The dienynes **9a** and **9b** are thus further examples where the formal cyclization rule of *Eschenmoser* and *Stork* is followed.

The cyclization of the monocyclic alkynes **10** and **11** (1:1 mixture) under the same conditions shows little or no specificity (see Table 1, Exp. 6f and g), implying that the intermediate(s) involved (if any) are not identical to the one(s) in the acyclic case.

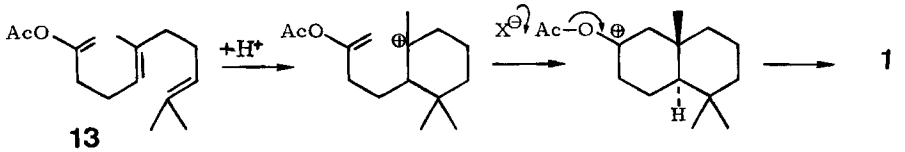
(1) Concerted addition to the double bond in **10** through a chair-like transition state **ii** would lead to the *cis*-decalone **2**, as would concerted addition to the double bond in **10** through a chair-like transition state **iii** (or through the less favorable twist-like transition state).



(2) A pathway through an intermediate of type **i** would preferentially lead to the *trans*-product and therefore cannot account for the *cis*-product formed.

In both the acyclic and the monocyclic cyclization the stereospecificity shows a remarkable solvent dependence. Hexane, compared to acetic acid, exhibits greater stereospecificity: the *trans*-isomer **9a** in hexane/H_2SO_4 gives 93% *trans*-decalone **1** while in AcOH/H_2SO_4 only 84% is obtained; the *cis*-isomer **9b** in hexane/H_2SO_4 yields 80% pure *cis*-decalone **2**, whereas in AcOH/H_2SO_4 only 55% **2** together with 45% of *trans*-isomer **1** is found. The same trend, although less pronounced, applies to the other cyclizations investigated (Table 1, Entries 6f–i).

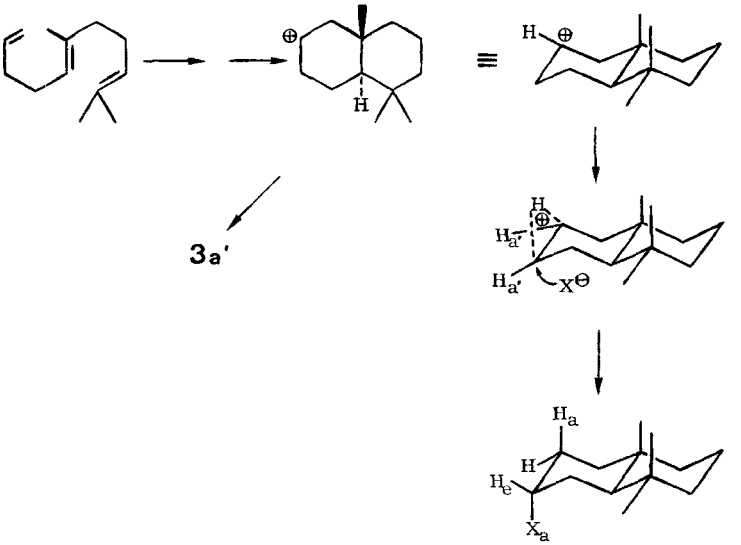
The enol acetates **13** and **14** as well as the alkynes **9**, **10** and **11** have the oxidation level of a ketone. Protonation of the isopropylidene double bond of **13** or **14**, followed by cyclization yields **1** and **2**. The same general arguments concerning the reaction mechanism apply to the cyclization step, which is responsible for the stereochemi try of products; for simplicity we illustrate only the most likely mechanistic pathway from **13** to **1**.



The failure to cyclize allene **12** in reasonable yields is sufficiently accounted for by its peculiar geometry. The stiff, linear allene bond probably does not allow the molecule to adopt the conformation necessary to yield a decalone.

In order to explain the results of cyclization of triene **15**, which gives about the same ratio of *cis*- and *trans*-decalins (see Table 2) as do **9a** and **13** (Table 1), again the same mechanistic arguments can be put forward. In this case, however, an additional center of chirality at C(2) is formed producing a further stereochemical problem. Experimentally the equatorial alcohols **3a'** and **4a'** have been formed together with the monocyclic byproduct **16b** and the structurally isomeric decalylalcohol **8a'**. Exclusive formation of an *equatorial* substituent at C(2) must originate from steric repulsion by the axial methyl group at C(9) since solvolysis of cyclohexanols[16]) gives a mixture of axial and equatorial compounds. On the other hand, the structurally isomeric by-product **8a'** has an axial OH group.

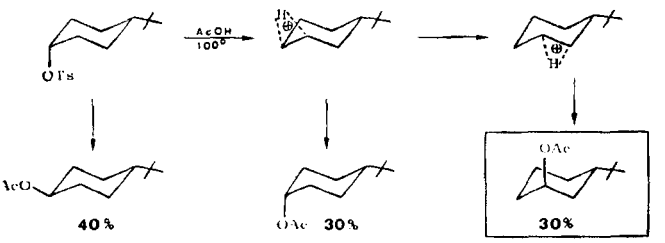
Formation of the by-product, though at first very misleading, can be visualized on the basis of some long known solvolysis experiments by *Winstein* & *Holness* [43][17]) as follows:



2. *Reductions of decalones.* The results obtained so far in the *trans*-decalone series (see Table 3) are in good agreement with the classical general rules[18]) of *Barton* [46],

[16]) See [12a] especially footnote 7) therein.

[17])



For further examples see [44] page 711ff.

[18]) For an excellent up-to-date review on reductions of ketones by means of both mixed hydrides and dissolving metals see [45], p. 45 and 145.

the specific examples taken from steroid chemistry [47] [48] [49][19]), and an investigation by *Marshall et al.* [50][20]).

The carbonyl group of *trans*-decalone **1** is sterically shielded by the axial methyl group at C(9); nucleophilic attack is therefore expected preferentially from the less hindered equatorial (α) side (called steric approach control, with an early reactant-like transition state [45] [51]), in full accord with the results obtained by $NaBH_4$ reduction of **1** (see Table 3). The *trans*-decalone **7**, on the other hand, is more or less sterically unhindered and on $NaBH_4$ reduction it is expected to yield the more stable equatorial alcohol in agreement with the results obtained (originally called product development control, exhibiting a late, product-like transition state [51]).

Although the concept of product development control may be generally useful, its application to the metal hydride reduction of sterically unhindered cyclic ketones has been severely criticized. The stereochemistry of the resulting alcohols is now considered to be determined by steric interference [50] [52] [53] and/or torsional strain [53] [54] [55] both in an early, reactant-like transition state[21]).

Reduction of **1** with Na/NH_3 yields exclusively, as expected, the more stable equatorial alcohol **3a'**. Although it has been well proved that dissolving metal reduction of cyclic ketones gives a mixture of epimeric alcohols (in a ratio close to but not always identical with that attained at thermodynamic equilibrium) the mechanism is still controversial[22]).

The non-rigidity of the *cis*-decalone system makes it much more difficult to explain the stereochemical trend of either Na or $NaBH_4$ reduction. Hence, the configurational assignment of the alcohols obtained is based mainly on the MS. and partly NMR. studies discussed already.

3. Grignard *addition to* **1**. It is generally admitted that *Grignard* addition to ketones exhibits an early, reactant-like transition state [58] [65], the reagent approaching from the least hindered side[23]). *Grignard* reaction with **1** is therefore sterically controlled by the C(9) methyl group and must yield the axial alcohol **3c**.

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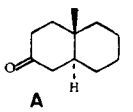
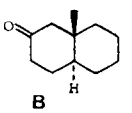
[19]) 5α-Cholestan-2-one with Na/PrOH ⟶ 3% OH_β + 97% OH_α
with $NaBH_4$/MeOH ⟶ 82–88% OH_β + 18–12% OH_α
(ref. [44] [45]).
5α-3-Ketosteroids with $NaBH_4$ ⟶ mainly OH_β
5β-3-Ketosteroids with $NaBH_4$ ⟶ mainly OH_α
(ref. [49]).

[20])



A



B

(ref. [50])

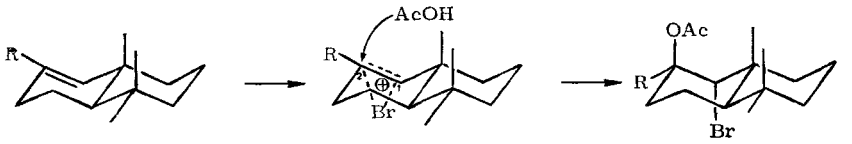
A with $NaBH_4$/EtOH ⟶ 86% OH_β + 14% OH_α
B with $NaBH_4/(CH_3OCH_2)_2$ ⟶ 41% OH_α + 59% OH_β
B with Na/*i*-PrOH ⟶ ~100% OH_α

[21]) However, some very recent papers such as [56] [57] [58] [59] are again in favour of a late product-like transition state (product development control).

[22]) For some recent discussions see [45] [60] [61] [62] [63] [64].

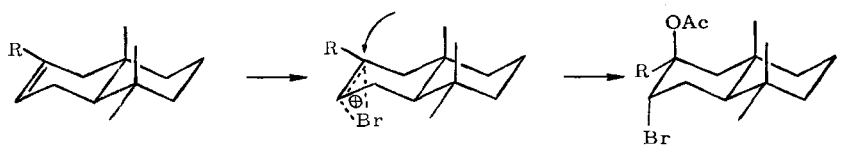
[23]) For an extremely detailed investigation of the *Grignard* reaction see *e.g.* [66].

4. *Electrophilic addition of bromoacetate and peracid to octalins.* The bromoacetate addition [28] [67–73] to octalins **23a**, **25a**, **23b** and **25b** is believed to involve an electrophilic attack by the protonated NBS [70] to give first a bromonium type intermediate.



23a R = H
b R = CH_3

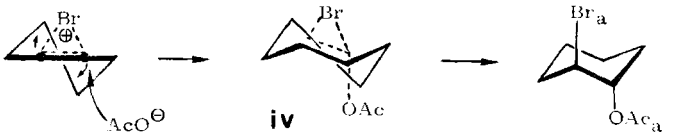
24a R = H

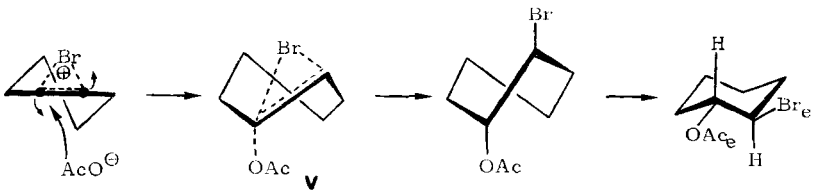


25a R = H
b R = CH_3

26a R = H

Subsequent axial attack of a nucleophile (AcOH) at C(2) opens the bromonium ion diaxially to yield **24a** and **26a** respectively. An explanation for the exclusive formation of diaxial, as opposed to diequatorial, products follows from a study of the corresponding transition states; the chair-like transition state **iv** leading directly to diaxial products is energetically favored over the twist-like transition state **v** giving diequatorial products.





The configuration of the bromoacetates obtained also determines the configuration of the epoxides (**5a** and **6b**) formed on subsequent treatment with base.

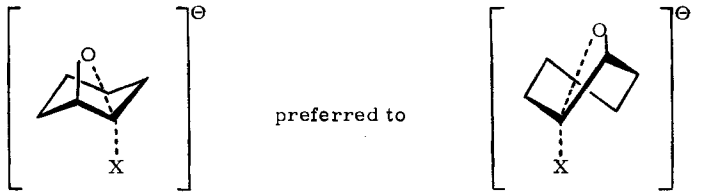
Direct epoxidation of octalins **23a**, **25a**, **23b** and **25b** gives the less hindered epoxides *via* attack of the peracid from the least hindered side[23a]).

5. *Reductive opening of epoxides with $LiAlH_4$.* Since the original paper on the stereochemistry of nucleophilic opening of steroid epoxides by *Fürst & Plattner* [74], many further examples have been found, all indicating that cyclohexene oxides are opened to form products in which the oxygen function and the nucleophile are in diaxial position (*trans*-diaxial rule of epoxide opening)[23b]).

[23a]) For an up-to-date review see [45], p. 292ff.

[23b]) See *e.g.* ref. [73], p. 254, and ref. [45], p. 104.

This stereoselectivity can be explained by the arguments already given for the diaxial opening of cyclohexane bromonium ions; a chair-like transition state leading to a diaxial product is preferred to a twist-like transition state leading to diequatorial products [75].



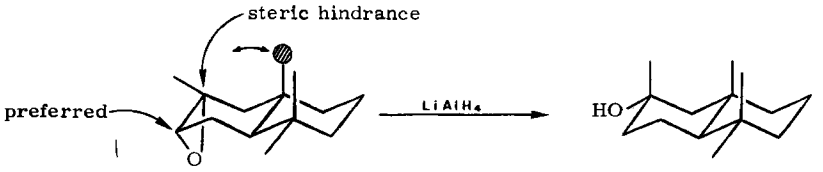
chair-like transition state

twist-like transition state

On the basis of these arguments, neither epoxide **5b'** nor **6a'** should give **3c'** on reduction with $LiAlH_4$, but rather **28** (from **5b'**) and **29** (from **6a'**)[24].

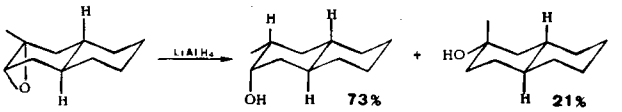
28 **29**

There is no doubt about the structure of the alcohol (**3c'**) obtained. This 'abnormal' ring opening might be explained by steric hindrance of the axial C(9) methyl group preventing the reagent from attacking at C(2) (1,3-diaxial interaction) and favoring the abnormal opening *via* attack at C(3)[25].

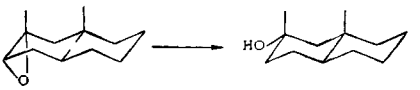


6a' **3c'**

[24]) See also [76]:



[25]) For a similar case of abnormal epoxide opening see [77]):



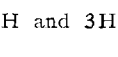
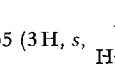
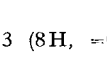
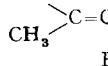
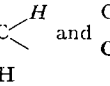
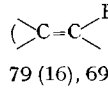
We are much indebted to Professor Dr. *A. Eschenmoser*, ETH Zurich, for helpful suggestions concerning the cyclization reactions and to Dr. *A. F. Thomas*, Firmenich SA, Geneva, for stimulating discussions. Our thanks are due to Professor Dr. *E. Wenkert*, Indiana University Bloomington, for a discussion of the NMR. spectra and the conformational stability of the *cis*-decalin derivatives. We are also grateful for the skillful technical assistance of Miss *Th. Manz* and Mr. *Peter Degen*.

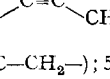
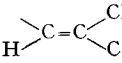
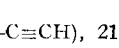
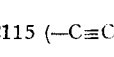
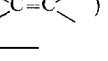
Experimental Part

Melting points were taken in an open capillary bulb on a *Büchi* apparatus (by Dr. *Tottoli*) and were uncorrected. Solvents were removed *in vacuo* on a *Büchi* Rotavapor (RV.). For bulb distillation a *Büchi* apparatus with external temperature reading was used. Anhydrous magnesium sulfate was used for all solution drying. Spectra were obtained under the supervision of Dr. *B. Willhalm* (NMR., and MS.) and Dr. *F. Gautschi* (IR., and UV.). The 60-MHz NMR. spectra were recorded with a *Varian* A-60 and a *Hitachi Perkin-Elmer* R-20B instrument, and the 90-MHz NMR. spectra were measured on a *Bruker* HFX-90/15 inch instrument using CCl_4 as solvent (unless otherwise stated) and tetramethylsilane as internal standard ($\delta = 0$ ppm); abbreviations: *s* = singlet, *d* = doublet, *t* = triplet, *q* = quartet, *m* = multiplet, b = broad. High temperature NMR. spectra (25–140°) were run in benzene-d_6 and low temperature NMR. spectra (25–100°) in acetone-d_6 using the *Bruker* instrument. The mass spectra were recorded on an *Atlas* CH-4 instrument; inlet temperature ca. 150°; electron energy ca. 70 eV; the intensity of molecular ions and of fragment ions are given in % relative to the most abundant one (100%). The IR. spectra were recorded in CCl_4 (unless otherwise stated) on a *Perkin-Elmer* 125 spectrometer. The UV. spectra were measured in ethanol on an *Optica* CF-4 instrument. For gas chromatography (GLPC.) on packed glass columns (specified in the text) a *Carlo Erba* GT and a *Varian Aerograph* series 1800 instrument were used; carrier gaz: 40 ml He/min.; column support: Chromosorb W/60-80 mesh. For GLPC. on metal capillary columns (specified in the text) a *Perkin-Elmer* 266 instrument was uesd; carrier gaz: 15–20 psi He. Silica gel (0,05–0,2 mm) for column chromatography was obtained from *E. Merck AG*, Darmstadt.

1. *Acyclic* cis-*dienyne* **9b** *from nerol.* Nerol (30.8 g; 0.2 mol) in abs. ether (100 ml) and abs. hexamethylphosphorous triamide (50 ml) was treated with 100 ml of etheral methyllithium (4.4%) under cooling with a water bath. To the white suspension obtained were added mesyl chloride (16.3 ml; 0.2 mol) and a suspension of lithium chloride (24 g) in ether (100 ml) and hexamethylphosphorous triamide (50 ml). After being stirred at room temperature overnight the mixture was poured on water and extracted with ether. The organic phase was washed, dried, concentrated and distilled at 67–85°/8 Torr to yield 19.8 g of neryl chloride.

This compound was transferred into a mixture of **9b** (80%) and **9a** (20%) in ~39% overall yield by the general method of *Corey & Kirst* [22c].

Spectral data of **9a**[26]. 60 MHz NMR.: 1.6 (3H and 3H, *s* and *s*,  and ); 1.65 (3H, *s*, ); 1.9–2.3 (8H, ); 5.1 (H and H, *m*,  and )ppm. – IR.: 3310 (–C≡CH), 2115 (–C≡C–), 1660 and 855 () cm^{-1}. – MS.: $M^+ = 176$ (1); *m/e*: 161 (11), 147 (1), 133 (11), 119 (2), 105 (8), 91 (21), 79 (16), 69 (100), 55 (8), 41 (59), 29 (6).

Spectral data of **9b**[26]. 60 MHz NMR.: 1.6 (3H, *s*, ); 1.65 (3H and 3H, *s* and *s*,  and); 1.9–2.3 (8H, ); 5.1 (H and H, *m*,  and ) ppm. – IR.: 3310 (–C≡CH), 2115 (–C≡C–), 1662 and 828 ()

[26]) The configuration assignment is in accordance with a closely related case of *Stork et al.* [23].

cm^{-1}. – MS.: $M^+ = 176$ (1); *m/e*: 161 (11), 147 (0), 133 (14), **119** (2), 105 (8), 91 (19), 79 (13), 69 (100), 53 (8), 41 (59), 29 (6).

2. *Monocyclic alcynes* **10**, **11**, *and allene* **12** *from dihydro-α-ionone* **19**[27]. Phosphorus pentachloride (21.6 g, 0.104 mol) was added in small portions with stirring to 20 g (0.109 mol) of dihydro-α-ionone. After the addition was complete the cooling bath was removed and the mixture allowed to warm to room temperature. The reaction mixture was poured on crushed ice and extracted with pentane. The pentane layer was washed (successively with aqueous saturated $NaHCO_3$ and with brine), dried, and evaporated at $< 30°$ giving 23 g of crude dichloride **20**. In a four-necked round bottomed flask filled with a thermometer, a reflux condenser, a mechanical stirrer and a dropping funnel 50 g of paraffin oil and 32 g of powdered sodium amide[28] were heated to 160–170°, and 23 g of crude dichloride **20** was added with efficient stirring during 10 min. After the mixture had been stirred for additional 5 h at 160–170° it was cooled to room temperature and filtrated through a sintered glass funnel. The precipitate, which consisted of the sodium derivatives of **10** and **11** and of $NaNH_2$, was washed with pentane, and decomposed by careful addition of ethanol. After the addition of water, pentane extraction and distillation gave 4.23 g (23%) of a 1:1 mixture[29] of **10** and **11**, b.p. 38–40°/0.05 Torr.

In order to obtain the allene **12** the filtrate was washed and distilled: 4.5 g allene **12** (90% pure[29]), b.p. 35–40°/0.03 Torr.

Spectral data of **10**. 60 MHz NMR.: 0.88 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.93 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.6 (3H, *s*, $=C<^{CH_3}$); 5.25 (1H, *m*, $=C<^{H}$) ppm. – IR.: 3320 ($\equiv C-H$), 2120 ($-C\equiv C-$), 1650 ($>C=C<$) cm^{-1}.

Spectral data of **11**. 60 MHz NMR.: 1.0 (3H and 3H, *s* and *s*, $>C<^{CH_3}_{CH_3}$); 1.6 (3H, *s*, $=C<_{CH_3}$) ppm. – IR.: 3320 ($\equiv C-H$), 2120 ($-C\equiv C-$), 1650 ($>C=C<$) cm^{-1}.

Spectral data of **12**. 60 MHz NMR.: 0.9 (3H and 3H, *s* and *s*, $>C<^{CH_3}_{CH_3}$); 1.6 (3H, *s*, $=C<_{CH_3}$); 4.46 (1H, *m*, $=C=C<^{H}_{H}$); 4.62 (1H, *m*, $=C=C<^{H}_{H}$); 5.35 (1H, *m*, $=C<^{H}_{H}$) ppm. – IR.: 3080 ($=C<^{H}_{H}$), 1655 ($>C=C<^{H}_{H}$), 890 ($=C<^{H}_{H}$) cm^{-1}.

3. *Acyclic enol acetates* **13** *and* **21** *from geranylacetone*[30]. A solution of 50 g (0.2 mol) of triphenylmethane in 250 ml of abs. dimethoxyethane under argon was treated with 7.8 g (0.2 mol) of finely cut potassium. After the resulting deep red solution had been stirred for 6 h at 25°. 31 g (0.16 mol) of *trans*-geranylacetone [25] was added. The yellow reaction mixture was poured onto vigorously stirred, cooled (water bath) acetic anhydride (82 g; 0.8 mol). The resulting mixture was stirred at 20–25° for 30 min, poured into a cold (0–5°) mixture of pentane (500 ml) and saturated aqueous $NaHCO_3$ (600 ml) and stirred for additional 10 min. The pentane layer was separated, dried, and concentrated. The semicrystalline oily residue was taken up in pentane (100 ml), left 15 h at $-20°$, and filtered through a sintered glass funnel to remove the triphenylmethane crystallized. This crystallization procedure was repeated, and the purified filtrate distilled twice through a *Widmer* column: 15 g (40%) of enol acetate mixture **13** (42%) and **21** (58%)[31], b.p. 85–90°/0.1 Torr.

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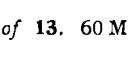
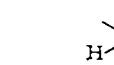
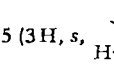
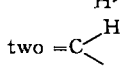
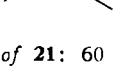
[27]) Following the method given by *Meunier & Desparmet* [24].

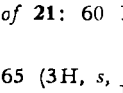
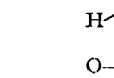
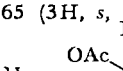
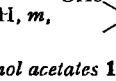
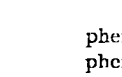
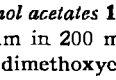
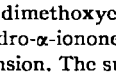
[28]) Commercially available as a suspension in toluene (*Fluka*, Buchs).

[29]) Determined by NMR. and more accurately by GLPC. using a $0.02'' \times 150''$ metal capillary column, UCON; temp. 130°; 15 psi He.

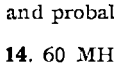
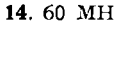
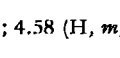
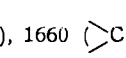
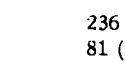
[30]) Following the method given by *House et al.* [26].

[31]) Determined from the NMR. of the enol acetate mixture. For signals typical of **13** or **21** see [26]: *n*-Bu $\diagdown\!\!\diagup$ CH_3 $\delta = 1.77$ ppm; *n*-Bu $\diagdown\!\!\diagup$ OAc $\delta = 1.77$ ppm; *n*-Bu $\diagdown\!\!\diagup$ OAc $\delta = 1.78$ ppm; *n*-Bu $\diagdown\!\!\diagup$ CH_3 $\delta = 1.82$ ppm; *n*-Bu $\diagdown\!\!\diagup$ OAc $\delta = 1.75$ ppm.

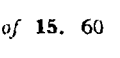
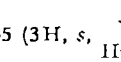
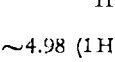
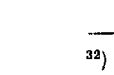
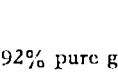
Spectral data of **13**. 60 MHz NMR.: 1.59 (3H and 3H, *s* and *s*,  and ); 1.65 (3H, *s*, ); 2.03 (3H, *s*, ); ~4.6 (2H, *m*, ); ~5.0 (H and H, *m*, two ) ppm.

Spectral data of **21**: 60 MHz NMR.: 1.59 (3H and 3H, *s* and *s*,  and ); 1.65 (3H, *s*, ); 1.82 (3H, '*d*', $J \sim 1$ Hz, ); 2.05 (3H, *s*, ); 4.6 (1H, *m*, ); 5.0 (H and H, *m*, two ) ppm.

4. *Monocyclic enol acetates* **14** *and* **22** *from dihydro-α-ionone* **19**. To a solution of 0.105 mol triphenylmethyl-lithium in 200 ml abs. dimethoxyethane and 150 ml hexane (prepared from triphenylmethane in dimethoxyethane by adding butyllithium in hexane under argon) 20.3 g (0.105 mol) of dihydro-α-ionone was added dropwise at 25°, changing the originally red solution into a yellow suspension. The suspension obtained was added dropwise to a stirred, cooled (water bath) solution of acetic anhydride (50 g) in hexane (150 ml), stirred at 25° for 30 min, then poured into a cold (0–5°) mixture of pentane (500 ml) and saturated aqueous $NaHCO_3$, and stirred an additional 10 min. The pentane layer was separeted, dried, and concentrated. The semicrystalline oily residue was taken up in ~100 ml of pentane, left 15 h at – 20°, and filtered through a sintered glass funnel to remove the crystalline triphenylmethane. This crystallization procedure was repeated and the purified filtrate distilled twice through a *Widmer* column: 5 g (21%) of enol acetate **14** (~80%) and probably **22** (20%)[31]), b.p. 95°/0.2 Torr.

Spectral data of **14**. 60 MHz NMR.: 0.87 (3H, *s*, ); 0.92 (3H, *s*,); 2.05 (3H, *s*,); 4.58 (H, *m*, ); 4.62 (H, *m*, ); 5.25 (1H, *m*, ) ppm. – IR. (liq.): 1755 (), 1660 (), 1650 (), 1190 () cm^{-1}. – MS.: M^+ = 236 (<1); *m/e*: 218 (<1), 204 (<1), 194 (3), 176 (7), 161 (7), 136 (70), 123 (58), 109 (43), 93 (35), 81 (58), 71 (31), 55 (23), 43 (100), 29 (9).

5. *6,10-Dimethyl-1,*trans*-5,9-undecatriene* **15** [27]. A solution containing allyl bromide (850 g, 7 mol), undistilled geranyl bromide[32]) (760 g; 3.5 mol) and abs. ether (2 l) was added with stirring to 168 g (7 mol) of magnesium turnings in abs. ether (300 ml). The addition rate was so chosen that a vigorous reflux was maintained, and after the addition was complete, the reaction mixture was heated at reflux for an additional hour. The reaction mixture was poured onto an ice cold aqueous solution of 20% NH_4Cl. The organic layer was separated, washed (brine), dried, concentrated and distilled. The fraction boiling at 95–100°/11 Torr was collected: 420 g (67%) of 90–95% pure (GLPC.[33])) **15**.

Spectral data of **15**. 60 MHz NMR.: 1.6 (3H and 3H, *s* and *s*,  and ); 1.65 (3H, *s*, ); 1.9–2.2 (8H, ); ~4.95 (1H, '*d*', $J \sim 10$ Hz, ); ~4.98 (1H, '*d*', $J \sim 17$ Hz,); ~5.1 (1H and H, *m*, 

[32]) Prepared from 92% pure geraniol (impurities 3.4% citronellol and 4.6% nerol) as described by [25].

[33]) 5 mm × 2.5 m column; 5% Apiezon; 200°.

and $\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!C\!=\!C\!<\!H$); ~5.85 (H, *t* of *d* of *d*, $J_t \sim 6$ Hz, $J_{dcis} \sim 10$ Hz, $J_{dtrans} \sim 17$ Hz, $H\!>\!C\!=\!C\!<\!\begin{matrix}H\\CH_2-\end{matrix}$) ppm. – IR.: 3080 (=C<), 3020 (=C<), 1635 (>C=C<), 1215, 990 and 910 (=CH_2) cm^{-1}. MS.: $M^+ = 178$ (0.6); *m/e*: 163 (3), 149 (0.1), 135 (6), 124 (6), 109 (5), 93 (4), 81 (22), 69 (100), 67 (29), 55 (17), 41 (53), 27 (6).

6. *5,5,9-Trimethyl*-trans-*2-decalone* **1** and *5,5,9-Trimethyl*-cis-*2-decalone* **2** via *acid catalyzed cyclization.* a) Dienyne **9a**[34]) [22] (2 g, 11.4 mmol) was added dropwise at 0–5° during 10 min to a stirred mixture of conc. H_2SO_4 (2.5 ml) and hexane (5 ml). The resulting red emulsion was stirred an additional 30 min at 0–5°, poured into ice-water, and extracted with pentane. The pentane layer was washed (successively with saturated aqueous $NaHCO_3$ and with brine), dried, concentrated and distilled at 71–73°/0.1 Torr; 1.43 g (65%) of **1** (93%) and **2** (7%). A more volatile by-product (~15%), 5,5,9-trimethyl-*trans*-4-decalone[35]), was also found. Pure analytical samples were collected by GLPC.[36]).

Physical data of **1**: m.p. 59–60°. 90 MHz NMR. (in CCl_4; with $Eu(fod)_3$, see Fig.): 0.87 (3H, *s*, $>\!C\!<\!\begin{matrix}CH_3(\beta)\\CH_3\end{matrix}$); 0.91 (3H, *s*, $-CH_3(\beta)$); 0.98 (3H, *s*, $>\!C\!<\!CH_3(\alpha)$) ppm. – IR.: 1705 (>C=O) cm^{-1}. – MS.: $M^+ = 194$ (73); *m/e*: 179 (48), 161 (45), 151 (14), 137 (50), 123 (53), 109 (67), 95 (87), 81 (57), 69 (94), 55 (81), 41 (100), 29 (30), 27 (33).

Physical data of **2**: m.p. 71–72°. 90 MHz NMR. (in CCl_4; with $Eu(fod)_3$, see Fig.): 0.98 (3H, *s*, $>\!C\!<\!\begin{matrix}CH_3(\alpha)\\CH_3\end{matrix}$), 1.06 (3H, *s*, $>\!C\!<\!\begin{matrix}CH_3\\CH_3(\beta)\end{matrix}$); 1.11 (3H, *s*, $-\overset{|}{C}-CH_3(\beta)$) ppm. – IR.: 1705 (>C=O) cm^{-1}. – MS.: $M^+ = 194$ (24); *m/e*: 179 (16), 161 (9), 151 (8), 136 (29), 123 (18), 111 (100), 95 (25), 81 (26), 69 (45), 55 (45), 41 (51), 27 (16).

b) Dienyne **9a** [22] (2.44 g; 13.9 mmol) was added dropwise at 35° during 2 h to a stirred solution of conc. H_2SO_4 (0.5 ml) and glacial acetic acid (5 g). The resulting red solution was stirred an additional 3 h at 35–40°, poured into ice-water and extracted with pentane. The pentane layer was washed (successively with saturated aqueous $NaHCO_3$ and with brine), dried, concentrated and distilled at 71–73°/0.1 Torr giving 1.35 g (59%) of an isomeric mixture (84% **1** and 16% **2** by GLPC.[36])) and 15% of a more volatile unknown by-product.

c) Under the conditions given in 6a), 1 g of **9b** (~80% of *trans*-isomer) yielded 0.6 g of a distillate (b.p. 90–130°[37])/0.03 Torr) which contained ~67% of decalones (~80% *cis*-**2** and ~20% *trans*-**1**) and ~27% of a more volatile by-product, 5,5,9-trimethyl-*trans*-4-decalone[35]).

d) Under the conditions given in 6b), 1 g of **9b** (~85% of *trans*-isomer) yielded 0.59 g of a distillate (b.p. 82–140°[37])/0.04 Torr) which contained ~61% of decalones (~55% *cis*-**2** and ~45% *trans*-**1**) and ~19% of the more volatile 5,5,9-trimethyl-*trans*-4-decalone[35]).

e) A 42:58 mixture of enol acetates **13** and **21** (1 g, 4.2 mmol) was added dropwise at 0–5° during 10 min to a stirred mixture of conc. H_2SO_4 (1.3 ml) and hexane (3 ml). The resulting emulsion was stirred an additional 30 min at 0–5°, poured into ice-water and extracted with pentane. The pentane layer was washed (successively with saturated aqueous $NaHCO_3$ and with brine), dried, concentrated and distilled by bulb distillation at 90–130°[37])/0.04 Torr, giving 250 mg (30%) of isomeric decalones (84% **1** and 16% **2**) and ~240 mg (29%) of two more volatile unknown by-products (molecular weight 194).

f) Using the conditions given in 6a), 1.7 g (77%) of isomeric mixture (34% **1** and 66% **2** (b.p. 70–75°/0.05 Torr) were obtained from 2 g (11.4 mmol) of a 1:1 mixture of enynes **10** and **11**.

g) Using the conditions given in 6b), 1.32 g (60%) of isomeric mixture (49% **1** and 51% **2** (b.p. 70–75°/0.04 Torr) were obtained from 2 g (11.4 mmol) of a 1:1 mixture of enynes **10** and **11**.

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[34]) Prepared according to *Corey & Kirst* [22c]; 95% pure *trans* isomer **9a** according to GLPC. (0.01″ × 150′ metal capillary column, Carbowax; temp. 100–200°/programmed at 6.25°/min; 15 psi He).

[35]) Identified by comparison with an authentic sample [78].

[36]) 5 mm × 2 m column; 15% 1,2,3-tricyanoethoxypropane (TCEP); 150°.

[37]) Bath temperature.

h) Using the conditions given in 6b), ~1 g of distillable product, b.p. 40–76°/0.05 Torr, was obtained from 2 g (11.4 mmol) of allene **12**. This distillate contained, apart from various unidentified volatiles, ~2% of the desired isomeric mixture (30% **1** and 70% **2**).

i) Allene **12** (2 g, 11.4 mmol) was added dropwise at 50° during 1 h to a stirred solution of conc. H_2SO_4 (1.7 ml), water (2.7 ml) and glacial acetic acid (18 g). The resulting solution was stirred an additional 15 h at 50°, poured into ice-water and extracted with pentane. The pentane layer was washed (successively with saturated aqueous $NaHCO_3$ and with brine), dried, concentrated and distilled at 57–120°/0.07 Torr to give 1.2 g of a complex mixture which contained ~2% of the desired decalones (51% **1** and 49% **2**).

k) Using the conditions given in 6c), 130 mg (30%) of isomeric mixture (39% **1** and 61% **2**) was obtained from 0.5 g (2.12 mmol) of a 4:1 mixture of enol acetate (**14** and **22**).

7. *5,5,9-Trimethyl*-trans-*2-decalone* **1** *from the corresponding methyl-1-carboxylate* [17]. 1α-Carbomethoxy-5,5,9α-trimethyl-*trans*-2-decalone [**17**] (500 mg; m.p. 100–101°[38])) was dissolved in abs. dimethylformamid (1 ml) and heated with 100 mg of dry powdered potassium iodide at reflux in an argon atmosphere during 5 h. The cold reaction mixture was poured into an aqueous solution of 10% HCl and extracted with ether. The etheral phase was washed (brine), dried, and evaporated yielding 20 mg crystalline **1**, m.p. 57°, spectral data (IR., NMR., and MS.), and retention time on GLPC.[36]) in accordance with **1**, from cyclisation experiments 6a–k.

8a. *5,5,9-Trimethyl*-cis-*2-decalone* **2** *from 5,5-dimethyl-*$\Delta^{1(9)}$*-2-octalone* [18]. Methyllithium (prepared from lithium (0.75 g, 107 mmol), methyl iodide (9.0 g, 63 mmol) in abs. ether (40 ml) at −20°) was added dropwise to a stirred suspension of powdered CuI (6 g, 31 mmol) in ether (130 ml) at −15° in an argon atmosphere. To this yellow suspension at −10° was added a solution of 0.89 g (5 mmol) octalone in abs. ether (40 ml). After the reaction mixture had been stirred 20 h at −10°, it was poured into an aqueous solution of 10% HCl, filtered through celite, and extracted with ether. The etheral phase was washed (successively with saturated aqueous $NaHCO_3$ and with brine), dried, concentrated, and distilled by bulb distillation at 110–120°/0.01 Torr to yield a mixture (1.07 g) consisting of 65% **2**, 20% starting material and 15% unknown ketone. A sample of **2** collected by GLPC.[39]) was identical (NMR., MS.) with **2** from cyclization experiments 6a–k.

8b. *5,5,9-Trimethyl*-cis-*2-decalone* **2** *from 5,5,9β-trimethyl*-cis-*2β-decalol* **4a**. A solution of 1.75 g (17.5 mmol) CrO_3 in water (10 ml) was added dropwise over 10 min to a stirred, heated (40–45°) solution of alcohol **4a** (3.4 g, 17.3 mmol) in glacial acetic acid (20 ml). After the mixture had been stirred 2 h at 60–70° it was poured onto water, and extracted twice with ether. The etheral phase was washed (successively with 10% aqueous $NaHCO_3$ and with brine), dried, concentrated and sublimed at 60–65°/0.001 Torr to give 3.1 g of waxy cristals; m.p. 61–66°; the spectra (IR., NMR., MS.) are identical with those of compound **2** obtained by method 6a–k and 8a.

9. *Decalyl acetates* **3b'** and **4b'** *and cyclohexyl acetate* **16a** *from triene* **15** via *cyclization in AcOH/*H_2SO_4. Triene **15** (35.6 g; 0.2 mol, prepared as described in 5) was added dropwise during $1^1/_2$ h to a stirred solution of glacial acetic acid (36 g) and conc. sulfuric acid (6 g) at 30–35°. After the addition was complete the mixture was stirred an additional 2 h at 35–40°, and then poured onto ice-water. The mixture was extracted with ether, the etheral phase washed (successively with 10% aqueous Na_2CO_3 and with water), dried and concentrated. The crude material (39.3 g) was distilled first at 68–98°/0.001 Torr to give 21.7 g of product and 5.4 g of residue. A second distillation at 87–92°/0.001 Torr afforded 17.7 g (37%) of acetates **16a** (21%), **3b'** (57%), and **4b'** (22%)[40]). Analytical samples were collected by GLPC[41]).

Spectral data of **3b'**. 60 MHz NMR.: 0.81 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.88 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.00 (3H, *s*, $-\overset{|}{\underset{|}{\overset{O}{\overset{\|}{C}}}}-CH_3$); 1.89 (3H, *s*, $-O-\overset{O}{\overset{\|}{C}}-CH_3$); ~4.8 (H, large *m*, $AcO-\overset{|}{\underset{|}{C}}-H$(a)) ppm. – IR.: 1730 and

[38]) Reference [17]: m.p. 100°.

[39]) 5 mm × 2 m column; 5% Carbowax 20M; 200°.

[40]) Identified by comparing their retention time on GLPC.[41]) and their spectra (IR., NMR., MS.) with the acetates **3b'** (see 16), **4b'** (see 35), and **16a** (see footnote 6) prepared differently.

[41]) 0.02″ × 200′ metal capillary column; Sp 1000 (modified Carbowax); 180°.

1245 (—O—C(=O)—CH_3) cm^{-1}. – MS.: M^+ = 238 (0); *m/e*: 223 (0.2), 192 (0.5), 178 (53), 163 (100), 149 (29), 137 (55), 124 (79), 109 (72), 93 (44), 81 (81), 69 (48), 55 (46), 43 (87), 31 (70).

Spectral data of **4b'**. 60 MHz NMR.: 0.98 (3H, *s*, —C(—CH_3)—); 1.08 (3H and 3H, *s* and *s*, >C(CH_3)(CH_3)); 1.92 (3H, *s*, —O—C(=O)—CH_3); ~4.9 (1H, large *m*, AcO—C(—H(a))—) ppm. – IR.: 1730 and 1245 (O=C(—O—)—CH_3) cm^{-1}. – MS.: M^+ = 238 (0); *m/e*: 178 (51), 163 (90), 149 (27), 135 (31), 124 (52), 109 (62), 93 (71), 82 (78), 69 (52), 55 (52), 43 (100), 29 (19).

Spectral data of **16a**: 60 MHz NMR.: 0.95 (3H, *s*, —C(—CH_3)—); 1.56 (3H, *s*, H—C=C(—CH_3)(CH_3)); 1.63 (3H, *s*, H—C=C(—CH_3)(CH_3)); 1.9 (3H, *s*, —O—C(=O)—CH_3); ~4.7 (1H, large *m*, AcO—C(—H)—); 5.0 (1H, *m*, =C(—H)—) ppm. – IR.: 1730 and 1245 (—O—C(=O)—CH_3) cm^{-1}. – MS.: M^+ = 238 (0); *m/e*: 178 (29), 163 (23), 149 (1), 135 (24), 122 (17), 109 (27), 95 (70), 82 (90), 69 (42), 55 (34) ,43 (100), 41 (55), 29 (29).

10. *Decalyl alcohols* **3a'** *and* **4a'** *and cyclohexyl alcohol* **16b** *from acetates* **3b'**, **4b'** *and* **16a**. A solution containing 13 g (55 mmol) of acetates **16a** (19%), **3b'** (57%) and **4b'** (22%) (for preparation see 13), KOH (10 g), water (10 ml) and methanol (100 ml) was heated at reflux for 2 h. After the methanol had been removed under diminished pressure, the residue was taken up in ether. The organic extract was washed (water), dried, concentrated and distilled at 85–87°/0.001 Torr to yield 10.8 g (91%) of alcohols **16b** (21%), **3a'** (61%) and **4a'** (18%)[42]).

MS. data of **16b**. M^+ = 196 (1); *m/e*: 178 (19), 163 (34), 149 (1), 135 (24), 122 (15), 111 (28), 95 (77), 82 (100), 69 (57), 55 (47), 41 (76), 29 (22).

11. *Decalones* **1**, **2** *and monocyclic ketone* **17**. A solution of 4.75 g (47.5 mmol) CrO_3 in water (25 ml) was added dropwise over 10 min to a stirred, heated (40–50°) solution containing 9.3 g (47.5 mmol) of alcohols **16b** (21%), **3a'** (61%) and **4a'** (18%) and acetic acid (50 ml). After the mixture had been stirred 2 h at 65°, it was poured onto water, and extracted twice with ether. The etheral phase was washed (successively with 10% aqueous Na_2CO_3 and with brine), dried, concentrated, and distilled at 75–79°/0.001 Torr to give 7.1 g (77%) of **17** (13%), **1** (62%) and **2** (24%)[44]). A pure analytical sample of **17** was obtained by GLPC.[36]). Crystallisation of the crude product from hexane (3 times) gave pure **1**, m.p. 58–59°.

Spectral data of **17**. 60 MHz NMR.: 0.92 (3H, *s*, —C(—CH_3)—); 1.58 (3H, *s*, H—C=C(—CH_3)(CH_3)); 1.63 (3H, *s*, H—C=C(—CH_3)(CH_3)); 5.05 (1H, *m*, =C(—H)—) ppm. – IR.: 1710 (>C=O), 1380 cm^{-1}. – MS.: M^+ = 194 (2); *m/e*: 179 (<1), 161 (<1), 151 (7), 135 (1), 123 (2), 111 (100), 97 (6), 83 (6), 69 (30), 55 (43), 41 (33), 29 (14).

12. *Decalyl alcohols* **8a'**, **3a'** *and* **4a'** *from triene* **15** via *cyclisation in* $HCOOH/H_2SO_4$ *and subsequent saponification*. Triene **15** (35.6 g, 0.2 mol, prepared as described in 5) was added dropwise during 30 min to a stirred solution of formic acid (400 g), conc. H_2SO_4 (40 g) and abs. dioxane (150 ml) at 50°. After the addition was complete, the mixture was stirred at 60° for 3 h. The reaction mixture was concentrated under reduced pressure to half of its original volume and then poured onto ice-water. The reaction product was taken up in ether, washed (successively with

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[42]) Identified by comparing their retention time on GLPC.[43]) with the alcohols **3a'** (see 15), **4a'** (see 34) and **16b** (see footnote 6) prepared differently.

[43]) 0.02″ × 200′ Metal capillary column; Sp 1000 (modified Carbowax); 190°.

[44]) Identified by comparing their retention time on GLPC.[36]) with **1**, **2** (method 6a–k and 8a) and **17** (see footnote 6) prepared differently.

10% aqueous Na_2CO_3 and water), dried, and concentrated. The crude bicyclic formiate (37 g) obtained was mixed with KOH (20 g), water (20 ml) and methanol (200 ml) and heated at reflux for 4 h. The methanol was removed under diminished pressure and the reaction product taken up in ether. The etheral phase was washed (water), dried, concentrated and distilled first at 82–92°/0.001 Torr to give 15.4 g distillate and 8.7 g residue. A second distillation at 84–88°/0.001 Torr yielded 14 g (35%) of alcohols **8a'** (20%), **3a'** (73%) and **4a'** (7%)[45]).

13. *Decalylacetates* **8b'**, **3b'** and **4b'** *from decalols* **8a'**, **3a'** and **4a'**. A solution containing 2.94 g (15 mmol) of alcohol **8a'** (20%), **3a'** (73%) and **4a'** (7%), acetic anhydride (2 g, 20 mmol) and abs. pyridine (2 g) was heated at 100° for 2 h. The cold reaction mixture was treated with water (3 ml) and extracted with ether. The etheral phase was washed (successively with 10% aqueous HCl, 10% aqueous Na_2CO_3 and with water), dried, concentrated and distilled at 90–91°/0.001 Torr to give 3 g (84%) of acetates **8b'** (19%), **3b'** (76%) and **4b'** (4%)[46]).

14. *Decalones* **1**, **2** and **7**. Oxydation, analogous to the one described before (see 11), of alcohols **8a'** (20%), **3a'** (73%) and **4a'** (7%) gave 78% of ketones **1** (75%), **2** (8%) and **7** (17%)[47]).

15. *5,5,9β-Trimethyl*-trans-*2α-decalol* **3a'** *from* **1** *by* Na/NH_3[48]). A solution of 5.82 g (30 mmol) of ketone **1** in 20 ml of abs. ethanol and 100 ml of liquid ammonia at −40° was treated with 3.9 g (170 mmol) of sodium in portions of about 0.2 g. The ammonia was allowed to evaporate overnight. The solid residue was transferred into water, acidified with 20% aqueous HCl, and extracted twice with ether. The etheral phase was washed (successively with 10% aqueous $NaHCO_3$ and with water), dried, concentrated and sublimed at 60–65°/0.001 Torr to give 5.1 g (87%) of cristalline **3a'**; m.p. 48–51°; purity by GLPC.[43]) 100%.

Spectral data of **3a'**. 90 MHz NMR. (in CCl_4; with $Eu(fod)_3$, see Fig. 2): 0.79 (3H, *s*, $>C(CH_3(a))(CH_3)$); 0.88 (3H, *s*, $>C(CH_3(e))(CH_3)$); 0.94 (3H, *s*, $-C(CH_3(a))-$); 3.82 (H, large *m*, $OH-C-H(a)$) ppm. – IR.: 3580 and 3300 (–OH) cm^{-1}. – MS.: $M^+ = 196$ (<1); *m/e*: 178 (28), 163 (82), 149 (3), 137 (100), 122 (21), 107 (27), 95 (38), 81 (48), 69 (41), 55 (40), 41 (50), 29 (16).

16. *5,5,9β-Trimethyl*-trans-*2α-decalyl acetate* **3b'** *from alcohol* **3a'**. A solution of 2.53 g (13 mmol) alcohol **3a'**, acetic anhydride (1.74 g, 17 mmol), and abs. pyridine (1.74 g) was heated to 100° for one h. Then it was cooled to room temperature, poured into 20 ml of water at 20°, and extracted twice with ether. The etheral phase was successively washed with 10% aqueous HCl to remove the pyridine, with 10% aqueous Na_2CO_3 and with brine until neutral, dried, and concentrated. Distillation through a *Vigreux* column gave 2.35 g (76%) of acetate **3b'**; b.p. 77–79°/0.001 Torr.

Spectral data of **3b'**. 60 MHz NMR.: 0.81 (3H, *s*, $>C(CH_3(a))(CH_3)$); 0.88 (3H, *s*, $>C(CH_3)(CH_3(e))$); 1.0 (3H, *s*, $-C(CH_3(a))-$); 1.89 (3H, *s*, $-O-C(CH_3)=O$); ~4.8 (H, broad *m*, $AcO-C-H(a)$) ppm. – IR.: 1730 and 1245 ($-O-C(CH_3)=O$) cm^{-1}. – MS.: $M^+ = 238$ (0); *m/e*: 223 (<1), 192 (<1), 173 (53), 163 (100), 149 (29), 137 (55), 124 (79), 109 (72), 93 (44), 81 (81), 69 (48), 55 (46), 43 (87), 31 (70).

17. *Decalyl alcohols* **3a** *and* **3a'** *from* **1** *by means of* $NaBH_4$. A solution of 1.9 g (50 mmol) of $NaBH_4$ in water (20 ml) was added dropwise to a stirred, heated (+50°) solution of 19.4 g (100 mmol) of ketone **1** in methanol (30 ml). After the addition was complete the reaction mixture was heated to boiling for 2 h, cooled to 20°, and taken up in ether. The etheral extract was washed

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[45]) Identified by comparing their retention time on GLPC.[43]) with **3a'** (see 15), **4a'** (see 34) and **8a'** (see 36) prepared differently.

[46]) Identified by comparing their retention time on GLPC.[41]) with **3b'** (see 16), **4b'** (see 35), and **8b'** (see 38) prepared differently.

[47]) Identified by comparing their retention time on GLPC.[41]) with **1** and **2** prepared by method 6a–k and 8a, and with **7** prepared by the method of [21c].

[48]) Following the method given by *Paquette & Nelson* [79].

(twice with 36% aqueous NaOH, and with water until neutral), dried and concentrated. The crude product (2g) contained about 63% **3a** and 37% **3a'**[49]).

18. *Decalyl acetates* **3b** *and* **3b'** *from alcohols* **3a** *and* **3a'**. A mixture containing ~20 g (~0.1 mol) crude alcohols **3a** (~63%) and **3a'** (37%), acetic anhydride (13.2 g) and abs. pyridine (13.2 g) was stirred at 100° for 2 h. The reaction was cooled to 20°, poured onto 100 ml of ice water, and taken up in ether. The etheral phase was washed (successively with 10% of aqueous HCl, 10% of aqueous Na_2CO_3, and with water until neutral), dried, concentrated, and distilled through a *Vigreux* column at 83–85°/0.001 Torr to give 22.8 g (96%) of a mixture of acetates **3b** (63%) and **3b'** (37%)[51]).

19. *5,5,9β-Trimethyl*-trans-*2β-decalyl acetate* **3b** *from bromoacetate* **24a**. A mixture of 10.5 g (30 mmol) of triphenyltin hydride [29] and 9.5 g (30 mmol) of bromoacetate **24a** under nitrogen, was heated slowly from 20° to 80° and left at 80–90° for 5 h. The product formed was directly removed from the reaction mixture by distillation at 68–75°/0.001 Torr. The crude distillate (6.7 g) was then redistilled through a *Vigreux* column to yield 6.1 g (85%) of 99% pure acetate **3b**; b.p. 76°/0.001 Torr.

Spectral data of **3b**. 60 MHz NMR.: 0.85 (3H, *s*, $>C(CH_3)_2$); 0.88 (3H, *s*, $>C(CH_3)_2$); 1.04 (3H, *s*, $-\overset{|}{C}-CH_3$(a)); 1.93 (3H, *s*, $-O-C(=O)-CH_3$); 4.94 (H, small *m*, AcO$-\overset{|}{C}-$H(e)) ppm. – IR.: 1730 and 1230 ($-O-C(=O)-CH_3$) cm^{-1}. – MS.: $M^+ = 238$ (0); *m/e*: 178 (47), 163 (87), 149 (29), 135 (24), 124 (100), 109 (82), 93 (49), 81 (85), 69 (48), 55 (43), 43 (86), 31 (44).

20. *5,5,9β-Trimethyl*-trans-*2β-decalol* **3a** *from acetate* **3b**. A solution of 1.76 g (7.4 mmol) acetate **3b** and 10 ml 10% ethanolic KOH was heated to reflux for 2 h. After the ethanol had been removed, the residue was taken up in ether, washed (brine), dried, concentrated, and recrystallized from pentane giving 1.41 g (98%) of alcohol **3a**; m.p. 82–83°.

Spectral data of **3a**. 90 MHz NMR. (in CCl_4, with $Eu(fod)_3$, see Fig. 2): 0.84 (3H, *s*, $>C(CH_3)_2$); 0.88 (3H, *s*, $>C(CH_3)_2$); 1.16 (3H, *s*, $-\overset{|}{C}-CH_3$(a)); 4.1 (H, small *m*, OH$-\overset{|}{C}-$H(e)) ppm. – IR.: 3630 and 3480 (–OH) cm^{-1}. – MS.: $M^+ = 196$ (5); *m/e*: 178 (17), 163 (100), 150 (4), 137 (20), 123 (24), 109 (36), 95 (42), 81 (59), 69 (54), 55 (50), 41 (61), 29 (19).

21. *2,5,5,9β-Tetramethyl*-trans-*2β-decalol* **3c** *from* **1**. a) *With Grignard*. A solution containing 9.7 g (50 mmol) ketone **1** (95% pure) in abs. ether (20 ml) was added to a *Grignard* solution (prepared from 1.32 g (55 mmol) Mg, 5.2 g (55 mmol) methyl bromide, and 18 ml abs. ether) so that a gentil reflux was obtained. The reaction mixture was heated to reflux an additional 1.5 h and then poured into a mixture of saturated aqueous NH_4Cl and ice. The organic layer was separated, washed (successively with 10% aqueous Na_2CO_3 and with brine), dried, and concentrated. The crude, crystalline material (10.5 g), containing (GLPC.[53])) still ~9% of starting material **1**, was recrystallized (twice) from pentane to give 7.0 g (67%) of **3c**; m.p. 99–100°. The mother liquor contained additional 20% of **3c**.

b) *With methyllithium*. Finely cut lithium (9 g; 1.29 mol) was covered with abs. ether (108 ml) and treated dropwise with stirring at –10° with a solution of methyl iodide (101 g, 0.71 mol) in abs. ether (216 ml). After the addition was complete, the mixture was stirred at 0° for 30 min, and then ketone **1** (63 g, 0.324 mol) in ether (216 ml) was added. The resulting mixture was heated 2 h at reflux, cooled and poured onto ice-water. The mixture was acidified by adding 20%

[49]) Identified by comparing their retention time on GLPC.[50]) with **3a**, prepared by method 20 and with **3a'** prepared by method 15.

[50]) 5 mm × 2.5 m column; 20% Carbowax 20M, 200°.

[51]) Identified by comparing their retention time on GLPC.[52]) with **3b**, prepared by method 19, and with **3b'**, prepared by method 16.

[52]) 0.02″ × 150′ metal capillary column; *Ucon* LB 550 X; 150°.

[53]) 5 mm × 2.5 m column; 5% Carbowax 20 M; 150°.

aqueous HCl, and extracted with ether. The organic extract was washed (successively with 10% aqueous Na_2CO_3 and with brine), dried, and concentrated to yield 67.6 g of crude crystalline material. Crystallization from pentane gave 56.3 g (83%) of alcohol **3c**; m.p. 99–101°.

Spectral data of **3c**. 60 MHz NMR. (CCl_4 and DMSO-d_6): 0.82 (3H, *s*, $>C(CH_3)_2$); 0.85 (3H, *s*, $>C(CH_3)_2$); 1.05 (3H, *s*, $-C(CH_3)(a)-$); 1.09 (3H, *s*, $>C(=O)CH_3(e)$); 3.34 (H, *s*, –OH) ppm. – IR.: 3610 (–OH) cm^{-1}. – MS.: $M^+ = 210$; *m/e*: 195 (65), 177 (92), 164 (5), 149 (5), 137 (34), 121 (30), 109 (50), 95 (55) ,83 (75), 69 (93), 57 (70), 43 (100), 29 (21).

22. *2,5,5,9β-Tetramethyl*-trans-*2β-decalyl acetate* **3d** *from alcohol* **3c**. A mixture of acetyl chloride (2 g), and acetic anhydride (1 g) was added to a stirred solution of alcohol **3c** (1.05 g; 5 mmol) in N,N-dimethylaniline (2 ml) while the temperature was kept below 20°. Stirring was continued 2 h at 20° and subsequently 2 h at 40°. The mixture obtained was poured onto ice-water, extracted with ether, washed (successively with 5% aqueous H_2SO_4 in order to remove the N,N-dimethylaniline, with 10% aqueous Na_2CO_3 and with brine), dried, and concentrated. Bulb distillation at 90–95°/0.001 Torr gave 1 g of a crystalline compound which was recrystallized once from pentane: 759 mg (60%) of **3d**; m.p. 41–43°.

Spectral data of **3d**. 60 MHz NMR.: 0.83 (3H, *s*, $>C(CH_3)_2$); 0.87 (3H, *s*, $>C(CH_3)_2$); 0.98 (3H, *s*, $-C(CH_3)(a)-$); 1.4 (3H, *s*, $>C(=O)CH_3$); 1.92 (3H, *s*, $-O-C(=O)CH_3$) ppm. – IR.: 1730 and 1240 ($-O-C(=O)CH_3$) cm^{-1}. – MS.: $M^+ = 252$ (0); *m/e*: 192 (74), 177 (100), 163 (2), 149 (18), 137 (38), 124 (53), 109 (78), 95 (54), 81 (59), 69 (54), 55 (41), 43 (78), 29 (16).

23. *2,5,5,9β-Tetramethyl*-trans-*2α-decalol* **3c'** *from epoxides* **5b'** *and* **6a'**. A mixture of 4 g (19 mmol) of epoxides **5b'** (14%) and **6a'** (86%) (for preparation see 26) was added, dropwise over 30 min, to a stirred suspension of $LiAlH_4$ (840 mg, 22 mmol) in abs. ether (70 ml) at reflux, and the mixture was allowed to boil for an additional 24 h. The excess of $LiAlH_4$ was decomposed by careful addition of 36% aqueous NaOH (15 ml) at 0°. The organic layer was decanted from the white inorganic layer, washed (brine), dried, and concentrated. The crude material obtained (4 g) was chromatographed on 40 g of silica gel. Elution with 400 ml of hexane/ether 95:5 gave 2.0 g (starting material and unidentified products). Subsequent elution with 200 ml of ether afforded 1.7 g of alcohol which was chromatographed a second time on 85 g of silica gel with 1 l of ether. One obtained 1.15 g of semi-crystalline product which upon bulb distillation at 112–115°/0.001 Torr, and subsequent recrystallization from pentane gave 945 mg of crystalline alcohol **3c'**; m.p. 55–56°.

Spectral data of **3c'**. 60 MHz NMR.: 0.77 (3H, *s*, $-C(CH_3)-$); 0.85 (3H, *s*, $-C(CH_3)-$); 0.95 (3H, *s*, $-C(CH_3)-$); 1.25 (3H, *s*, $>C(=O)CH_3(a)$); 3.48 (H, *s*, –OH) ppm. – IR.: 3620 and 3370 (–OH) cm^{-1}. – MS.: $M^+ = 210$ (6); *m/e*: 192 (57), 177 (88), 163 (3), 149 (14), 137 (100), 123 (43), 109 (52), 95 (58), 83 (75), 69 (96), 52 (73), 43 (92), 29 (20).

24. *2,5,5,9β-Tetramethyl*-trans-*2α-decalyl acetate* **3d'** *from alcohol* **3c'**. A mixture of acetyl chloride (1 g) and acetic anhydride (0.5 g) was added to a stirred solution of 500 mg (2.38 mmol) of alcohol **3c'** in N,N-dimethylaniline (1 ml) at 20°. Stirring was continued 2 h at 20°, and subsequently 4 h at 40°. The cold (25°) reaction mixture was poured onto ice, and extracted with ether. The organic phase was washed (with 5% aqueous H_2SO_4 in order to remove the N,N-dimethylaniline, with 10% aqueous Na_2CO_3 and with brine), dried, and concentrated. Bulb distillation at 90–95°/0.001 Torr gave 395 mg (66%) of acetate **3d'**.

Spectral data of **3d'**. 60 MHz NMR.: 0.78 (3H, *s*, $-C(CH_3)-$), 0.87 (3H, *s*, $-C(CH_3)-$); 0.98 (3H, *s*, $-C(CH_3)-$); 1.57 (3H, *s*, $>C(OAc)CH_3$); 1.83 (3H, *s*, $-O-C(=O)CH_3$) ppm. – IR. (liq.): 1730 and 1250

(—O—C(CH$_3$)=O) cm^{-1}. – MS.: M^+ = 252 (0); *m/e*: 192 (72), 177 (100), 163 (3), 149 (21), 137 (68), 123 (57), 109 (97), 95 (64), 81 (71), 69 (62), 55 (45), 43 (80), 29 (26).

25. *2,5,5,9-Tetramethyl-Δ^1*-trans-*octalin* **23b** *and 2,5,5,9-Tetramethyl-Δ^2*-trans-*octalin* **25b** *by means of acid catalyzed dehydration of alcohol* **3c**. Slow distillation of a mixture of 1.05 g (5 mmol) alcohol **3c** and 50 mg $KHSO_4$ at ~100°/10 Torr gave a mixture of hydrocarbons and water. Drying over molecular sieves (*Linde*, 4 Å), subsequent filtration through 10 g of silica gel (*Merck*, 0.05–0.2 mm) with hexane as a solvent, and bulb distillation at 125°/10 Torr yielded 0.8 g (83%) of **23b** (14%), and **25b** (86%). Analytical samples of **23b** and **25b** were obtained by separation on GLPC.[54]).

Spectral data of **23b**. 60 MHz NMR.: 0.84 (3H, *s*, —C(CH$_3$)—); 0.88 (3H, *s*, —C(CH$_3$)—); 0.92 (3H, *s*, —C(CH$_3$)—); 1.57 (3H, '*s*', =C(CH$_3$)—); 1.9 (2H, *m*, =C(CH$_2$—)); 5.0 (H, *m*, =C(H)—) ppm. – MS.: M^+ = 192 (39); *m/e*: 177 (100), 163 (2), 149 (21), 136 (15), 123 (50), 107 (63), 95 (52), 81 (63), 69 (49), 55 (26), 41 (52), 29 (14).

Spectral data of **25b**. 60 MHz NMR.: 0.86 (3H, 3H and 3H, *s*, *s* and *s*, >C(CH$_3$)$_2$ and —C(CH$_3$)—); 1.55 (3H, '*s*', =C(CH$_3$)—); 1.76 (2H, *m*, —C(CH$_2$—)); 1.96 (2H, *m*, =C(CH$_2$—)); 5.28 (H, *m*, =C(H)—) ppm. – MS.: M^+ = 192 (36); *m/e*: 177 (31), 163 (< 1), 149 (6), 137 (22), 124 (49), 109 (100), 95 (31), 81 (36), 69 (28), 55 (26), 41 (36), 29 (11).

26. *2,5,5,9β-Tetramethyl-1α,2α-epoxy*-trans-*decalin* **5b′** and *2,5,5,9β-tetramethyl-2α,3α*-trans-*decalin* **6a′** *from octalins* **23b** *and* **25b**. A solution of 40% peracetic acid in acetic acid (6.5 g, 34 mmol) and anhydrous sodium acetate (0.2 g) were added dropwise to a stirred mixture of 6.5 g (34 mmol) octalene (86% of **25b**, and 14% of **23b**; for preparation see 25), of sodium acetate (6.8 g), and methylene chloride (30 ml) at 5°. After the addition was complete the temperature was allowed to rise to 20° during 2 h. The sodium acetate was removed by filtration, and washed with methylene chloride. The organic phase was washed (successively with 10% aqueous Na_2CO_3 and with brine), concentrated, and distilled through a *Vigreux* column at 60–62°/0.001 Torr. The distillate (6.6 g) consisted (GLPC.[55]) of **5b′** (14%), and **6a′** (86%). 2.25 g of this mixture were chromatographed twice on 225 g of silica gel with hexane/ether 98:2 as a solvent to give 327 mg of pure **5b′** and 925 mg of pure **6a′**.

Spectral data of **5b′**. 60 MHz NMR.: 0.79 (3H, *s*, —C(CH$_3$)—); 0.83 (3H, *s*, —C(CH$_3$)—); 0.97 (3H, *s*, —C(CH$_3$)—); 1.18 (3H, *s*, >C(O)CH$_3$); 2.25 (H, *s*, >C(O)H) ppm. – MS.: M^+ = 208 (26); *m/e*: 193 (38), 175 (13), 165 (10), 150 (11), 137 (74), 123 (81), 109 (68), 95 (84), 81 (72), 69 (74), 55 (55), 43 (100), 29 (28).

Spectral data of **6a′**. 60 MHz NMR.: 0.84 (3H, 3H and 3H, *s*, *s*, and *s*, >C(CH$_3$)$_2$ and —C(CH$_3$)—); 1.18 (3H, *s*, >C(O)CH$_3$); 2.85 (H, *d* of *d*, J_1 ~ 2 Hz, J_2 ~ 2 Hz, >C(O)H) ppm. – MS.: M^+ = 208 (13); *m/e*: 193 (87), 180 (16), 165 (17), 149 (5), 137 (38), 123 (63), 109 (100), 95 (49), 81 (48), 69 (60), 55 (47), 41 (78), 29 (24).

27. *2,5,5,9β-Tetramethyl-1β,2β-epoxy*-trans-*decalin* **5a′**, *and 2,5,5,9β-tetramethyl-2β,3β*-trans-*decalin* **6b′** *and 2,5,5,9-tetramethyl*-trans-*Δ^{1,2}-octal-3-one* **24b** *from octalin* **23b** *and* **25b** *by means of NBS/base*. A solution of 30 g $AgNO_3$ in water (30 ml) was diluted with acetone (750 ml), and with efficient stirring silicagel (300 g) was slowly added. The slurry was filtered off and dried under vacuum: 14 h at 60°/12 mm and subsequently 2 h at 80°/12 mm [80].

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[54]) 5 mm × 2.5 m column; 15% Apiezon L; 220°.

[55]) 5 mm × 2.5 m column; 5% Carbowax 20 M; 175°.

A mixture of octalins (3 g: 22% of **23b** and 78% of **25b**) was chromatographed on ~300 g of this $AgNO_3$-impregnated silicagel. After 4 runs 1,3 g of a 1:1 mixture of **23b** and **25b** was obtained. This amount (1.3 g, 6.8 mmol) was shaken with water (18 ml), acetic acid (0.4 ml) and N-bromosuccinimide (1.2 g, 6.8 mmol) at 20° for 25 h. The oily reaction mixture was taken up in ether, washed (successively with 10% aqueous Na_2CO_3 and water), dried and concentrated to give 1.7 g of an oil. This material was chromatographed on silicagel (19 g). Elution with hexane (100 ml) gave 0.9 g of a non-polar not further investigated fraction, and subsequent elution with ether (100 ml) gave 0.4 g of a mixture of bromohydrines.

0.4 g of bromohydrine was dissolved in *t*-butyl alcohol (0.4 ml) and added to a solution of potassium *t*-butoxide (0.16 g, subl.) in abs. *t*-butyl alcohol (0.8 ml) at 20°. After this solution had been stirred 18 h at 20° it was poured onto water and extracted with ether. The etheral phase was washed (water), dried and concentrated to give 0.3 g of crude material. Bulb distillation at 160–210°/9 mm gave 0.21 g of a mixture of **5a'** (10%), **6b'** (40%) and **27** (40%).

Spectral data of **5a'**. 90 MHz NMR.: 0.8 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.86 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.05 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.3 (3H, *s*, $>C(-O-CH_3)$); 2.55 (1H, *s*, $>C(-O-H)$) ppm. – MS.: $M^+ = 208$ (13); *m/e*: 194 (15), 175 (10), 165 (9), 150 (14), 137 (26), 123 (49), 109 (59), 95 (63), 81 (49), 69 (68), 55 (44), 44 (68), 43 (100), 41 (73), 39 (23), 29 (25).

Spectral data of **6b'**. 60 MHz NMR.: 0.81 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.85 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.95 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.18 (3H, *s*, $>C(-O-CH_3)$); 2.84 (1H, *d* of *d*, $J = 5$ Hz, $J_2 \sim 2$ Hz) ppm. – MS.: $M^+ = 208$ (14); *m/e*: 193 (98), 180 (17), 165 (20), 149 (5), 135 (26), 123 (35), 109 (100), 95 (40), 81 (39), 69 (60), 55 (41), 43 (79), 29 (18).

Spectral data of **27**. 90 MHz NMR.: 0.9 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.91 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.09 (3H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.75 (3H, *d*, $J = 2$ Hz, $=C(-CH_3)$); 6.4 (1H, *t*, $J = 2$ Hz, $=C(-H)$) ppm. – MS.: $M^+ = 206$ (39%); *m/e*: 191 (11), 177 (0), 163 (26), 149 (17), 135 (20), 121 (32), 109 (58), 93 (22), 83 (100), 69 (42), 55 (49), 41 (55), 29 (13). – IR.: 1700 and 1660 ($=\overset{|}{C}-\overset{|}{C}=O$) cm^{-1}.

28. *5,5,9-Trimethyl-$\Delta^{1(2)}$-*trans*-octalin* **23a**, *and 5,5,9-trimethyl-$\Delta^{2(3)}$-*trans*-octalin* **25a** via *pyrolysis of a mixture of acetates* **3b** *and* **3b'**. A mixture of acetates (63% **3b**, 37% **3b'**; 22.8 g, 0.096 mol) in abs. toluene (25 ml) was passed dropwise in a stream of nitrogen during 2 h through a vertical column (50 × 2 cm) filled with glass helices and heated to ~ 450°. After the pyrolysis was finished the column was flushed with 100 ml of toluene, and the product was taken up in ether, washed (successively with 10% of aqueous Na_2CO_3 and brine), dried, and concentrated. The crude material (~ 15 g) was chromatographed twice on 50 g of silica gel with hexane as a solvent, and distilled through a *Vigreux* column at 91–94°/10 Torr to give 12.8 g (72%) of a mixture of isomers **23a** (32%), and **25a** (68%). Pure analytical samples of **23a** and **25a** were obtained by separation on GLPC.[56]).

Spectral data of **23a**. 60 MHz NMR.: 0.85 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.88 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.97 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.8–2.2 (2 H, *m*, $=\overset{|}{C}-CH_2$); 5.27 (H and H, *m*, $-CH=CH-$) ppm. – IR.: 1645 ($>C=C<$) cm^{-1}. – MS.: $M^+ = 178$(33); *m/e*: 163 (80), 149 (42), 135 (25), 122 (43), 109 (100), 93 (67), 81 (86), 69 (65), 55 (37), 41 (68), 29 (18).

Spectral data of **25a**. 60 MHz NMR.: 0.87 (3 H and 3 H, *s* and *s*, $-\overset{|}{\underset{|}{C}}-CH_3$ and $-\overset{|}{\underset{|}{C}}-CH_3$); 0.88 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_2$); 1.57–2.08 (2 H and 2 H, *m*, $-CH_2-CH=CH-CH_2-$); 5.5 (H and H, *m*,

[56]) 5 mm × 2.5 m column; 15% Apiezon L; 200°.

—*HC*=C*H*—) ppm. – IR.: 1655 (>C=C<) cm^{-1}. – MS.: $M^+ = 178$ (12); *m/e*: 163 (12), 149 (< 1), 137 (5), 124 (95), 109 (100), 93 (24), 81 (32), 69 (25), 55 (20), 41 (32), 29 (9).

29. *5,5,9β-Trimethyl-1α,2α-epoxy*-trans-*decalin* **5b**, *and 5,5,9β-trimethyl-2α,3α-epoxy*-trans-*decalin* **6a** *from octalins* **23a** *and* **25a**. A solution of 40% peracetic acid in acetic acid (5.7 g, 30 mmol) was added dropwise to a stirred mixture containing 5.34 g (30 mmol) of octalins (68% **25a**, and 32% **23a**; for preparation see 28), sodium acetate (5 g), and methylene chloride (25 ml) at 5°. After the addition was complete the temperature was allowed to rise to that of the room during 2 h. The sodium acetate was removed by filtration, and washed with methylene chloride. The filtrate was washed (successively with 10% aqueous Na_2CO_3 and brine), concentrated and distilled through a *Vigreux* column at 46–54°/0.001 Torr to give a mixture consisting (GLPC.)[55] of **6a** (75%) and **5b** (25%). The mixture was separated by repeated column chromatography on silica gel with hexane/ether 35:5 as solvent to yield 1.8 g **6a** (99% pure), b.p. 128–132°/10 Torr, and 570 mg **5b** (92–95% pure), b.p. 125–127°/10 Torr. A pure analytical sample of **5b** was obtained by additional separation on GLPC.[55]).

Spectral data of **5b**. 60 MHz NMR.: 0.78 (3 H, *s*, —C(—)—CH_3); 0.83 (3 H, *s*, —C(—)—CH_3); 1.02 (3 H, *s*, —C(—)—CH_3); 2.46 (H, *d*, $J \sim 4$ Hz, >C(—O—)H); 2.88 (H, *m*, >C(—O—)H) ppm. – MS.: $M^+ =$ 194 (3); *m/e*: 179 (43), 161 (100), 150 (13), 135 (45), 123 (25), 107 (49), 95 (56), 81 (59), 69 (68), 55 (58), 41 (84), 29 (25).

Spectral data of **6a**. 60 MHz NMR.: 0.84 (3 H and 3 H, *s* and *s*, —C(—)—CH_3 and —C(—)—CH_3); 0.88 (3 H, *s*, —C(—)—CH_3); 2.7–3.1 (H and H, *m*, —*HC*(—O—)—*CH*—) ppm. – MS.: $M^+ = 194$ (2); *m/e*: 179 (16), 161 (38), 151 (6), 137 (35), 123 (35), 109 (100), 95 (46), 81 (51), 69 (48), 55 (44), 41 (71), 29 (24).

30. *5,5,9β-Trimethyl-1α-bromo*-trans-*2β-decalyl acetate* **24a**, *and 5,5,9β-trimethyl-3α-bromo*-trans-*2β-decalyl acetate* **26a** *from octalins* **23a** *and* **25a**. A mixture of 7.5 g (42 mmol) of octalin (68% of **25a**, and 32% of **23a**; for preparation see 28) was added to a stirred suspension of bromoacetamide (6.9 g, 50 mmol) in glacial acetic acid (20 ml) at 15–20°. Stirring was continued at 20° an additional period of 6 h. The mixture was poured onto ice, extracted with ether and washed (successively with 10% of aqueous $NaHCO_3$ and with brine), dried and concentrated to yield 12.8 g of isomeric bromoacetates. Repeated crystallization from pentane gave 2.2 g of isomer **24a**, m.p. 153–154.5°, and 2.3 g of isomer **26a**, m.p. 81–83°.

Spectral data of **24a**. 60 MHz NMR. (C_6D_6 and $(CD_3)_2CO$): 0.85 (3 H, *s*, >C(CH_3)(CH_3)); 0.9 (3 H, *s*, >C(CH_3)(CH_3)); 1.22 (3 H, *s*, —C(—)—CH_3); 1.97 (3 H, *s*, —O—C(=O)—CH_3); 4.13 (H, small *m*, >C(Br)H(e)); 5.21 (H, small *m*, >C(OAc)H(e)) ppm. – IR.: 1740 and 1235 (—O—C(=O)—CH_3) cm^{-1}. – MS.: $M^+ =$ 316 and 318 (0); *m/e*: 302 and 304 (3), 256 and 258 (9), 241 and 243 (12), 215 (1), 195 (4), 177 (100), 161 (28), 149 (4), 137 (25), 121 (28), 107 (30), 95 (50), 81 (48), 69 (52), 55 (30), 43 (81), 29 (10).

Spectral data of **26a**. 60 MHz NMR. (CCl_4 and DMSO-d_6): 0.85 (3 H, and 3 H, *s* and *s*, >C(CH_3)(CH_3)); 1.05 (3 H, *s*, —C(—)—CH_3); 2.03 (3 H, *s*, —O—C(=O)—CH_3); 4.49 (H, small *m*, >C(Br)H); 4.95 (H, small *m*, >C(OAc)H) ppm. – IR.: 1740 and 1230 (—O—C(=O)—CH_3) cm^{-1}. – MS.: $M^+ = 316$ and 318 (0); *m/e*: 256 and 258 (4), 241 and 243 (2), 215 (< 1), 194 (3), 177 (24), 161 (15), 147 (1), 135 (2), 124 (100), 109 (33), 95 (15), 81 (16), 69 (24), 55 (16), 43 (42), 29 (4).

31. *5,5,9β-Trimethyl-1β,2β-epoxy*-trans-*decalin* **5a** *from bromoacetate* **24a**. The bromoacetate **24a** (1.32 g, 4.15 mmol) was stirred in a solution (40 ml) of 10% methanolic KOH at 20° for 20 h. After the methanol had been evaporated, the residue was taken up in ether, washed (brine), dried, and distilled at 108–112° (bath temperature)/10 Torr yielding 614 mg (76%) **5a**, 100% pure (GLPC.)[55].

Spectral data of **5a**. 60 MHz NMR.: 0.78 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.82 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.02 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 2.52 (H, *d*, J = 3.8 Hz, $\rangle C\langle^{O}_{H}$); 2.93 (H, *m*, $\rangle C\langle^{O}_{H}$) ppm. MS.: M^+ = 194 (11); *m/e*: 179 (19), 161 (31), 150 (31), 137 (35), 123 (31), 109 (38), 95 (57), 81 (65), 69 (100), 55 (69), 41 (91), 29 (29).

32. *5,5,9β-Trimethyl-2β,3β-epoxy*-trans-*decalin* **6b** *from bromoacetate* **26a**. Using the conditions given in **31**, 883 mg (69%) of epoxide **6b**, b.p. 110–114° (bath)/10 Torr, 100% pure (GLPC.)[55], was obtained from bromoacetate **26a** (2.19 g, 6.6 mmol).

Spectral data of **6b**. 60 MHz NMR.: 0.81 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.85 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.95 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 2.77–3.17 (H and H, *m*, $-HC(O)-CH-$) ppm. – MS.: M^+ = 194 (4); *m/e*: 179 (26), 161 (17), 151 (12), 135 (14), 124 (24), 109 (100), 95 (38), 81 (45), 69 (49), 55 (41), 41 (63), 29 (19).

33. *5,5,9β-Trimethyl*-cis-*2α-decalol* **4a'** *and 5,5,9β-Trimethyl*-cis-*2β-decalol* **4a** *from* **2** *by Na*. a) Ketone **2** (38.8 mg, 0.2 mmol) in 2-propanol (1 ml) was heated to 80° and treated with sodium (48 mg). After complete dissolution of the sodium, the reaction was cooled to 25°, poured onto water and extracted with ether. The etheral phase was washed (water), dried, and concentrated to give 40 mg of crude alcohol which was shown by GLPC.[55] to contain 77% of **4a'** and 23% of **4a**. Pure analytical samples were collected by GLPC.[55].

b) Finely cut sodium (40 g, 1.75 mol) was added portionwise to a heated (80°) solution of a ketone mixture (68 g, ~ 0.35 mol) consisting of **2** (70%), **1** (12%), and an unknown impurity (18%) in 2-propanol (500 ml). After all sodium had reacted the solution was cooled to 25°, diluted with water (300 ml), and extracted with ether. The etheral phase was washed (brine), dried, concentrated, and distilled at 75–89°/0.001 Torr to give 47.8 g of crude product which was chromatographed on 1 kg of silica gel (*Merck* 0.05–0.2 mm) with hexane/ether 9:1 as a solvent. One fraction (~ 8 g) containing ~ 90% of **4a'** was recrystallized 5 times from hexane to yield 3.9 g of **4a**, m.p. 91–93°.

Spectral data of **4a'**. 90 MHz NMR. (in CCl_4; with $Eu(fod)_3$, see Fig. 2): 0.93 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.98 (3 H, *s*, $\rangle C\langle^{CH_3(a)}_{CH_3}$); 1.04 (3 H, *s*, $\rangle C\langle^{CH_3}_{CH_3(e)}$); 3.78 (H, large *m*, $HO-\overset{|}{\underset{|}{C}}-H(a)$) ppm. – IR.: 3630 and 3350 (–OH) cm^{-1}. – MS.: M^+ = 196 (1); *m/e*: 178 (22), 163 (89), 149 (3), 135 (38), 122 (43), 107 (41), 95 (60), 82 (100), 69 (55), 55 (61), 41 (79), 29 (26).

Spectral data of **4a**. 90 MHz NMR. (in CCl_4; with $Eu(fod)_3$, see Fig. 2): 0.87 (3 H, *s*, $\rangle C\langle^{CH_3(a)}_{CH_3}$); 1.12 (3 H and 3 H, *s* and *s*, $\rangle C\langle^{CH_3}_{CH_3(e)}$ and $-\overset{|}{\underset{|}{C}}-CH_3(a)$); 3.72 (H, large *m*, $HO-\overset{|}{\underset{|}{C}}-H(a)$) ppm. – IR.: 3630 and 3350 (–OH) cm^{-1}. – MS.: M^+ = 196 (< 1); *m/e*: 178 (32), 163 (87), 149 (5), 137 (47), 122 (29), 111 (100), 95 (54), 81 (56), 69 (62), 55 (62), 41 (79), 29 (28).

34. *5,5,9β-Trimethyl*-cis-*2α-decalol* **4a'**, *and 5,5,9β-Trimethyl*-cis-*2β-decalol* **4a** *from* **2** *by* $NaBH_4$. A solution of $NaBH_4$ (305 mg, 8 mmol) in water (4 ml) was added dropwise to a heated (+ 50°), stirred solution containing 3.1 g (16 mmol) of ketone **1b** in methanol (5 ml). After the addition was complete the reaction mixture was heated to reflux for 2 h, cooled to 25°, and taken up in ether. The etheral phase was washed (twice with 36% aqueous NaOH, and with brine until neutral), dried, and concentrated to give 3 g of crude product consisting of 55% **4a'** and 45% **4a** according to GLPC.[55]. Subsequent chromatography on 150 g of silica gel with hexane/ether 8:2

as a solvent yielded 1.99 g (63%) of a mixture of two alcohols, **4a'** (38%), and **4a** (62%). Pure analytical samples of **4a'** and **4a** were obtained by GLPC.[55]). For their spectral data see 33.

35. *5,5,9β-Trimethyl*-cis-*2α-decalyl acetate* **4b'**, *and 5,5,9β-trimethyl*-cis-*2β-decalyl acetate* **4b** *from alcohols* **4a'** *and* **4a**. A solution containing 588 mg (3 mmol) of alcohols **4a'** (62%) and **4a** (38%) (for preparation see 34), acetic anhydride (408 mg, 4 mmol) and pyridine (400 mg) was heated to 100° for 2 h. After the reaction mixture had been cooled to 25°, it was poured onto water (2 ml), and extracted twice with ether. The etheral phase was washed (successively with 10% aqueous HCl to remove the pyridine, with 10% aqueous Na_2CO_3, and with brine), dried, and concentrated. Bulb distillation at 70–75°/0.001 Torr gave 498 mg (70%) of a mixture of two epimeric alcohols, **4b'** (38%), and **4b** (62%). Pure analytical samples of **4b'** and **4b** were obtained by separation on GLPC.[39]).

Spectral data of **4b'**. 60 MHz NMR.: 0.98 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.08 (3 H, and 3 H, *s* and *s*, $\diagup C \diagdown^{CH_3}_{CH_3}$); 1.92 (3 H, *s*, $-O-C(=O)-CH_3$); ~ 4.9 (H, broad *m*, $\diagup C \diagdown^{OAc}_{H(a)}$) ppm. – IR.: 1730 and 1245 ($-O-C(=O)-CH_3$) cm^{-1}. – MS.: $M^+ = 238$ (0); *m/e*: 178 (51), 163 (90), 149 (27), 135 (31), 124 (52), 109 (62), 93 (71), 82 (78), 69 (52), 55 (52), 43 (100), 29 (19).

Spectral data of **4b**. 60 MHz NMR.: 0.88 (3 H, *s*, $\diagup C \diagdown^{CH_3(a)}_{CH_3}$); 1.11 (3 H and 3 H, *s* and *s*, $\diagup C \diagdown^{CH_3}_{CH_3(e)}$ and $-\overset{|}{\underset{|}{C}}-CH_3$); 1.9 (3 H, *s*, $-O-C(=O)-CH_3$); ~ 4.7 (H, broad *m*, $\diagup C \diagdown^{OAc}_{H(a)}$) ppm. – IR.: 1730 and 1245 ($-O-C(=O)-CH_3$) cm^{-1}. – MS.: $M^+ = 238$ (0); *m/e*: 178 (40), 163 (80), 149 (24), 135 (30), 124 (38), 109 (55), 93 (64), 81 (69), 69 (48), 55 (49), 43 (100), 29 (19).

36. *5,5,9β-Trimethyl*-trans-*3β-decalol* **8a** *and 5,5,9β-trimethyl*-trans-*3α-decalol* **8a'** *from* **7** *by means of* $NaBH_4$. A solution of 722 mg (9 mmol) of $NaBH_4$ in water (8 ml) was added to a stirred, heated (50°) solution of 7.4 g (38 mmol) 5,5,9-trimethyl-*trans*-3-decalone **7** [21][57]) in methanol (10 ml). After the addition was complete the reaction mixture was heated to boiling for 2 h, cooled to 20°, and taken up in ether. The etheral phase was washed (twice with 36% aqueous NaOH, and with brine until neutral), dried, concentrated, and distilled at 89–91°/0.001 Torr to give 6.67 g (87%) of an epimeric mixture (88% of **8a**, and 12% of **8a'** by GLPC.[55])). The mixture was chromatographed on 200 g of silica gel with hexane/ether 3:2 as solvent. The fractions containing mainly **8a** were chromatographed a second time (silica gel; hexane/ether 4:1) to give, after bulb distillation 2.94 g of oily alcohol **8a**, b.p. 85–87°[37])/0.001 Torr. The fractions containing mainly **8a'** were also chromatographed a second time (silica gel; hexane/ether 4:1) to yield, after sublimation at 55–60°/0.001 Torr, 0.8 g of alcohol **8a'**, m.p. 85–87° (recrystallized once from hexane).

Spectral data of **8a**. 60 MHz NMR.: 0.84 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.87 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.96 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 3.5 (H, broad *m*, $\diagup C \diagdown^{OH}_{H(a)}$) ppm. – IR. (liq.): 3340 (–OH) cm^{-1}. – MS.: $M^+ = 196$ (10); *m/e*: 181 (23), 163 (100), 149 (2), 138 (37), 123 (64), 107 (41), 95 (46), 81 (68), 69 (61), 55 (56), 41 (67), 31 (57).

Spectral data of **8a'**. 60 MHz NMR.: 0.8 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.85 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.93 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 4.1 (H, small *m*, $\diagup C \diagdown^{OH}_{H(e)}$) ppm. – IR.: 3630 and 3390 cm^{-1}. – MS.: $M^+ = 196$ (1); *m/e*: 178 (38), 163 (100), 149 (6), 135 (18), 123 (24), 107 (35), 95 (37), 81 (44), 69 (44), 55 (43), 41 (48), 29 (17).

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[57]) Prepared in larger amounts according to ref. [21c] and references cited therein; m.p. 37–38° (from pentane).

37. *5,5,9β-Trimethyl*-trans-*3β-decalyl acetate* **8b** *from alcohol* **8a**. A solution of 1.18 g (6 mmol) of alcohol **8a**, 1 g (10 mmol) of acetic anhydride, and 1 g of pyridine was heated to 100° for 4 h. The reaction mixture was cooled to 20°, poured onto ice water, and taken up in ether. The etheral phase was washed (10% aqueous HCl to remove the pyridine, 10% aqueous Na_2CO_3, and water), dried, concentrated, and distilled at 94–96°/0.001 Torr to give 1.27 g (89%) of **8b**.

Spectral data of **8b**. 60 MHz NMR.: 0.82 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.88 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 0.98 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.94 (3 H, *s*, $-O-C(=O)-CH_3$); ~ 4.55 (H, broad *m*, $>C(OAc)H(a)$) ppm. – IR.: 1735 and 1240 ($-O-C(=O)-CH_3$) cm^{-1}. – MS.: $M^+ = 238$ (0); *m/e*: 192 (1), 178 (83), 163 (99), 149 (4), 135 (37), 124 (56), 107 (48), 93 (61), 81 (95), 69 (52), 55 (50), 43 (100), 29 (17).

38. *5,5,9β-Trimethyl*-trans-*3α-decalyl acetate* **8b′** *from alcohol* **8a′**. A mixture of 490 mg (2.5 mmol) of alcohol **8a′**, 356 mg (3.5 mmol) of acetic anhydride, and 350 mg of pyridine was heated at 100° for 4 h. After the reaction mixture had been cooled to 20° it was poured onto ice water, and taken up in ether. The etheral phase was washed (with 10% aqueous HCl to remove the pyridine, with 10% aqueous Na_2CO_3, and with brine), dried, concentrated and distilled at 94–96°/0.001 Torr (bulb distillation): 526 mg (96%) of **8b**.

Spectral data of **8b′**. 60 MHz NMR.: 0.8 (3 H and 3 H, *s* and *s*, $-\overset{|}{\underset{|}{C}}-CH_3$ and $-\overset{|}{\underset{|}{C}}-CH_3$); 0.94 (3 H, *s*, $-\overset{|}{\underset{|}{C}}-CH_3$); 1.96 (3 H, *s*, $-O-C(=O)-CH_3$); 5.06 (H, small *m*, $>C(OAc)H(e)$) ppm. – IR.: 1730 and 1240 ($-O-C(=O)-CH_3$) cm^{-1}. – MS.: $M^+ = 238$ (0); *m/e*: 178 (64), 163 (100), 149 (2), 135 (32), 124 (39), 108 (40), 93 (47), 81 (49), 69 (35), 55 (37), 43 (70), 29 (12).

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