The Conformational Behaviour of 10-Substituted Spiro[4.5]decanes

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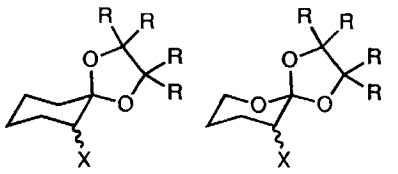
The conformational behaviour of 10-X-substituted 1,4-dioxa- and 1,4,6-trioxaspiro[4.5]decanes **1**–**4** has been studied by ^{13}C-, ^{19}F- and ^{1}H-NMR spectroscopy. Two X-ray analyses (of **2a,e**) are presented, and their implications to cleavage reactions of chiral acetals are discussed. Participation of twist boat forms in the conformeric equilibrium of at least **1c** has been made plausible by observing $^{13}C,^{19}F$-NMR coupling constants. The ratios of axial to equatorial conformer in **1**–**4** have been calculated by molecular mechanics.

In connection with an investigation aimed at elucidating the origins of stereoselectivity in reactions of allylboronic esters[1], quantitative data were needed on the conformational behaviour of some model compounds, spiro ketals and spiro ortholactones. For this purpose, a range of 10-X-substituted 1,4-dioxaspiro[4.5]decanes **1**, **2** and 1,4,6-trioxaspiro[4.5]decanes **3**, **4** has been prepared (Scheme 1). The conformational behaviour of these compounds has been studied, especially the equilibrium between X in an axial and an equatorial position. Implications of these data to organic synthesis will also be dealt with.

Scheme 1

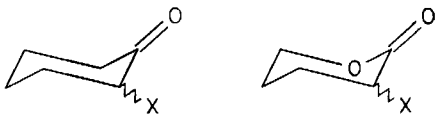


1: R = H **3**: R = H
2: R = CH_3 **4**: R CH_3

1-4	a	b	c	d	e	f	g	h	i
X	H	CH_3	F	Cl	Br	OCH_3	SCH_3	*t*Bu	$SCEt_3$

Syntheses

Ketals **1**, **2** were prepared by acid-catalysed reaction of the corresponding α-substituted cyclohexanones **5** with glycol or pinacol. Reaction of the corresponding δ-valerolactones **6** with glycol under acid catalysis also furnished the ortholactones **3**. BF_3-catalysed addition[2] of tetramethyloxirane to lactones **6** yielded the ortholactones **4** in poor to fair yields.



5 **6**

Conformational Analysis

Method

The ^{1}H-, ^{13}C- and, where possible, ^{19}F-NMR spectra of compounds **1**–**4** in CD_2Cl_2 were recorded at 173 K, and the signals were integrated. At this temperature, the flip of the six-membered rings was in the slow-exchange region, whereas the five-membered rings still underwent fast exchange. Spectra of the unsubstituted compounds (X = H; **2a**, **3a**, **4a**) verified this observation. No additional signals appeared, as would have been expected if the motion of the five-membered ring had been frozen. The six-membered ring of the ortholactones **3**, **4** proved to be more mobile than that of the ketals, in accord with observations made by Perrin[3].

Some ethylene ketals have been studied previously[4]. Due to the experimental method chosen by the authors, some of their findings are in error and will be corrected in this publication without further notice.

Conformeric Ratios

Percentages of conformers with equatorial X are given in Table 1 and conformer energies have been calculated accordingly. Assignments were made on the basis of Karplus relationships (^{1}H, ^{19}F NMR); in addition, an X-ray analysis has been performed on **2e** (see below). The remaining compounds have been assigned by analogy, supported by ^{13}C-NMR chemical-shift arguments derived from the trends observed in the ethylene ketals **1**.

Discussion

The data in Table 1 show that the content of axial conformer is drastically increased when going from the glycol

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Table 1. Free enthalpy difference between axial and equatorial conformers $RT \ln(c_{ax}) - RT \ln(c_{eq})$ [kJ/mol]; negative values indicate that the axial conformer is more stable

	1	2	3	4
b	+5.0	−4.4	≥ +6.6 (?)	+3.6
c	+1.0	−4.5	+2.7	+1.4
d	+2.4	≤ −6.0	+4.5	−0.6
e	+2.7	≤ −6.3	+4.4	−1.4
f	+1.3	≤ −6.5	+5.6	+1.5
g	+2.8	≤ −6.6	+6.6	−0.2
h	+2.9			
i	+3.6			

Table 2. Free enthalpy difference between axial conformers of **1**, **2** and **3**, **4** [kJ/mol]; the values indicate how much more stable the axial conformer in the "pinacol" compounds **2**, **4** is compared to the "ethylene glycol" compounds **1**, **2**

	b	c	d	e	f	g
2 − **1**	9.4	5.4	≥8.4	≥9.0	≥7.8	≥9.4
4 − **3**	≥3.0	1.3	3.9	5.8	4.2	6.8

former is drastically increased when going from the glycol compounds **1**, **3** to the pinacol compounds **2**, **4**; this is more pronounced for the ketals **1**, **2**. This phenomenon almost certainly rests on steric interactions of the additional methyl groups in **2**, **4** with the α substituent (see Table 2). More subtle effects, however, also play a role. The ethylene ketals will be discussed first. The observed increase in content of axial conformer runs parallel to the increase in polarity of X: $CH_3 < SCH_3$, Br < Cl < OCH_3 < F. If only steric effects analogous to those in monosubstituted cyclohexanes were operating, the following order would be the expected one: $CH_3 < SCH_3 < OCH_3$ < Cl < Br < F (based on the corresponding *A* values[5] of 7.11, 4.47, 2.51, 1.80, 1.59, 0.63 kJ/mol). Apparently, the order actually observed is influenced by "polar" factors, and the well-known[6] "gauche effect" may be invoked to explain this phenomenon. Certainly, they also operate in the pinacol ketals, as in the case of X = F (**2c**) and X = CH_3 (**2b**) the same conformer ratio was found, which would not have been expected from simple steric arguments.

Regarding the ortholactones, the decreased amount of axial conformer when compared to the ketals may be explained as follows. When a methylene group in the six-membered ring is replaced by an oxygen atom, the steric interaction between this site and the five-membered ring is decreased. Consequently, this ring may more easily bend away from the substituent X, reducing its interaction with X. This effect must be quite strong, since one 1,3-diaxial interaction between X and the ring sites is also attenuated, which should favour the axial conformer (e.g., the *A* value of 2-methyltetrahydropyran is 6.0 kJ/mol[7] in comparison to 7.3 kJ/mol in methylcyclohexane). Again, in the ortholactones, there is a polar effect; but it operates in the opposite direction: The content of axial conformer is *decreased* when the polarity of X is increased. This effect may be ascribed to a greater difference in dipole moments between axial and equatorial conformers as compared to the ketals. Support for this hypothesis resulting from molecular mechanics calculations is given below.

Hitherto all experimental results have been discussed under the tacit assumption that the six-membered ring of the compounds under observation all adopt a chair conformation. For low temperatures (i.e., below 220 K) this assumption is substantiated by the appearance of only two sets of signals in the ^{13}C-NMR spectra and the lack of any irregularity in the thermal anisotropy factors in the X-ray analyses (see below). There is strong evidence, however, for this not to be the case for room-temperature conditions. For the fluorine-containing compounds **1c**, **2c**, **3c**, **4c**, a set of ^{13}C,^{19}F coupling constants for both axial and equatorial conformers at 173 K has been obtained. From this set, it should be possible to calculate conformeric equilibria at room temperature by measuring the averaged ambient-temperature coupling constants. Mathematically, this means: $a \cdot J_{ax} + b \cdot J_{eq} = J_{obs}$ ($a + b = 1$), where *a* and *b* are the relative amounts of axial and equatorial conformer.

When this formalism was applied to the ethylene ketal **1c**, where the coupling constants could be determined most precisely, erratic results were obtained for the conformeric equilibria (Table 3). The differences in calculated conformeric ratios are definitely beyond experimental error. At room temperature, therefore, there must be at least one more conformer with a geometry of the six-membered ring other than a chair form. A careful search for such a third conformer in the ^{19}F-NMR spectrum at 183 K, however, did not reveal any signal in addition to those observed for axial and equatorial conformer. The detection limit was estimated equal, or less than, 0.5%. This means, that the unknown form is enthalpically disfavoured but entropically favoured which is true for the twist-boat family of cyclohexanes. Hence, twist-boat forms are suggested to play an important role in the conformational equilibria of these compounds at room temperature.

Table 3. ^{13}C-, ^{19}F-NMR coupling constants in **1c** and conformer ratios at room temperature calculated therefrom

	J_{ax} (173 K)	J_{eq} (173 K)	J_{av} (293 K)	axial conformer (293 K)
C-1,F	20.4	17.1	19.1	61
C-2,F	174.7	183.9	181.7	24
C-3,F	21.6	14.9	17.7	42

X-ray Analyses

Figure 1 is a SCHAKAL[8] view of 10-bromo-2,2,3,3-tetramethyl-1,4-dioxaspiro[4,5]decane (**2e**). The bromine substituent occupies the axial position of a chair-like six-membered ring. The methyl-bearing carbon atoms within the five-membered ring adopt a gauche conformation relative to each other (regarding the C−O−C−O−C fragment), probably a manifestation of the exoanomeric effect[9], since

the five-membered ring of **2a** adopts the same conformation (see below). With respect to the ketal carbon atom, a notable difference in lenghts between the axial and equatorial C–O bonds is observed, the axial one being 1.438 Å, the equatorial one 1.411 Å. The C–O bond lenghts within the five-membered ring amount to 1.440 and 1.441 Å. This implies a considerable shortening of the equatorial C–O bond. There may be several reasons for this phenomenon: it may be a consequence of the gauche array of bromine and oxygen atoms or else an intrinsic property of (spiro) ketals of six-membered rings. In addition, it is well-known that a crystal field can also influence bond lengths[10]. Neither MNDO[11] nor force-field calculations have reproduced this difference[12]. Clarification of the origins of this effect could be useful to preparative organic chemistry: For example, the longer bond of dioxane **7** is selectively cleaved in its reduction by DIBAL[13]. Ketals **8** and **9** come closer to the compounds used in this study (Scheme 2); they were made to react with nucleophiles under Johnson's[14] conditions. Cleavage of the equatorial bond was deduced solely on the basis of the product stereochemistry[15,16]. No structural analyses were performed. Unfortunately, the pinacol ketals **2** – conformationally near to homogeneous with respect to the axial position of X – did not undergo Johnson-type chemistry, thus precluding a direct comparison[17].

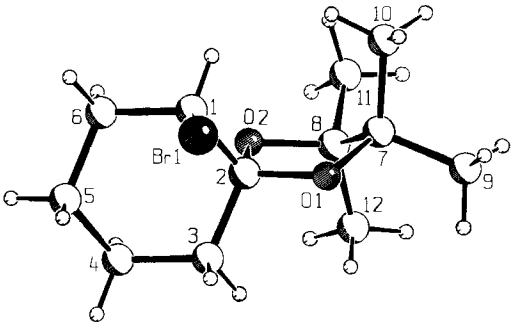
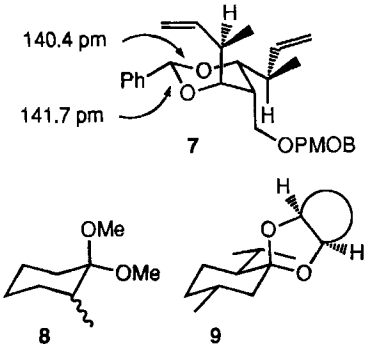


Figure 1. SCHAKAL view of **2e**

Scheme 2



To clarify the origins of bond shortening further, the unsubstituted pinacol ketal **2a** has also been studied by X-ray analysis (Figure 2). The five-membered ring adopts the same conformation as the one in the bromo ketal **3e** does. The equatorial C–O bond is still shortened, but only so by 0.011 Å. Hence, a short equatorial C–O bond seems to be an intrinsic property of the ketal system which is remarkably enhanced in the case of the bromine-substituted ketal **2e**.

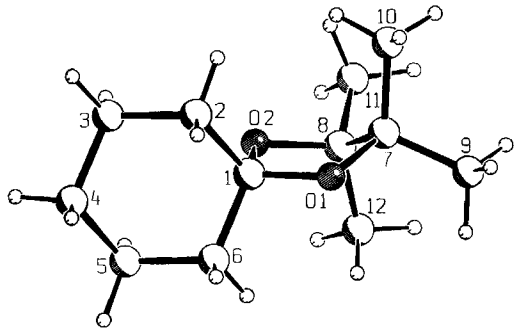


Figure 2. SCHAKAL view of **2a**

Calculation of Conformeric Equilibria by Molecular Mechanics

The experimental data collected in this study allow to test the power of empirical calculations with respect to predicting subtle conformational effects in relatively complex polar systems. As **1**–**4** were designed to model transition states in reactions of allylboronic esters with carbonyl compounds, this was of special importance: We hoped to obtain some information about the usefulness of "transition-state modelling"[18] as applied to these reactions. Use was made of the programme SYBYL[19], as MM2 proved to produce greater aberrations. We considered the calculations to have converged at an energy difference of 0.005 kcal/mol between subsequent iterations. Partial charges were taken into account by the Pullman method. For substituents X consisting of more than one atom, i.e., OCH_3, SR, a set of rotamers around the C–X bond was obtained by driving the dihedral angle in units of 30°. The rotamers thus produced have been optimised separately. The starting geometry of the five-membered ring was chosen according to the X-ray analyses. Several other conformations for this ring were also found, but were slightly higher in energy (ca. 1 kJ/mol). Results of these calculations together with experimental data for comparison are shown in Table 4.

Table 4. Molecular mechanics calculations on **1**–**4**; $\Delta G_{ax} - \Delta G_{eq}$ (calcd.)/$\Delta G_{ax} - \Delta G_{eq}$ (exp.) [kJ/mol]

	1	**2**	**3**	**4**
b	+1.0/+5.0	−4.7/−4.4	+2.1/> +6.6	+1.2/+3.6
c	−2.0/+1.0	−4.4/−4.5	+3.1/+2.7	+1.8/+1.4
d	−0.6/+2.4	−7.5/< −6.0	+3.1/+4.5	+1.5/−0.6
e	−0.5/+2.7	−9.3/< −6.3	+2.2/+4.4	+0.0/−1.4
f	−2.6/+1.3	−8.9/< −6.5	+1.9/+5.6	−1.3/+1.5
g	+0.5/+2.8	−6.7/< −6.6	+1.6/+6.6	+1.1/−0.2

The agreement is satisfactory in most cases if a constant amount of energy is added to the calculated numbers. In order to explain and compute stereoselectivities, however, these results are unsatisfactory. For this purpose, much

more accurate data are needed. There may well be a better quantitative agreement with the experiment if the solvent is taken into account. We have not attempted to do this; instead, we have rather tried to support the qualitative reasoning of general trends in the conformational behaviour by additional calculations: Dipole moments of all conformers have been computed from the partial charges already employed for the calculation of conformer energies (Table 5). Semiempirical calculations (MNDO), performed for a representative number of compounds yielded different absolute values but almost exactly the same differences in dipole moments between axial and equatorial conformers of a particular compound.

Table 5. Molecular mechanics calculations on dipole moments of **1**–**4**; $(\text{dipole moment})_{ax} - (\text{dipole moment})_{eq}$ [Debye]

	1	2	3	4
b	−0.14	−0.07	+0.75	+0.23
c	+0.27	+0.55	+1.86	+1.47
d	+0.23	+0.28	+1.78	+1.30
e	+0.26	+0.20	+1.36	+0.95
f	+0.58	+1.37	+1.19	+0.06
g	−0.01	+0.26	+0.95	+1.16

The difference in dipole moments between axial and equatorial conformers is much greater in the case of the ortholactone series than in the ketal series. The axial conformer has a much higher dipole moment than the equatorial has [for X = OCH_3, there is an apparent exception; however, there are rotamers with higher dipole moments for the axial conformer quite close in energy (0.5 kJ/mol) to the one listed in Table 5; in a polar solvent, they may well lie below it]. Hence, the higher tendency to adopt the equatorial conformation in the case of the ortholactones can be explained, at least partially, by a simple electrostatic argument in addition to the steric argument put forward above.

Professors *R. W. Hoffmann*, Marburg, and *S. F. Nelsen*, Madison, as well as *P. A. Petillo*, Madison, are thanked for many helpful discussions. J. J. W. would like to express his gratitude to the *Stiftung Volkswagenwerk* and the *Fonds der Chemischen Industrie* for a Kekulé grant (1987–1989).

Experimental

General Comments: All solvents were distilled prior to use. Chromatography was performed on silica gel with a column containing ca. 75 g of LiChroprep Si 60, 15–25 μm (Merck), > 3000 theoretical plates. Mixtures of petroleum ether (boiling range 40–60°C) and ethyl acetate were used as eluents; this was also the solvent system used in silica-gel filtrations. – NMR spectra were recorded with a Bruker AC 300 (at 300.133 MHz for ^1H) for room-temperature ^1H, ^{13}C, and ^{19}F spectra (in the latter case also for low-temperature spectra), and with a Bruker WM 400 (at 400.135 MHz for ^1H) for low-temperature ^1H and ^{13}C spectra. Solvent peaks were used to calibrate the spectra on the δ scale. For ^{19}F spectra, $CFCl_3$ was used as external standard. – Melting points were determined with a Kofler hotstage and are given uncorrected. – Elemental analyses were performed by the microanalytical department of the Philipps-Universität, Marburg.

Procedures. – a) *Syntheses of Ethylene Ketals {Dioxaspiro[4.5]-decanes* **1***} and Pinacol Ketals {2,2,3,3-Tetramethyldioxapsiro[4.5]-decanes* **2***}.* – 1. *Starting Materials: Cyclohexanone* and its *2-methyl, 2-chloro,* and *2-methoxy* derivatives (**5a,b,d,f**) were commercially available. – *2-Fluorocyclohexanone*[20] (**5c**) (contaminated by the corresponding cyclohexanol), *2-bromocyclohexanone*[21] (**5e**) (bp 51 to 56°C/1 Torr), *2-(methylthio)cyclohexanone*[22] (**5g**) (bp 34 to 36°C/1 Torr) and *2-(tert-butyl)cyclohexanone*[23] (**5h**) (bp 50 to 54°C/1 Torr) were prepared according to literature procedures. For the preparation of the latter compound, ethanol as a solvent should be replaced by THF to suppress a Favorskij rearrangement as sidereaction.

2-(1,1-Diethylpropylthio)cyclohexanone (**5i**): 3-Ethyl-3-pentanol (bp 140–143°C) was obtained from diethylketone and ethylmagnesium bromide. In analogy to a literature procedure[24], this alcohol (29.5 g, 253 mmol) was shaken with a solution of thiourea [21.2 g (279 mmol)] in hydrobromic acid [54.0 g (0.32 mol) of a 48% aqueous solution] for 12 h. To the biphasic mixture was then added a concd. solution of *p*-toluenesulfonic acid monohydrate [49.5 g (260 mmol)] in water, whereupon the mixture solidified. The tosylate was separated by suction filtration and washed three times with ice-cold water (ca. 60 ml total volume). A small amount of tosylate separating from the filtrate was also collected. Drying at 0.5 Torr afforded the thiuronium salt as a slightly brownish powder [(46.2 g (53%)]. This salt [5.54 g (16.0 mmol)] was transferred to an aqueous solution of sodium hydroxide [0.96 g (24 mmol) in water (2 ml)]. After 2 h of stirring, the phases were separated, and the thiol formed [ca. 1.45 g (ca. 71%)] was dried with sodium sulfate. – The thiol was dissolved in dry THF (40 ml), and at 0°C, with stirring, *n*-butyllithium [8.00 ml (12.4 mmol) of a 1.49 M solution] was added. The homogeneous solution was cooled to −65°C, and a solution of 2-bromocyclohexanone [2.00 g (11.3 mmol)] in THF (3 ml) was added within 5 min. Stirring was continued for 15 min at this temperature and for 24 h at room temperature. The solvents were removed in vacuo, and the residue was taken up in petroleum ether (boiling range 40–60°C) (70 ml). It was washed with water (2 × 10 ml) and satd. brine (10 ml). Drying with sodium sulfate and removal of the solvent in vacuo yielded the crude ketone (2.47 g) which was purified by Kugelrohr distillation (120°C/0.5 Torr) to yield **5i** as a colourless oil [2.13 g (83%)]. – ^1H NMR ($CDCl_3$): δ = 0.77 (t, *J* = 7.1 Hz, 9H), 1.39 (q, *J* = 7.2 Hz, 6H), 1.45–1.65 (m, 2H), 1.68–2.07 (m, 4H), 2.08–2.22 (m, 1H), 2.97 (td, *J* = 13.2 and 5.8 Hz, 1H), 3.06–3.17 (m, 1H). – ^{13}C NMR ($CDCl_3$): δ = 7.85, 21.32, 27.18, 27.88, 34.96, 37.85, 47.75, 56.37, 210.51.

2. *Synthesis of Ethylene Ketals* **1**: The corresponding cyclohexanone, dissolved in chloroform (ca. 50 ml for 30 mmol of ketone), was heated to reflux with ethylene glycol (1.2 equiv.) and *p*-toluenesulfonic acid monohydrate (ca. 30 mg for 30 mmol of ketone) for 4–12 h, the water thus formed being collected with a Dean-Stark trap. Generally, the theoretical amount of water had been collected after 4 h. The chloroform was removed in vacuo and the residue taken up in petroleum ether (100 ml). Washing with 10 ml each of a 20% aqueous solution of potassium hydroxide, water, and satd. brine, followed by drying with potassium carbonate and removal of the solvent in vacuo yielded the crude ketal. This was filtered through a short column of silica gel (ca. 5 g) and purified by chromatography. The product was subsequently further purified by either Kugelrohr distillation or crystallisation from petroleum ether at −20°C. – A representative yield was determined for the bromo ketal **1e**. From 5.63 g (31.8 mmol) of 2-bromocyclohexan-

one, there was obtained 6.43 g (92%) of *(R,S)-6-bromo-1,4-dioxaspiro[4.5]decane*. After crystallisation (to remove traces of ethyl acetate) there remained 4.95 g (70%), mp ca. 20°C. – ^{1}H NMR ($CDCl_3$): δ = 1.22–1.36 (m, 1H), 1.40–1.70 (m, 4H), 1.89–2.01 (m, 2H), 2.09–2.19 (m, 1H), 3.85–4.12 (m, 5H). – ^{13}C NMR ($CDCl_3$): δ = 22.97, 24.23, 34.00, 34.72, 57.00, 65.36, 65.51, 107.75.

$C_8H_{13}BrO_2$ (221.1) Calcd. C 43.46 H 5.93
Found C 43.64 H 5.72

Accordingly were obtained: *(R,S)-6-Methyl-1,4-dioxaspiro[4.5]-decane* (**1b**): ^{1}H NMR ($CDCl_3$) δ = 0.82 (d, *J* = 6.5 Hz, 3H), 1.20–1.68 (m, 9H), 3.82–3.93 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 14.18, 24.03, 24.68, 32.26, 34.72, 39.49, 64.71, 64.98, 110.69.

$C_9H_{16}O_2$ (156.2) Calcd. C 69.19 H 10.31
Found C 69.10 H 10.18

(R,S)-6-Fluoro-1,4-dioxaspiro[4.5]decane (**1c**): ^{1}H NMR (CD_2Cl_2): δ = 1.18–1.88 (m, 8H), 3.79–3.96 (m, 4H), 4.26 (ddd, *J* = 49.3, 8.1 and 4.3 Hz, 1H). – ^{13}C NMR (CD_2Cl_2): δ = 21.64 (d, *J* = 7.7 Hz), 23.08, 29.77 (d, *J* = 10.9 Hz), 33.37, 65.65, 65.69, 92.66 (d, *J* = 181.7 Hz), 107.55 (d, *J* = 17.7 Hz). – ^{19}F NMR (CD_2Cl_2): δ = –192.28 (ddt, *J* = 49.4, 19.5 and 8.4 Hz).

$C_8H_{13}FO_2$ (160.2) Calcd. C 59.98 H 8.18
Found C 59.77 H 8.29

(R,S)-6-Chloro-1,4-dioxaspiro[4.5]decane (**1d**): ^{1}H NMR ($CDCl_3$): δ = 1.24–1.39 (m, 1H), 1.40–1.75 (m, 4H), 1.81–1.92 (m, 2H), 2.02–2.11 (m, 1H), 3.90–4.16 (m, 5H). – ^{13}C NMR ($CDCl_3$): δ = 22.99, 23.14, 33.84, 33.99, 63.55, 65.56, 65.69, 108.25.

$C_8H_{13}ClO_2$ (176.6) Calcd. C 54.40 H 7.42
Found C 54.29 H 7.45

(R,S)-6-Methoxy-1,4-dioxaspiro[4.5]decane (**1f**): ^{1}H NMR ($CDCl_3$): δ = 1.15–1.23 (m, 1H), 1.32–1.61 (m, 5H), 1.62–1.71 (m, 2H), 3.07 (dd, *J* = 8.2 and 3.7 Hz, 1H; in CD_2Cl_2: *J* = 8.3 and 3.6 Hz), 3.54 (s, 3H), 3.85–4.07 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 21.77, 23.09, 28.14, 33.36, 57.67, 64.98, 65.13, 81.55, 109.23.

$C_9H_{16}O_3$ (172.2) Calcd. C 62.77 H 9.36
Found C 62.48 H 9.33

(R,S)-6-Methylthio-1,4-dioxaspiro[4.5]decane (**1g**): ^{1}H NMR ($CDCl_3$): δ = 1.16–1.54 (m, 6H), 1.67–1.75 (m, 1H), 1.80–1.90 (m, 1H), 2.01 (s, 3H), 2.54 (dd, *J* = 10.0 and 4.1 Hz, 1H; in CD_2Cl_2: *J* = 10.3 and 4.3 Hz), 3.74–3.99 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 15.54, 23.18, 24.05, 30.89, 34.44, 53.03, 64.88, 65.00, 110.16.

$C_9H_{16}O_2S$ (188.3) Calcd. C 57.41 H 8.57
Found C 57.32 H 8.59

(R,S)-6-(1,1-Dimethylethylthio)-1,4-dioxaspiro[4.5]decane (**1h**): Needles, mp 29.5–30.5°C. – ^{1}H NMR ($CDCl_3$): δ = 1.15 (s, 9H), ca. 1.15–1.64 (m, 7H), ca. 1.81–1.91 (m, 1H), 2.49 (dd, *J* = 10.3 and 4.4 Hz, 1H; in CD_2Cl_2: *J* = 10.8 and 4.5 Hz), 3.70–4.00 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 23.23, 24.45, 31.15, 34.93, 35.20, 42.29, 48.96, 65.01, 65.38, 109.31.

$C_{12}H_{22}O_2S$ (230.4) Calcd. C 62.57 H 9.63
Found C 62.67 H 9.68

(R,S)-6-(1-Ethyl-3-pentylthio)-1,4-dioxaspiro[4.5]decane (**1i**): ^{1}H NMR ($CDCl_3$): δ = 0.85 (t, *J* = 7.3 Hz, 9H), 1.18–1.30 (m, 1H), 1.36 (dq, *J* = 14.4 and 7.2 Hz, 3H), 1.43 (dq, *J* = 14.4 and 7.2 Hz, 3H), ca. 1.41–1.79 (m, 6H), 1.88–1.98 (m, 1H), 2.52 (dd, *J* = 10.5 and 4.3 Hz, 1H), 3.85–4.11 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 7.93, 23.46, 24.95, 28.35, 34.80, 35.69, 47.56, 54.24, 65.21, 65.54, 109.69.

$C_{15}H_{28}O_2S$ (272.5) Calcd. C 66.13 H 10.36
Found C 66.24 H 10.60

3. *Synthesis of Pinacol Ketals* **2**. – *General Procedure:* A solution of the corresponding cyclohexanone **5**, anhydrous pinacol (1.2 equiv.) and *p*-toluenesulfonic acid monohydrate (330 mg per 30 mmol of ketone) in chloroform (50 ml) was heated to reflux for 70 h, while collecting the water thus formed with a Dean-Stark trap. Generally, more than the theoretical amount of water separated. The reaction mixture was worked up according to the procedure given for the ethylene ketals (see above). Representative yields were determined for the parent compound **2a** (79%) and the bromo derivative **3e** [3.99 g (36%) from 7.08 g (40 mmol) of ketone]. The major side reaction was the self-condensation of the starting ketones. All ketals were obtained as pleasantly smelling solids melting near or shortly above room temperature.

2,2,3,3-Tetramethyl-1,4-dioxaspiro[4.5]decane (**2a**): Mp ca. 10°C. – ^{1}H NMR ($CDCl_3$): δ = 1.15 (s, 12H), 1.23–1.33 (m, 2H), 1.48–1.59 (m, 8H). – ^{13}C NMR ($CDCl_3$): δ = 24.01, 24.77, 25.09, 37.14, 81.87, 106.58.

$C_{12}H_{22}O_2$ (198.3) Calcd. C 72.68 H 11.18
Found C 72.52 H 11.08

(R,S)-2,2,3,3,6-Pentamethyl-1,4-dioxaspiro[4.5]decane (**2b**): ^{1}H NMR ($CDCl_3$): δ = 0.94 (d, *J* = 7.1 Hz, 3H), 1.18 (s, 6H), 1.20 (s, 3H), 1.21 (s, 3H), ca. 1.20–1.61 (m, 6H), 1.65–1.87 (m, 3H). – ^{13}C NMR ($CDCl_3$): δ = 15.11, 20.46, 24.11, 25.09, 25.23, 25.51, 25.74, 30.69, 34.81, 40.11, 81.92, 82.05, 108.70.

$C_{13}H_{24}O_2$ (212.3) Calcd. C 73.54 H 11.39
Found C 73.60 H 11.50

(R,S)-6-Fluoro-2,2,3,3-tetramethyl-1,4-dioxapsiro[4.5]decane (**2c**): Mp ca. 15°C. – ^{1}H NMR (CD_2Cl_2): δ = 1.01 (s, 3H), 1.14 and 1.15 (2 s, 9H), ca. 1.21–1.87 (m, 8H), 4.27 (dddd, *J* = 49.8, 5.1, 2.3 and 1.3 Hz, 1H). – ^{13}C NMR (CD_2Cl_2): δ = 19.87 (d, *J* = 3.7 Hz), 23.22, 24.85, 25.12 (double intensity), 25.33, 29.63 (d, *J* = 20.3 Hz), 34.76, 83.17, 83.21, 93.11 (d, *J* = 178.5 Hz), 105.00 (d, *J* = 20.4 Hz). – ^{19}F NMR (CD_2Cl_2): δ = –190.00 (t, *J* = 43.6 Hz).

$C_{12}H_{21}FO_2$ (216.3) Calcd. C 66.64 H 9.79
Found C 66.94 H 9.80

(R,S)-6-Chloro-2,2,3,3-tetramethyl-1,4-dioxaspiro[4.5]decane (**2d**): Mp 48–49°C. – ^{1}H NMR ($CDCl_3$): δ = 1.21 (s, 6H), 1.23 (s, 3H), 1.25 (s, 3H), 1.32–1.43 (m, 1H), 1.46–1.72 (m, 4H), 1.84–1.92 (m, 1H), 2.00–2.14 (m, 2H), 4.06 (dd, *J* = 4.8 and 3.6 Hz, 1H). – ^{13}C NMR ($CDCl_3$): δ = 18.62, 23.03, 24.73, 24.76, 24.84, 24.96, 32.05, 32.79, 64.62, 82.97, 83.45, 105.96.

$C_{12}H_{21}ClO_2$ (232.8) Calcd. C 61.93 H 9.09
Found C 61.86 H 9.01

(R,S)-6-Bromo-2,2,3,3-tetramethyl-1,4-dioxaspiro[4.5]decane (**2e**): Prisms, mp 38.5–40.5°C. – ^{1}H NMR ($CDCl_3$): δ = 1.20 (s, 3H), 1.21 (s, 3H), 1.22 (s, 3H), 1.25 (s, 3H), 1.36–1.45 (m, 1H), 1.46–1.74 (m, 4H), 1.90–1.98 (m, 1H), 2.06–2.25 (m, 2H), 4.24 (dd, *J* = 5.0 and 3.0 Hz, 1H). – ^{13}C NMR ($CDCl_3$): δ = 19.45, 23.13, 24.75 (triple intensity), 24.91, 32.70, 33.07, 59.17, 83.05, 83.66, 105.56.

$C_{12}H_{21}BrO_2$ (277.2) Calcd. C 52.00 H 7.64
Found C 51.96 H 7.76

(R,S)-6-Methoxy-2,2,3,3-tetramethyl-1,4-dioxaspiro[4.5]decane (**2f**): Mp ca. 15°C. – ^{1}H NMR ($CDCl_3$): δ = 1.15 (s, 6H), 1.17 (s, 3H), 1.18 (s, 3H), ca. 1.11–1.60 (m, 6H), 1.73–1.88 (m, 2H), 3.11 (dt, *J* = 2.0 and 3.8 Hz, 1H), 3.34 (s, 3H). – ^{13}C NMR ($CDCl_3$): δ = 19.18, 23.36, 24.88, 24.98, 25.30, 25.34, 27.28, 34.16, 57.45, 82.35 (double intensity), 82.39, 106.92.

$C_{13}H_{24}O_3$ (228.3) Calcd. C 68.38 H 10.60
Found C 68.56 H 10.53

(R,S)-2,2,3,3-Tetramethyl-6-methylthio-1,4-dioxaspiro[4.5]decane (**2g**): Mp 34.5–35.5°C. – ^{1}H NMR (CD_2Cl_2): δ = 1.13 and 1.14 (2 s, 12H), 1.23–1.53 (m, 5H), 1.68–1.77 (m, 1H), 1.86–2.06 (m, 2H), 2.12 (s, 3H), 2.73 (dt, *J* = 2.1 and 3.6 Hz, 1H). – ^{13}C NMR (CD_2Cl_2): δ = 17.38, 20.80, 24.07, 25.09, 25.11, 25.18, 25.23, 30.89, 34.54, 55.17, 82.70, 82.85, 109.15.

$C_{13}H_{24}O_2S$ (244.4) Calcd. C 63.89 H 9.90
Found C 64.01 H 9.75

b) *Synthesis of Ortholactones* **3**, **4**. – 1. *Starting δ-Valerolactones* **6**. – *δ-Valerolactone* (**6a**), commercially available, was depolymerised by distillation at atmospheric pressure, bp ca. 230°C.

(R,S)-2-Methyl-δ-valerolactone (**6b**): Synthesized by alkylation of **6a** in analogy to a literature procedure[25] in ca. 70% yield. The product contained 2 mol% of HMPA. – ^{1}H NMR ($CDCl_3$): δ = 1.14 (d, *J* = 6.9 Hz, 3H), 1.43 (ddt, *J* = 13.3, 11.1 and 7.4 Hz, 1H), 1.80 (m, 2H), 2.00 (ddt, *J* = 13.5, 7.0 and 7.0 Hz, 1H), 2.48 (ddq, *J* = 11.1, 7.0 and 7.0 Hz, 1H), 4.21 (m, 2H). – ^{13}C NMR ($CDCl_3$): δ = 16.42, 21.78, 26.85, 34.37, 68.44, 175.10.

(R,S)-2-Chloro-δ-valerolactone (**6d**): A solution of 2-trimethylsilyloxy-5,6-dihydropyran[26] [3.45 g (20.0 mmol)] and dry triethylamine [2.05 g (20.3 mmol)] in dry dichloromethane (20 ml) was cooled to –75°C. With stirring, a solution of chlorine (ca. 25 mmol) in carbon tetrachloride (25 ml) was added within 15 min, whereupon a colourless precipitate formed. The cooling bath was removed, the reaction mixture was diluted with dichloromethane (40 ml), shaken with satd. ammonium chloride solution (twice, 10 ml each) and dried with sodium sulfate. Removal of the solvents in vacuo yielded the crude lactone (2.94 g) which was subjected to a short-path distillation at 0.01 Torr. **6d** was obtained as a slightly yellow, nonviscous oil [2.15 g (80%)]. – ^{1}H NMR ($CDCl_3$): δ = 1.70–2.16 (m, 3H), 2.32–2.46 (m, 1H), 4.21–4.43 (m, 2H), 4.46 (dd, *J* = 7.2 and 6.3 Hz, 1H). – ^{13}C NMR ($CDCl_3$): δ = 20.05, 29.66, 52.42, 69.40, 167.22.

(R,S)-2-Bromo-δ-valerolactone (**6e**): A solution of 2-trimethylsilyloxy-5,6-dihydropyran[26] [7.05 g (40.9 mmol)] and dry triethylamine [4.77 g (47.1 mmol)] in dry dichloromethane was cooled to –15°C. A solution of bromine [2.10 ml (40.9 mmol)] in dichloromethane was then added with stirring within 30 min. The cooling bath was removed and the reaction mixture washed with satd. ammonium chloride solution (twice, 10 ml each). Drying with sodium sulfate and removal of the solvent in vacuo afforded a yellow oil (7.96 g) which was triturated with anhydrous ether (10 ml). A small amount of precipitate thus formed was removed by filtration. The filtrate was freed from solvent to yield **4e** as a yellow-brownish, slightly viscous oil [7.38 g (quant.)] which could be used for the preparation of ortholactones **3e** and **4e**. Rapid short-path distillation at 0.005 Torr yielded a slightly yellow, less viscous oil without apparent improvement in purity. Prolonged heating leads to polymerisation. – ^{1}H NMR ($CDCl_3$): δ = 1.77–1.92 (m, 1H), 2.13–2.53 (m, 3H), 4.28–4.41 (m, 1H), 4.50–4.59 (m, 2H). – ^{13}C NMR ($CDCl_3$): δ = 19.88, 30.20, 40.78, 69.83, 166.79.

(R,S)-2-Methylthio-δ-valerolactone (**6g**): To a solution of methanethiol in anhydrous THF [20.0 ml (33.2 mmol) of a 1.66 M solution], *n*-butyllithium [22.2 ml (33.1 mmol) of a 1.49 M solution] was added at 0°C with stirring. The suspension thus formed was cooled to –80°C, and a solution of **6e** [5.93 g (33.1 mmol)] in anhydrous THF (10 ml) was added within 5 min. After 30 min, the thiolate had dissolved, and stirring was continued for 11 h, leaving the flask in the cooling bath. By then, the temperature had risen to 10°C, and the mixture had become biphasic. The solvent was removed in vacuo and the residue taken up in dichloromethane (50 ml). The solution was subsequently washed with satd. ammonium chloride solution (twice, 10 ml each) and dried with sodium sulfate. Removal of the solvent in vacuo left a viscous, complex mixture [6.32 g (quant.)], which contained the desired thiomethyl lactone **6g** as a major component. It could be used for the synthesis of ortholactones without further purification. – ^{13}C NMR ($CDCl_3$; most intense signals): δ = 13.55, 25.46, 26.23, 46.60, 67.80, 171.77.

(R,S)-2-Methoxy-δ-valerolactone (**6f**): Dicthyl methoxymalonate was prepared according to a literature procedure[27]. It was then alkylated at 0°C in DMF with 1-bromo-3-chloropropane (thrcefold excess) in analogy to a published procedure[28] to yield diethyl (*R,S*)-(3-chloropropyl)(methoxy)malonate, which contained ca. 10 mol% of diethyl (*R,S*)-(3-bromopropyl)(methoxy)malonate. – ^{1}H NMR ($CDCl_3$): δ = 1.17 (t, *J* = 7.2 Hz, 6H), 1.60–1.70 (m, 2H), 2.06–2.12 (m, 2H), 3.25 (s, 3H), 3.44 (t, *J* = 6.2 Hz, 2H), 4.14 (q, *J* = 7.2 Hz, 4H). – ^{13}C NMR ($CDCl_3$): δ = 13.82, 26.12, 29.95, 44.40, 53.18, 61.57, 84.10, 168.06. The impurity showed additional signals at δ = 26.26, 31.18, 32.96, 44.27. – The ester [8.69 g (34.1 mmol)] was mixed with a sodium hydroxide solution (50 ml of a 4 M aqueous solution) and heated to reflux for 2 h.The ethanol thus formed was distilled at atmospheric pressure, and to the remaining solution was added, after cooling, sulfuric acid (ca. 50 ml of a 65% aqueous solution). Heating under reflux was resumed for further 2 h. The mixture was then cooled and saturated with sodium sulfate. Extraction with ether (five times, 60 ml each), washing of the combined extracts with satd. brine (10 ml), drying with sodium sulfate and removal of the solvent in vacuo yielded a highly viscous oil (1.56 g). This was flask-to-flask-distilled at 0.1 Torr by heating with a Bunsen burner. A viscous oil, very impure as judged by ^{1}H NMR, was obtained [1.27 g (29%)] which could nevertheless be used for the synthesis of ortholactones.

(R,S)-2-Fluoro-δ-valerolactone (**6c**): Diethyl (*R,S*)-(3-chloropropyl)(fluoro)malonate was obtained in analogy to a published procedure[28] by alkylation of diethyl fluoromalonate with a threefold excess of 1-bromo-3-chloropropane. It was Kugelrohr-distilled at 120°C/0.5 Torr and contained 39% of diethyl (*R,S*)-(3-bromopropyl)(fluoro)malonate. – ^{13}C NMR ($CDCl_3$): δ = 13.87, 26.05 (d, *J* = 3.0 Hz), 31.58 (d, *J* = 21.5 Hz), 44.01, 62.61, 94.26 (d, *J* = 198.4 Hz), 165.83 (d, *J* = 25.5 Hz). Diethyl (*R,S*)-(3-bromopropyl)-(fluoro)malonate showed signals at δ = 13.87, 26.16 (d, *J* = 3.1 Hz), 32.79 (d, *J* = 21.4 Hz), 32.33, 62.61, 94.19 (d, *J* = 198.5 Hz), 165.83 (d, *J* = 25.5 Hz). – The mixture of alkylated fluoromalonic esters [15.37 g (56.5 mmol)] was mixed with hydrochloric acid (80 ml of a 20% aqueous solution) and heated to reflux for 20 h. The solution was cooled and extracted with ether (four times, 80 ml each). The combined extracts were reextracted with satd. sodium hydrogen carbonate solution (100 ml). The new aqueous phase (pH = 9) was washed with ether (50 ml) and then brought to pH = 0 with concd. hydrochloric acid. It was then extracted with ether (four times, 80 ml each); the combined organic extracts were washed with water (5 ml) and satd. brine (10 ml) and then dried with sodium sulfate. Evaporation of the solvents in vacuo yielded 5-chloro-2-fluorovaleric acid [4.30 g (49%)]. – ^{1}H NMR ($CDCl_3$): δ = 1.79–2.20 (m, 4H), 3.53 (t, *J* = 6.2 Hz, 2H), 4.94 (ddd, *J* = 48.9, 7.2 and 4.1 Hz, 1H), 8.52 (br. s, integrating for 2H, probably due to residual water). – ^{13}C NMR ($CDCl_3$): δ = 27.31 (d, *J* = 2.8 Hz), 29.64 (d, *J* = 20.9 Hz), 43.92, 87.78 (d, *J* = 184.4 Hz), 173.88 (d, *J* = 24.2 Hz). – In analogy to a literature report[29], this acid [4.30 g, (27.8 mmol)] was heated to reflux with sodium hydroxide [2.22 g (55.6 mmol)] in water (10 ml) for 40 min. The cooled solution was neutralised against phenolphthaleine with a few drops of 1 N HCl. Then 1 equiv. (28 ml) of 1 N HCl was added and the water removed in vacuo. The residue was triturated with

ether (50 ml); the organic phase was separated, dried with sodium sulfate and the solvent removed. The residue (2.6 g) was flask-to-flask-destilled at 0.05 Torr by heating with a Bunsen burner. This yielded a still water-containing product, which was taken up in dichloromethane and dried with magnesium sulfate. Removal of the solvent in vacuo gave very impure **6c** [1.86 g (57%)] which, however, could be used successfully for the synthesis of ortholactones.

Tetramethyloxirane: The following procedure is based on a literature report[30]. Anhydrous pinacol [64.0 g, (0.542 mol)] was treated for 30 min with a vigorous stream of dry hydrogen chloride. The pinacol melted to form a honey-like syrup which darkened and became less viscous. The mixture was left to stand for 12 h. Nitrogen was then bubbled through to remove part of the hydrogen chloride. The brown liquid was then poured onto potassium hydroxide (90 g) with cooling; the colour changed to yellow. The salts were filtered and dissolved in water (100 ml). The organic layer was separated and combined with the filtrate, it was then heated to reflux with potassium hydroxide (10 g) for 30 min and then distilled through a 15-cm vacuum-jacketed Vigreux column. The azeotrope boiling from 70–95°C was collected and dried with potassium carbonate. The crude mixture (26.3 g) was then fractionated by means of a 1-m spinning-band column; potassium carbonate (1 g) was added to prevent decomposition. The epoxide was collected at 86.5–87.2°C [14.30 g (26%)]; it contained 3% of 2,3-dimethylbutadiene and 0.8% of pinacolone (by ^{1}H NMR and GC). – ^{1}H NMR ($CDCl_3$): δ = 1.27 (s). – ^{13}C NMR ($CDCl_3$): δ = 20.97, 61.93.

2. *Synthesis of Glycol Ortholactones (1,4,6-Trioxaspiro[4.5]decanes)* **3**. – a) *By Acid Catalysis; Typical Procedure. – (R,S)-10-Methyl-1,4,6-trioxaspiro[4.5]decane* (**3b**): In analogy to a literature procedure[31], a solution of **6b** [1.14 g (10.0 mmol)], *p*-toluenesulfonic acid monohydrate (0.30 g) and ethylene glycol [0.93 g (15 mmol)] in toluene (40 ml) was heated to reflux for 16 h while collecting the water thus formed with a Dean-Stark trap (ethylene glycol also forms an azeotrope with toluene, so more than the theoretical amount of water appeared to have separated). The solvent was removed in vacuo and the residue taken up in petroleum ether (100 ml). The solution was vigorously shaken with a 20% potassium hydroxide solution (10 ml) and washed with water (5 ml) and satd. brine (10 ml). Drying with potassium carbonate and removal of the solvent in vacuo yielded the crude ortholactone (1.17 g) which was filtered through a short column of silica gel (5 g) and purified by chromatography to yield **3b** as a colourless liquid [0.83 g (52%)]. A trace of ethyl acetate (residual eluent) was removed by Kugelrohr distillation at 30°C/0.5 Torr. – ^{1}H NMR (CD_2Cl_2): δ = 0.90 (d, *J* = 6.7 Hz, 3H), 1.40–1.66 (m, 3H), 1.69–1.80 (m, 1H), 1.84–1.95 (m, 1H), 3.65–3.74 (m, 2H), 3.86–4.12 (m, 4H). – ^{13}C NMR (CD_2Cl_2): δ = 15.41, 25.35, 30.17, 36.62, 64.26, 64.78, 65.12, 121.34.

$C_8H_{14}O_3$ (158.2) Calcd. C 60.74 H 8.92
Found C 60.61 H 8.93

Similarly were prepared: *1,4,6-Trioxaspiro[4.5]decane* (**3a**): ^{1}H NMR (CD_2Cl_2): δ = 1.45–1.57 (m, 2H), 1.71–1.83 (m, 4H), 3.73 (dd, $J_1 \approx J_2$ = 5.4 Hz, 2H), 3.87–4.12 (m, 4H). – ^{13}C NMR (CD_2Cl_2): δ = 22.02, 25.08, 32.29, 64.25 (double intensity), 64.85, 119.25.

$C_7H_{12}O_3$ (144.2) Calcd. C 58.32 H 8.39
Found C 58.41 H 8.54

(R,S)-10-Fluoro-1,4,6-trioxaspiro[4.5]decane (**3c**): ^{1}H NMR ($CDCl_3$): δ = 1.54–1.80 (m, 2H), 1.87–2.17 (m, 2H), 3.72–3.76 (m, 2H), 4.01–4.19 (m, 4H), 4.47 (ddd, *J* = 49.1, 9.6 and 4.7 Hz, 1H; in CD_2Cl_2: *J* = 49.6, 9.6 and 4.6 Hz). – ^{13}C NMR ($CDCl_3$): δ = 22.87 (d, *J* = 6.9 Hz), 27.49 (d, *J* = 19.2 Hz), 64.04, 64.95, 65.22, 87.10 (d, *J* = 185.9 Hz), 117.43 (d, *J* = 20.5 Hz); (CD_2Cl_2): δ = 23.34 (d, *J* = 6.8 Hz), 27.97 (d, *J* = 19.1 Hz), 64.33, 65.32, 65.57, 87.63 (d, *J* = 185.4 Hz), 117.84 (d, *J* = 20.2 Hz). – ^{19}F NMR (CD_2Cl_2): δ = –190.98 (dt, *J* = 49.0 and 12.7 Hz).

$C_7H_{11}FO_3$ (162.2) Calcd. C 51.85 H 6.84
Found C 51.78 H 6.92

(R,S)-10-Methoxy-1,4,6-trioxaspiro[4.5]decane (**3f**): ^{1}H NMR ($CDCl_3$): δ = 1.54–1.76 (m, 3H), 1.96–2.17 (m, 1H), 3.31 (dd, *J* = 10.0 and 4.6 Hz, 1H), 3.43 (s, 3H), 3.69 (dd, *J* = 7.3 and 3.7 Hz, 2H), 3.96–4.16 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 23.81, 27.21, 58.39, 63.98, 64.28, 64.74, 77.42, 119.34.

$C_8H_{14}O_4$ (174.2) Calcd. C 55.16 H 8.10
Found C 54.93 H 8.40

(R,S)-10-Methylthio-1,4,6-trioxaspiro[4.5]decane (**3g**): ^{1}H NMR ($CDCl_3$): δ = 1.55–1.86 (m, 3H), 2.04–ca. 2.14 (m, 1H), 2.15 (s, 3H), 2.85 (dd, *J* = 11.7 and 4.5 Hz; in CD_2Cl_2: *J* = 11.7 and 4.5 Hz), 3.75 (dd, *J* = 7.0 and 4.2 Hz, 2H), 3.96–4.20 (m, 4H). – ^{13}C NMR ($CDCl_3$): δ = 15.66, 25.33, 28.96, 48.70, 64.28, 64.50, 65.26, 120.43.

$C_8H_{14}O_3S$ (190.3) Calcd. C 50.50 H 7.42
Found C 50.52 H 7.52

b) *By Lewis Acid Catalysis; Typical Procedure. – (R,S)-10-Bromo-1,4,6-trioxaspiro[4.5]decane* (**3e**): In analogy to a published procedure[2], **6e** [1.99 g (11.1 mmol)] was dissolved in dry dichloromethane (15 ml), and Et_2O–BF_3 (0.15 ml) was added. A stream of ethylene oxide was passed through this mixture for 30 min. It was then left to stand for further 4 h and then diluted with petroleum ether (80 ml), vigorously shaken with a 50% potassium hydroxide solution (10 ml), followed by washing with water (5 ml) and drying with potassium carbonate. Filtration through a short column of silica gel (5 g) yielded the crude ortholactone (1.54 g) which was purified by chromatography to give **5e** as a colourless oil [1.03 g (42%)]; Kugelrohr distillation at 100°C/1.5 Torr removed traces of solvent. – Mp shortly below room temperature. – ^{1}H NMR ($CDCl_3$): δ = 1.55–1.71 (m, 2H), 2.04–2.32 (m, 2H), 3.70–3.81 (m, 2H), 3.98–4.18 (m, 5H). – ^{13}C NMR ($CDCl_3$): δ = 25.65, 32.78, 49.59, 64.23, 65.05, 65.70, 117.70.

$C_7H_{11}BrO_3$ (223.1) Calcd. C 37.69 H 4.97
Found C 37.94 H 5.05

Similarly was prepared: *(R,S)-10-Chloro-1,4,6-trioxaspiro[4.5]decane* (**3d**): ^{1}H NMR (CD_2Cl_2): δ = 1.65–1.76 (m, 2H), 1.99–2.12 (m, 1H), 2.23 (ddq, *J* = 13.3, 1.1 and 4.5 Hz, 1H), 3.76–3.84 (m, 2H), 4.02–4.19 (m, 5H). – ^{13}C NMR (CD_2Cl_2): δ = 25.31, 32.52, 58.51, 64.64, 65.62, 66.17, 118.77.

$C_7H_{11}ClO_3$ (178.6) Calcd. C 47.07 H 6.21
Found C 47.02 H 6.30

3. *Synthesis of Pinacol Ortholactones (2,2,3,3-Tetramethyl-1,4,6-trioxaspiro[4.5]decanes)* **4**. – *Typical Procedure. – (R,S)-10-Bromo-2,2,3,3-tetramethyl-1,4,6-trioxaspiro[4.5]decane* (**4e**): In analogy to a literature procedure[3], **6e** [1.79 g (10.0 mmol)] was dissolved in dry dichloromethane (20 ml), and Et_2O–BF_3 (0.15 ml) was added. Then tetramethyloxirane [1.00 g (10.0 mmol)] was added over a period of 2 min, whereupon the mixture became warm and darkened. Stirring was continued for 5 h, the reaction mixture was then diluted with petroleum ether (100 ml) and vigorously shaken with a 50% potassium hydroxide solution (10 ml). The colour changed to yellow, and few precipitate formed. The organic layer was washed with water (5 ml) and satd. brine (5 ml) and was then dried with potassium carbonate. Removal of the solvents in vacuo yielded a crude product which was filtered through silica gel

(5 g). The resulting oil (1.22 g) was chromatographed to yield **4e** as an aromatically smelling semisolid [1.00 g (36%)]. Crystallisation from petroleum ether at −20°C yielded prisms, mp 23−24.5°C. − ^{1}H NMR (CD_2Cl_2): δ = 1.24 (s, 3H), 1.25 (s, 3H), 1.31 (s, 3H), 1.33 (s, 3H), 1.43−1.55 (m, 1H), 1.76−1.89 (m, 1H), 2.09 (dtt, *J* = 10.8, 7.0 and 3.8 Hz, 1H), 2.32 (dp, *J* = 13.8 and 4.1 Hz, 1H), 3.76−3.88 (m, 2H), 4.03 (dd, *J* = 7.5 and 3.9 Hz, 1H). − ^{13}C NMR (CD_2Cl_2): δ = 23.47, 24.66, 24.72, 24.81, 24.84, 32.50, 52.72, 64.43, 84.78, 85.06, 115.79.

$C_{11}H_{19}BrO_3$ (279.2) Calcd. C 47.33 H 6.86
Found C 47.37 H 6.86

Similarly were prepared: *2,2,3,3-Tetramethyl-1,4,6-trioxaspiro[4.5]decane* (**4a**): 10-mmol scale; 59% yield; prisms, mp 23 to 24°C. − ^{1}H NMR ($CDCl_3$): δ = 1.10 (s, 6H), 1.23 (s, 6H), 1.36 to 1.44 (m, 2H), 1.60−1.70 (m, 4H), 3.74 (m, 2H). − ^{13}C NMR ($CDCl_3$): δ = 21.43, 23.82, 24.08, 24.47, 35.59, 64.46, 83.04, 116.87.

$C_{11}H_{20}O_3$ (200.3) Calcd. C 65.97 H 10.07
Found C 65.99 H 9.85

(R,S)-2,2,3,3,10-Pentamethyl-1,4,6-trioxaspiro[4.5]decane (**4b**): 10-mmol scale; 59% yield; mp shortly below room temp. − ^{1}H NMR (CD_2Cl_2): δ = 0.92 (d, *J* = 6.6 Hz, 3H), 1.17 (s, 3H), 1.18 (s, 3H), 1.32 (s, 3H), 1.34 (s, 3H), 1.36−1.56 (m, 3H), 1.68−1.80 (m, 2H), 3.73 (br. dd, *J* = 6.4 and 4.4 Hz, 2H). − ^{13}C NMR (CD_2Cl_2): δ = 15.90, 24.34, 25.18, 25.22, 25.34, 25.40, 29.91, 37.82, 64.54, 83.40, 83.50, 119.41.

$C_{12}H_{22}O_3$ (214.3) Calcd. C 67.26 H 10.26
Found C 67.24 H 10.38

(R,S)-10-Fluoro-2,2,3,3-tetramethyl-1,4,6-trioxaspiro[4.5]decane (**4c**): 7.6-mmol scale; ca. 4% yield. − ^{1}H NMR (CD_2Cl_2): δ = 1.19 (s, 3H), 1.21 (s, 3H), 1.30 (s, 3H), 1.33 (s, 3H), 1.47−1.61 (m, 1H), 1.70 (ddp, *J* = 13.6, 2.2 and 4.5 Hz, 1H), 1.81−2.10 (m, 2H), 3.68−3.78 (m, 2H), 4.26 (ddd, *J* = 49.5, 9.0 and 4.3 Hz, 1H). − ^{13}C NMR (CD_2Cl_2): δ = 23.05 (d, *J* = 6.3 Hz), 24.24, 24.28, 24.38, 24.45, 27.87 (d, *J* = 19.7 Hz), 63.99, 84.59 (double intensity), 88.45 (d, *J* = 185.8 Hz), 115.68 (d, *J* = 20.1 Hz).

$C_{11}H_{19}FO_3$ (218.3) Calcd. C 60.53 H 8.77
Found C 60.61 H 8.73

(R,S)-10-Chloro-2,2,3,3-tetramethyl-1,4,6-trioxaspiro[4.5]decane (**4d**): 8.17-mmol scale; 33% yield. − ^{1}H NMR ($CDCl_3$): δ = 1.196 (s, 3H), 1.203 (s, 3H), 1.28 (s, 3H), 1.31 (s, 3H), 1.41−1.53 (m, 1H), 1.66−1.82 (m, 1H), 1.95 (tt, *J* = 13.1 and 4.4 Hz, 1H), 2.18 (dp, *J* = 13.5 and 3.9 Hz, 1H), 3.77 (dd, *J* = 6.6 and 5.7 Hz, 2H), 3.85 (dd, *J* = 8.3 and 4.0 Hz, 1H; in CD_2Cl_2: *J* = 7.9 and 3.9 Hz). − ^{13}C NMR ($CDCl_3$): δ = 22.72, 24.34, 24.44, 24.46, 24.50, 31.28, 58.88, 63.88, 84.30, 84.48, 115.86.

$C_{11}H_{19}ClO_3$ (234.7) Calcd. C 56.29 H 8.16
Found C 56.26 H 7.88

(R,S)-10-Methoxy-2,2,3,3-tetramethyl-1,4,6-trioxaspiro[4.5]decane (**4f**): 9.76-mmol sacle; 7% yield. − ^{1}H NMR (CD_2Cl_2): δ = 1.20 (s, 3H), 1.21 (s, 3H), 1.29 (s, 3H), 1.31 (s, 3H), 1.38−1.52 (m, 1H), 1.57−1.71 (m, 2H), 1.85−1.95 (m, 1H), 3.05 (dd, *J* = 8.7 and 4.1 Hz, 1H), 3.34 (s, 3H), 3.69 (dd, *J* = 6.9 and 3.8 Hz, 2H). − ^{13}C NMR (CD_2Cl_2): δ = 23.57, 24.53, 24.57 (double intensity), 24.63, 27.46, 58.68, 64.07, 79.23, 83.91, 84.02, 117.76.

$C_{12}H_{22}O_4$ (230.3) Calcd. C 62.58 H 9.63
Found C 62.56 H 9.67

(R,S)-2,2,3,3-Tetramethyl-10-methylthio-1,4,6-trioxaspiro[4.5]decane (**4g**): 13.3-mmol scale; 12% yield; mp 41.0−42.5°C. − ^{1}H NMR (CD_2Cl_2): δ = 1.24 (s, 3H), 1.26 (s, 3H), 1.32 (s, 3H), 1.34 (s, 3H), 1.42−1.55 (m, 1H), 1.58−1.69 (m, 1H), 1.80 (tt, *J* = 13.2 and 4.5 Hz, 1H), 2.11 (ddt, *J* = 13.3, 7.1 and 4.8 Hz, 1H), 2.16 (s, 3H), 2.66 (dd, *J* = 9.0 and 4.2 Hz, 1H), 3.76 (dd, *J* = 6.3 and 4.8 Hz, 1H). − ^{13}C NMR (CD_2Cl_2): δ = 16.41, 24.34, 24.92, 24.97, 25.01, 25.12, 29.36, 50.96, 64.34, 84.14, 84.17, 118.82.

$C_{12}H_{22}O_3S$ (264.4) Calcd. C 58.50 H 9.00
Found C 58.65 H 9.05

Low-Temperature NMR Spectra. − General Comments: Ca. 50 mg of the compound under investigation was weighed, dissolved in CD_2Cl_2 (previously dried with basic aluminium oxide, activity I), and its ^{13}C-, ^{1}H- and (where possible) ^{19}F-NMR spectra were recorded at 173 K (the temperature given here is the reading of the instrument control; the actual temperature may have been rather a few degrees higher). The ^{13}C-NMR signals were assigned to one set of either belonging to the equatorial or axial conformer on the basis of their intensity. The assignment of the two sets thus obtainced, in turn, was made by use of ^{1}H,^{1}H- or ^{1}H,^{19}F Karplus relationships, by means of an X-ray analysis for **2e** and by analogy for those compounds where neither of these techniques could be applied. The conformer ratios were then calculated by the average of all the ratios for the single carbon atoms. In the high-field region, assignments of the corresponding signals for one particular carbon atom were guided by the half-widths of the signals at room temperature. A high value pointed to a high difference between chemical shifts of equatorial and axial conformer. Consistency was achieved, very few dubious cases notwithstanding. The integrations from ^{1}H-, ^{19}F- and ^{13}C-NMR spectra agreed well with each other (difference of 1.5% at maximum). Only those proton signals are quoted which could be used for assigning the conformers and their ratios; "eq" and "ax" in conjunction with NMR data refer to the position of the substituent. Diethyl ketals of α-substituted cyclohexanones **5** probably show a behaviour close to the pinacol ketals **2** having the substituents in axial position (data in ref.[17]). Karplus relationships could only be used for the fluoro-substituted compound (96% axial). In all other cases, there was only one conformer observed, and the absorption of the proton geminal to the substituent was obscured; therefore, only chemical-shift arguments could be used.

Table 6. ^{13}C-NMR data of axial and equatorial conformers of ethylene ketals **1** at 173 K

		C-1	C-2	C-3	C-4	C-5	C-6	X
b	eq	109.65	39.16	31.78	24.73	23.52	34.78	13.55
	ax	110.23	35.51	28.88	18.27	23.32	29.20	14.01
c	eq	107.07	93.28	29.00	22.26	22.08[a]	33.81	–
	ax	105.54	88.62	27.84	17.22	22.08[a]	29.84	–
d	eq	107.17[a]	64.30	33.89	24.54	22.20[a]	34.96	–
	ax	107.17[a]	60.67	30.79	17.56	22.20[a]	28.89	–
e	eq	106.82	58.20	34.90	25.79	22.33[a]	35.03	–
	ax	106.99	55.30	31.55	18.48	22.33[a]	29.28	–
f	eq	108.60	81.40	27.57	22.78	22.48	34.26	56.75
	ax	107.38	76.97	24.45	17.41	22.36	29.86	55.45
g	eq	109.17	53.12	31.00	24.88	22.82[a]	35.06	14.98
	ax	110.27	49.40	29.90	19.31	22.82[a]	29.02	16.22
h	eq	108.38	48.73	35.39	25.33	23.00	35.46	41.80[b]
	ax	108.98	45.25	32.02	19.60	22.39	31.65	43.11
i	eq	108.67	47.39	34.94	25.49	23.03	35.55	ca. 53.25[c]
	ax	109.15	43.37	32.00	19.54	22.53	30.82	ca. 53.25

[a] No separation between signals for axial and equatorial conformers. − [b] Methyl groups at δ = 30.19 for both conformers. − [c] Assignments for C-3 and C-6 uncertain, methylene groups of substituent at δ = 26.98, methyl groups at δ = 7.24; signal for X of the axial conformer is probably obscured by the solvent absorption.

1. *Ethylene Ketals* **1**. – a) *^{13}C-NMR Data:* These are given in Table 6 which was used to help in assigning signals in other compounds. C-2,3,4,6 are strongly shifted to higher field in the axial conformer, C-7,8 show the same trend, but smaller differences. There is little effect on C-5; in the cases were the signals due to the individual conformers could be resolved, the one due to the axial conformer was also shifted upfield. C-1 is generally shifted downfield in the axial conformer with the exception of X = F and OCH_3. For C-2,3,4,5,6 the general trends agree with those observed in monosubstituted cyclohexanes[32].

b) *^{1}H- and ^{19}F-NMR Data.* – **1b**: ^{19}F NMR (193 K): δ = −191.90 (t, J = 46.0 Hz, F_{ax}), −192.25 (d, J = 48.6 Hz, F_{eq}); ratio ca. 36/64 (signals overlap).

1f: ^{1}H NMR: δ = 2.59 (dd, J = 12.2 and 3.8 Hz, H_{ax}), 2.67 (s, 8 Hz width at half height, H_{eq}), 2.00 and 2.05 (2 s, slightly overlapping); ratio 87.4/12.6.

1g: ^{1}H NMR: δ = 2.48 (dd, J = 13.3 and 4.0 Hz, H_{ax}), 2.61 (s, 8 Hz width at half height, H_{eq}); ratio 87.7/12.3.

1h: ^{1}H NMR: δ = 2.35 (dd, J = 12.9 and ca. 4 Hz, H_{ax}), 2.51 (s, ca. 8 Hz width at half height); ratio 92.2/7.8.

2. *Pinacol Ketals* **2**: In all compounds except **2c**, the only signal observed for the proton geminal to the substituent X was a broad singlet; no other signal could be detected in that region. In the ^{13}C-NMR spectra, some signals of the minor conformer in the high-field region could not be detected due to overlap.

2a: ^{13}C NMR: δ = 23.45, ca. 23.78, 23.82, 24.21, 38.06, 80.96, 81.56, 105.88.

2b: ^{13}C NMR (ax): δ = 15.96, 19.77, 25.20, 26.60, 30.88, 33.88, 40.85, 82.66, 83.10, 109.59; (eq): δ = 16.71, 26.54, 27.37, 27.94, 28.14, 33.61, 82.82, 83.36, 109.23; ratio 94.8/5.2.

2c: ^{1}H NMR: δ = ca. 4.11 (dd, J = 48 and 13 Hz, H_{ax}), 4.36 (br. d, J = 50.0 Hz, H_{eq}), ratio ca. 4/96. – ^{19}F NMR (183 K): δ = −185.02 (d, J = 44.9 Hz, F_{eq}), −190.99 (t, J = 48.6 Hz, F_{ax}), ratio 94.9/5.1. – ^{13}C NMR (ax): δ = 17.66, 22.02, 23.56, 23.81, 23.98, 28.07 (d, J = 20.2 Hz), 32.39, 82.08, 82.38, 92.19 (d, J = 174.1 Hz), 103.40 (d, J = 21.4 Hz); (eq): δ = 22.23, 22.51, 24.57, 24.79, 25.20 (d, J = 17.7 Hz), 36.89, 81.57, 82.46, 91.41 (d, J = 186.7 Hz), 105.36 (d, J = 14.9 Hz). – Ratio 95.7/4.3.

2d: ^{13}C NMR (ax): δ = 17.53, 22.32, 23.50, 23.64, 23.83, 23.87, 31.07, 31.52, 64.33, 82.29, 82.87, 105.00; ratio >98.5/<1.5.

2e: ^{13}C NMR (ax): δ = 18.40, 22.42, 23.42, 23.57, 23.84, 23.90, 31.73, 31.88, 59.27, 83.05, 83.37, 104.66; ratio >98.7/<1.3.

2f: ^{13}C NMR (ax): δ = 17.58, 22.53, 23.58, 24.05, 24.15, 25.34, 32.53, 56.07, 80.78, 81.49, 105.55; ratio >98.9/<1.1.

2g: ^{13}C NMR (ax): δ = 17.31, 19.50, 22.92, 23.56, 23.62, 23.94, 30.12, 32.67, ca. 53.24 (obscured by solvent signal), 81.71, 108.24; ratio >99.0/<1.0.

3. *Ethylene Glycol Ortholactones* **3**: The mobility of the six-membered ring in all the lactones under investigation proved to be higher as compared to the ketals. In general, the lines of the ^{1}H-NMR spectra were too broad to be of any diagnostic value.

3a: ^{13}C NMR: δ = 20.87, 23.65, 30.69, 62.47 (br.), 63.92 (br.), 117.88.

3b: ^{13}C NMR (eq): δ = 14.88, 24.61, 28.97, 35.43, 63.10, 63.95, 64.55, 120.08. – The assignment to the equatorial conformer is highly plausible, but in the absence of the other conformer and any revealing Karplus relationships is not proved.

3c: ^{19}F NMR (183 K): δ = −188.24 (d, J = 49.1 Hz, F_{eq}), −195.43 (t, J = 42.4 Hz, F_{ax}); ratio 83.7/16.3. – ^{13}C NMR (eq.): δ = 23.62 (d, J = 7.6 Hz), 26.91 (d, J = 17.7 Hz), 63.37, 63.94, 65.04, 86.40 (d, J = 186.6 Hz), 116.90 (d, J = 19.8 Hz); (ax): δ = 17.80, 26.29 (d, J = 16.9 Hz), 86.67 (d, J = 171.9 Hz), 115.14 (d, J = ca. 22 Hz); ratio 86.8/13.2.

3d: ^{13}C NMR (eq): δ = 25.31, 31.56, 57.46, 63.73, 64.43, 65.61, 117.55; (ax) δ = 17.52, 29.11, 65.01, 66.57, 116.41; ratio 95.8/4.2.

3e: ^{13}C NMR (eq): δ = 26.30, 32.55, 49.74, 63.80, 64.42, 65.65, 117.05; (ax): δ = 18.32, 29.68, 50.01, 64.84, 64.92, ca. 116.10; ratio 95.5/4.5.

3f: ^{13}C NMR (eq.): δ = 23.88, 26.53, 57.58, 63.25 (double intensity), 64.41, 75.94, 118.66; δ = ca. 18.0, ca. 56.5, ca. 117.2; ratio ca. 98/2.

3g: ^{1}H NMR: δ = 2.79 (dd, J = 11.8 and 4.5 Hz), no other absorption that could have accounted for a corresponding equatorial proton was observed. – ^{13}C NMR (eq.): δ = 15.10, 25.41, 28.35, 47.47, 63.64 (double intensity), 65.07, 119.50; (ax): δ = ca. 19.3, ca. 26.9, ca. 64.5, ca. 118.4 (last two peaks are doubtful). – Ratio 99/1.

4. *Pinacol Ortholactones* **4**: Comments under point 3 are also pertinent to compounds **4**.

4a: ^{13}C NMR: δ = 20.90, 22.73 (br.), 23.63, 34.94, 64.06, 82.52 (680 Hz width at half height), 116.25.

4b: ^{13}C NMR (eq): δ = 15.77, 23.95, 24.19, 24.55, 24.71, 24.91, 29.19, 36.45, 63.53, 82.21, 82.70, 118.31; (ax): δ = 13.53, 18.11, 22.47 (triple intensity), 23.40, 26.93, 64.08, ca. 117.98; ratio 92.4/7.6.

4c: ^{19}F NMR (188 K): δ = −191.96 (t, J = 44.5 Hz, F_{ax}), −182.85 (d, J = 49.7 Hz, F_{eq}); ratio 32.6/67.4. – ^{13}C NMR (eq): δ = 22.86, 23.13, 23.75, 26.91 (d, J = 18.4 Hz), 63.05, 83.34, 83.89, 87.00 (d, J = 187.7 Hz), 115.05 (d, J = 19.8 Hz); (ax): δ = 17.74, 26.17 (d, J = 18.8 Hz), 63.60, 83.54 (in addition, partially resolved signal to lower field), 88.54 (d, J = 176.2 Hz), 113.12 (d, 19.1 Hz). – Ratio 72.2/27.8.

4d: ^{13}C NMR (eq): δ = 23.60, 24.01, 24.45, 24.66, 25.65, 31.99, 57.74, 63.29, 83.42, 115.83; (ax): δ = 17.05, ca. 22.83, 22.96, 23.19, 28.95, 60.32, 63.93, 84.15, 84.26, 114.40; ratio 39.2/60.8.

4e: ^{1}H NMR: The minor component has an axial proton geminal to Br, half of a dd with a smaller J of 4.4 Hz and a br. s are visible. – ^{13}C NMR (eq): δ = 23.75, 24.31, 24.56, 24.82, 26.50, 32.91, ca. 50.13, 63.21, 83.29, 83.91, ca. 115.07; (ax): δ = 18.17, 22.72, 22.75, 22.88, 22.96, 29.41, 53.93, 63.88, 84.09, 84.41, 113.94. – Ratio 27.3/72.7.

4f: ^{13}C NMR (ax): δ = 23.03, 23.16, 23.84, 23.96, 24.21, 25.68, 58.15, 63.05, 77.21, 82.50, 83.64, 117.01; (eq): δ = 17.89, 22.51, 23.61, 56.52, 63.77, 77.76, 115.15; ratio 73.3/26.7.

4g: ^{1}H NMR: δ = 2.04 and 2.11 (two overlapping s). – ^{13}C NMR (eq): δ = 15.07, (22.48, 23.10, 23.63, 23.87, 24.24, 24.38, 24.54), 25.23, 28.52, 51.11, 63.13, 82.65, 82.52, 117.75 (values in parentheses cannot be definitely assigned to one conformer); (ax): δ = 17.08, 19.44, (22.48, etc., see above), 27.53, 47.91, 63.97, 83.53, 83.56, 117.20. – Ratio 49.6/50.4.

X-ray Analyses. – 1. *(R,S)-6-Bromo-2,2,3,3-tetramethyl-1,4-dioxaspiro[4.5]decane* (**2e**): $C_{12}H_{21}BrO_2$; mol. mass 277.20; monoclinic; space group $P2_1/n$; a = 6.531(2), b = 11.877(6), c = 16.860 Å; β = 90.92(3)°; V = 1271.6(9) Å^3; Z = 4; $d_{calcd.}$ = 1.448 g · cm^{-3}; μ(Mo-K_α) = 31.8 cm^{-1}; Enraf-Nonius CAD4 diffractometer; Mo-K_α radiation; graphite monochromator; T = 193 K; ω scans. 2873 reflections measured (Θ_{max} = 25°); 2181 independent reflections (R_{int} = 0.0317); 1954 reflections observed [$F_o > 5\sigma(F_o)$].

Solved by an automatised Patterson method[33]; refinement[34] to R = 0.057, wR = 0.041 [$w = 1/\sigma^2(F_o)$]; all non-hydrogen atoms refined anisotropically, hydrogen atoms on calculated positions with common isotropic temperature factors; 150 parameters. Empirical absorption correction in the ENRAF-Nonius SDP program system. Table 7 shows the atomic parameters of the non-hydrogen atoms.

Table 7. Coordinates and equivalent isotropic temperature factors for **2e**; $U(\text{eq.}) = 1/3\ \Sigma_{ij}(U_{ij} \cdot a_i^* \cdot a_j^* \cdot a_i \cdot a_j)$

Atom	x/a	y/b	z/c	U(eq.)
BR1	0.0435(1)	0.20765(6)	0.31740(3)	0.0348(2)
O1	0.2649(5)	0.2550(3)	0.1576(2)	0.018(1)
O2	-0.0067(5)	0.3441(3)	0.0936(2)	0.019(1)
C1	-0.0841(8)	0.2650(5)	0.2177(3)	0.019(2)
C2	0.0875(8)	0.3239(5)	0.1704(3)	0.020(2)
C3	0.1551(9)	0.4321(5)	0.2093(3)	0.025(2)
C4	-0.0300(9)	0.5103(5)	0.2276(3)	0.029(2)
C5	-0.1948(9)	0.4520(5)	0.2776(3)	0.028(2)
C6	-0.2673(8)	0.3429(5)	0.2379(3)	0.024(2)
C7	0.2560(8)	0.2123(5)	0.0777(3)	0.021(2)
C8	0.1399(8)	0.3087(5)	0.0342(3)	0.020(2)
C9	0.4806(8)	0.1903(5)	0.0522(3)	0.031(2)
C10	0.1373(9)	0.0998(5)	0.0761(3)	0.031(2)
C11	0.0099(8)	0.2724(5)	-0.0387(3)	0.031(2)
C12	0.2835(8)	0.4058(5)	0.0125(3)	0.032(2)

Table 8. Coordinates and equivalent isotropic temperature factors for **2a**; $U(\text{eq.}) = 1/3\ \Sigma_{ij}(U_{ij} \cdot a_i^* \cdot a_j^* \cdot a_i \cdot a_j)$

Atom	x/a	y/b	z/c	U(eq.)
O1	0.5380(2)	0.0014(1)	0.38800(8)	0.0282(5)
O2	0.6518(2)	0.1540(1)	0.31316(7)	0.0238(4)
C1	0.5875(3)	0.1205(2)	0.3952(1)	0.0240(6)
C2	0.7731(3)	0.1428(2)	0.4621(1)	0.0291(7)
C3	0.8170(4)	0.2710(2)	0.4726(1)	0.0342(7)
C4	0.6216(4)	0.3371(2)	0.4937(1)	0.0361(7)
C5	0.4359(4)	0.3140(2)	0.4284(1)	0.0341(7)
C6	0.3931(3)	0.1854(2)	0.4178(1)	0.0287(6)
C7	0.6119(3)	-0.0433(2)	0.3106(1)	0.0253(6)
C8	0.5922(3)	0.0641(2)	0.2521(1)	0.0234(6)
C9	0.4661(4)	-0.1422(2)	0.2820(2)	0.0347(7)
C10	0.8389(4)	-0.0865(2)	0.3273(1)	0.0342(7)
C11	0.7472(4)	0.0676(2)	0.1833(1)	0.0312(7)
C12	0.3681(4)	0.0845(2)	0.2121(1)	0.0331(7)

2. *2,2,3,3-Tetramethyl-1,4-dioxaspiro[4.5]decane* (**2a**): $C_{12}H_{22}O_2$; mol. mass 198.30; monoclinic; space group $P2_1/n$; $a = 6.326(1)$, $b = 11.667(1)$, $c = 15.709(2)$ Å; $\beta = 94.90(1)°$; $V = 1155.2(3)$ Å; $Z = 4$; $d_{calcd.} = 1.140\ \text{g} \cdot \text{cm}^{-3}$; $\mu(\text{Cu-}K_\alpha) = 5.6\ \text{cm}^{-1}$. Enraf-Nonius CAD4 diffractometer; Cu-K_α radiation; graphite monochromator; $T = 183$ K; ω scans. 1878 reflections measured ($\Theta_{max} = 60°$); 1639 independent reflections ($R_{int} = 0.0419$); 1616 reflections observed [$F_o > 5\sigma(F_o)$]. Solved by direct methods[33]; refinement[34] to $R = 0.049$, $R_w = 0.054$ [$w = 1/\sigma^2(F_o)$]; all non-hydrogen atoms refined anisotropically, hydrogen atoms with a common isotropic temperature factor, positions refined; 195 parameters. Extinction parameter $x = 2.54(6) \cdot 10^{-6}$. Table 8 shows the atomic parameters of the non-hydrogen atoms. All calculations have been performed with a Micro-VAX II[35,36].

CAS Registry Numbers

1b: 129917-45-9 / **1c**: 129917-46-0 / **1d**: 129917-47-1 / **1e**: 97764-94-8 / **1f**: 129917-82-4 / **1g**: 129917-48-2 / **1h**: 129917-49-3 / **1i**: 129917-50-6 / **2a**: 32893-35-9 / **2b**: 129917-51-7 / **2c**: 129917-52-8 / **2d**: 129917-53-9 / **2e**: 129917-69-7 / **2f**: 129917-54-0 / **2g**: 129917-55-1 / **3a**: 177-26-4 / **3b**: 129917-56-2 / **3c**: 129917-57-3 / **3d**: 129917-58-4 / **3e**: 129917-59-5 / **3f**: 129917-60-8 / **3g**: 129917-61-9 / **4a**: 129917-62-0 / **4b**: 129917-63-1 / **4c**: 129917-64-2 / **4d**: 129917-65-3 / **4e**: 129917-66-4 / **4f**: 129917-67-5 / **4g**: 129917-68-6 / **5i**: 129917-71-1 / **6a**: 542-28-9 / **6b**: 107242-87-5 / **6c**: 129917-76-6 / **6d**: 129917-72-2 / **6e**: 129917-73-3 / **6g**: 129917-74-4 / **6f**: 129917-75-5 / 3-ethyl-3-pentanol: 597-49-9 / thiourea: 62-56-6 / 3-ethyl-3-pentanol thiuronium salt: 129917-70-0 / 3-ethyl-3-pentanethiol: 5827-80-5 / 2-bromocyclohexanone: 822-85-5 / ethylene glycol: 107-21-1 / pinacol: 76-09-5 / 2-trimethylsilyloxy-5,6-dihydropropan: 129917-77-7 / diethyl (*R,S*)-(3-chloropropyl)(methoxy)-malonate: 129917-78-8 / methanethiol: 74-93-1 / diethyl (*R,S*)-(3-bromopropyl)(methoxy)malonate: 129917-79-9 / diethyl (*R,S*)-(3-bromopropyl)(fluoro)malonate: 129917-80-2 / 5-chloro-2-fluorovaleric acid: 129917-81-3 / tetramethyloxirane: 5076-20-0 / ethylene oxide: 75-21-8

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