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SULFUR YLIDES IN REACTIONS WITH 5-X-ADAMANTAN-2-ONES. STEREOCHEMISTRY AND REACTIVITY

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Abstract – This work describes the stereochemistry and the relative rates of epoxidation reactions of the title compounds with sulfur ylides (methylenedimethylsulfurane and methylenedimethyloxysulfurane) in DMSO and C_6H_6. The electronic perturbative effect of substituent X depends on the solvent and on the reactant. It is transmitted in opposite way in solvents of different polarity depending on the reactant. The electronegativity of the substituent scarcely affects the percentages of axial/equatorial attack. The percentage of equatorial attack with methylenedimethyloxysulfurane is markedly lower for 5-X-adamantan-2-ones than for 4-X-cyclohexanones.

INTRODUCTION

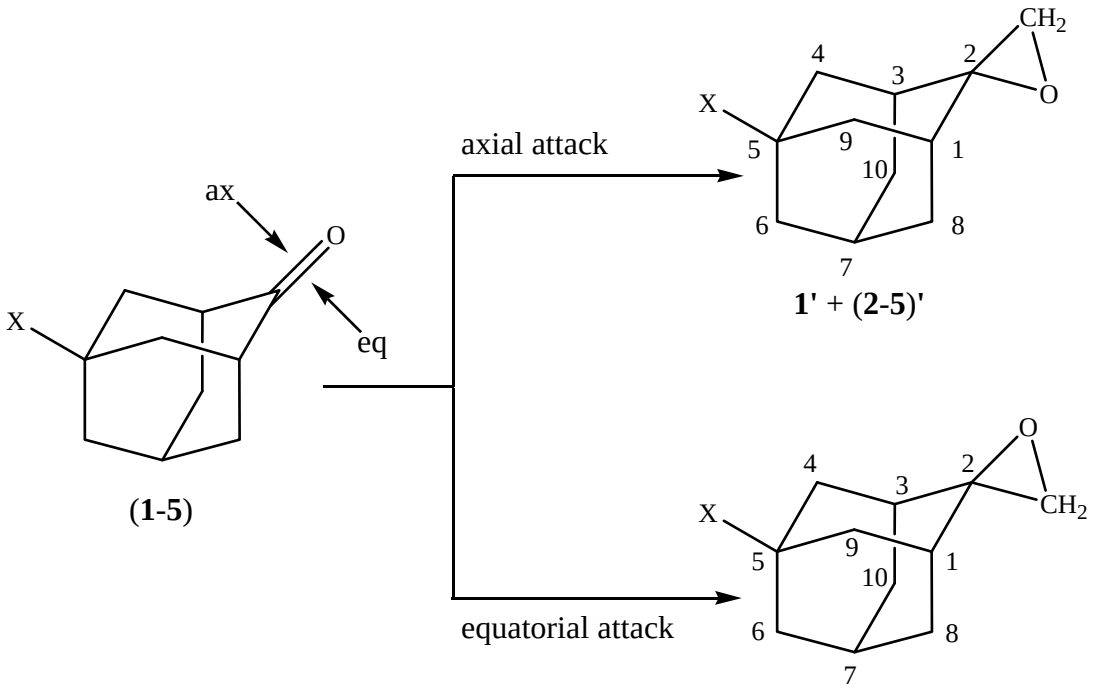
The possibility of inducing face selectivity in additions to trigonal carbon through remote electronic perturbation is currently actively explored.[1] We already discussed addition and reduction reactions on a series of 5-X-adamantan-2-ones[2,3] and 5-X-bicyclo[4.4.0]decan-2-ones.[4,5] In those cases, and in previous works as well, our experimental data clearly evidenced the need and the importance of knowing the relative rates of attack, k_{ax} and k_{eq}, in exploring questions about π face diastereoselection. Actually, it is their knowledge that shows what really happens on the two sides of a stereogenic centre. The stereochemical bias k_{ax}/k_{eq} merely represents the average outcome of the two faces of addition of a reactant to a trigonal centre. The effect of substituents in the 4 position in a cyclohexanone system was interpreted by Houk[6] on the basis of dipole-dipole interactions. It could also be discussed in terms of ground state properties, as Klein[7] proposed for cyclohexanones. Using MO theories he proposed hyperconjugation of the carbonyl π system with the ring β-CC bonds that produces a non equivalent

distribution of π-electron density and, as a consequence, the HOMO orbital is more extended on the equatorial side of the CO bond, whereas the LUMO orbital is more extended on the axial face. These considerations can be also extended to substituents at position 4 with respect to the CO bond (see refs. 2 and 4 for the complete perturbative schemes and their building up). The equatorial C4-X bond and the β-CC bonds should sum their effects both in the HOMO and in the LUMO of the CO bond, distorting the HOMO orbital towards the equatorial face, and the LUMO toward the axial one. On the other hand, an axial C4-X bond should distort both the HOMO and LUMO orbital towards the axial face. Yet, that is only half of the story otherwise one should predict uniform stereochemical outcomes for addition reactions conducted with different reagents. Of course, only the experimental data confirm the above considerations. We often experienced that the two faces in the molecule could behave independently from one another, and that they are influenced in a different way by a remote X substituent. Usually we experienced a monotonic trend for the *axial reactivity*. With respect to nucleophiles, it always increases with increasing electronegativity of the X group irrespective of its conformation. On the other hand, the *equatorial reactivity* is much less predictable: we found[4,5] several times a so called "paradoxical kinetic divergence" (according to Cieplak[1]).

RESULTS AND DISCUSSION

We were interested in studying epoxidation reactions, in the view of the widespread applications of the oxirane ring for synthetic purposes,[8] and in order to explore the different stereochemical potentialities inherent to a particular substituent. We describe here the stereochemical outcome and the kinetic results of epoxidation reactions of the title compounds, in which X=H (**1**), Ph (**2**), OMe (**3**), Cl (**4**) and Br (**5**) with common epoxidation reagents, such as sulfur ylides.[9,10] The various reaction conditions tested were: **a**) methylenedimethylsulfurane in DMSO at 25°C; **b**) methylenedimethyloxysulfurane in DMSO at 55°C; **c**) methylenedimethylsulfurane in C_6H_6 at 60°C; **d**) methylenedimethyloxysulfurane in C_6H_6 at 80°C. We had very low reaction yields in THF. We tried (the used temperatures were not the same for the different substrates, see EXPERIMENTAL) a simple and fast methylene transfer reaction carried out in the solid state,[11] in order to make the experimental procedure for the ylide generation easier. In this way we could compare the stereochemical outcome obtained by this methodology with that of Corey's procedure.[10]

Under each reaction conditions tested, we obtained the 2-adamantanspirooxirane (**1'**) from **1** and the diastereomeric mixtures of epoxides (**2-5**)**'** and (**2-5**)**"** from substrates (**2-5**), which derived respectively from an axial and an equatorial attack to the ketonic function. Compound (**1'**) is known.[12,13] Compounds (**2'**) and (**2"**) were characterized as a diastereomeric mixture by ^{1}H NMR spectrum.[14] All our attempts to separate **2'** from **2"** by different chromatographic techniques, were unsuccessful, whereas by means of HPLC techniques we succeeded in separating compounds (**3-5**)**'** from compounds (**3-5**)**"**.



(**1**-**5**) **1'** + (**2**-**5**)'

X= H(**1**); Ph(**2**); OCH_3(**3**); Cl(**4**); Br(**5**) **1'** + (**2**-**5**)''

In the NMR spectrum, the chemical shift of an axial substituent appears upfield from that of an equatorial substituent. A structural discrimination based on this well-known generalization does not hold for the methylene group of the oxirane ring: there are no, or too small, chemical shift differences. Literature data are scarce and not consistent with this rule.[15] Indeed neither the oxygen nor the methylene group of an epoxide ring exocyclic to a six membered ring can occupy a true axial or a true equatorial position although we will refer to axial or equatorial orientations for convenience. The ^{1}H NMR spectra for each isolated compound were measured on a 500 MHz spectrometer and allowed - together with 2D COSY experiments - an unambiguous stereochemical assignment of (**3**-**5**)**'** and (**3**-**5**)**''** respectively (see the EXPERIMENTAL for their full characterization). Our assignment might likely be extended to similar compounds. The resolution is somewhat lower for diastereomers (**3'**) and (**3''**). The main distinction between the diastereomers consists in two doublets whose chemical shift difference varies (namely, it increases or decreases) from one diastereomer to the other. These doublets are attributed to the $H4_{ax}$ (and $H9_{ax}$) and to $H8_{ax}$ (and $H10_{ax}$) protons respectively, due to the shielding and/or deshielding effect of the oxirane ring which is *cis* and *trans* with respect to them. The assigned stereochemistry was further confirmed through reduction (which is quantitative and regiospecific) of each diastereomer to the corresponding known methylcarbinols[2,16] independently synthesized, and by comparison of their GLC retention times on two different chromatographic columns. In the case of **2'** and **2''** the two diastereomers, as stated, could not be separated. The assignement based on the reduction of a 70/30 mixture to their corresponding known methylcarbinols was unambigous.

For each set of reaction conditions, we determined the stereochemistry of epoxidation reactions by GLC. Table 1 collects the stereochemical outcome of several reactions (five experiments at least for each substrate in all reaction conditions). We list the X-substituents according to their electronegativity as expressed by Taft's σ_I.[17]

Table 1. Stereochemical product ratios (k_{ax}/k_{eq}) for 5-X-adamantan-2-ones (**1**-**5**)

Substrates	σ_I	**Stereochemical product ratios (k_{ax}/k_{eq})**					
		$(CH_3)_2S^+CH_2^-$			**$(CH_3)_2SO^+CH_2^-$**		
		DMSO	**C_6H_6**	**Solid state**	**DMSO**	**C_6H_6**	**Solid state**
1	0.00	1	1	1	1	1	1
2	0.12	1.39	1.37	1.38	0.78	0.77	0.87
3	0.30	1.58	1.46	1.80	0.64	0.68	0.70
4	0.47	1.79	1.85	1.71	0.44	0.43	0.61
5	0.47	1.63	1.54	1.69	0.42	0.50	0.48

The figures in Table 1 show:

1. A monotonic trend, that is an increase of the k_{ax}/k_{eq} ratio with increasing substituent electronegativity for reactions with methylenedimethylsulfurane and a decrease of the k_{ax}/k_{eq} ratio for reactions with methylenedimethyloxysulfurane. Our data for compound (**2**) in DMSO with methylenedimethyloxysulfurane differ from those reported by Budepudi and Le Noble.[14]

2. This different behaviour between the two ylides is well known.[10] In the case of 4-substituted cyclohexanones,[18] the percentage of equatorial attack we observed was very high and varied between 90% and 97%. In this case, a more rigid molecular skeleton causes a marked decrease of the relative percentage of the equatorial attack that varies between 70% and 56%.

3. Likewise, in a conformational rigid system, the substituent electronegativity seems to have a small effect on the relative percentages of axial and equatorial attack (see again, for a comparison, our previous data[18] of 4-X-cyclohexanones).

4. The stereochemical outcome of reactions performed in the solid state is quite similar to that obtained in solution. We would like to stress that the solid state reaction is very easy to carry out and very convenient.

As previously stated, we often observed that stereochemical results may hide more subtle situations and that only kinetic data can provide an exact insight into what happens. We performed a series of competitive reactions on equimolecular mixtures of compound (**1**) with each of the compounds (**2**) to **5**. The competition method avoids most of the complications associated with kinetic analysis such as, for example, fast reaction rates and ensuing low reproducibility. Due to overlapping of peaks in the GLC analysis, it was not possible to perform competition experiments in which all the compounds (**1**, **2**, **3**, **4**, and **5**) were present at the same time. The relative reaction rates were inferred by GLC determination of the reaction yields. We measured the areas for starting materials and products, dividing each area by the corresponding molecular weight. GLC responses of compounds (**1-5**) on the one hand, and of the epoxides (**1'**), (**2-5**)**'** and (**2-5**)**"** on the other, were very close to each other: thus, no correction was required. The yields varied with the quenching time and the material balance (*i.e.*, the sum of starting and final products) was always higher than 90%. In order to minimize the errors in computing the relative rates, we used only those data from reactions with yields ranging from 15 to 85%. Outside this range, larger errors in reading the GLC peaks of products originated from large differences in rates. Owing to the great difference in reactivity (see Table 2) between the substrates (**1**) and (**4**) and (**1**) and (**5**) respectively, we performed suitable control competition experiments between **4** and **5**, between **4** and **3,** and between **5** and **3** in order to get the exact reactivity differences with respect to substrate (**1**). Competitive kinetic experiments provided highly reproducible results largely independent of the concentration of the reactants thus showing that the reaction order is the same for all ketones.[19] The relative reaction rates are calculated by assuming that all reactions are first order in ketone and in sulfur ylide concentration and dividing the overall rate for compound (**1**) (k_{ax} =k_{eq}=1) by two.

The experimental data are collected in Table 2. They are an average of at least five different experiments. The relative rates of attack (k_{ax} and k_{eq}) for each substrate were calculated from the data of Tables 1 and 2.

Table 2. Overall rates ratio for competition reactions on 5-X-adamantan-2-ones (**1-5**)

Substrates	σ_I	**Overall ratio of rates k_n/k_1***			
		$(CH_3)_2S^+CH_2^-$		**$(CH_3)_2SO^+CH_2^-$**	
		DMSO	**C_6H_6**	**DMSO**	**C_6H_6**
1	0.00	1	1	1	1
2	0.12	3.64	2.41	4.61	2.76
3	0.30	12.54	4.87	10.46	5.43
4	0.47	7.81	15.54	67.24	26.71
5	0.47	9.08	16.92	80.50	25.25

* mean standard deviation: 0.02

The results are reported in Table 3. We always had good LFER ($0.88 < r^2 < 0.99$) in all the experienced reaction conditions.

Table 3. Relative rates k_{ax} and k_{eq} of reaction on 5-X-adamantan-2-ones (**1**-**5**)

Substrates	σ_I	Relative rates k_{ax} and k_{eq}							
		$(CH_3)_2S^+CH_2^-$				$(CH_3)_2SO^+CH_2^-$			
		k_{ax}		k_{eq}		k_{ax}		k_{eq}	
		DMSO	C_6H_6	DMSO	C_6H_6	DMSO	C_6H_6	DMSO	C_6H_6
1	0.00	1	1	1	1	1	1	1	1
2	0.12	4.24	2.78	3.05	2.03	4.48	2.41	5.72	3.11
3	0.30	15.39	5.78	9.73	3.96	8.13	4.39	12.79	6.47
4	0.47	10.05	20.17	5.62	10.90	41.07	16.14	93.40	37.28
5	0.47	11.26	20.52	6.89	13.33	47.43	16.78	112.67	33.72

Hence, we found increasing rates (with a slight prevalence for k_{ax}) on increasing the substituent electronegativity, both for k_{ax} and k_{eq}. The stereochemical results reflect the different reaction rates of attack on the two faces of the molecule. With methylenedimethylsulfurane, the axial attack prevails and is the most sensitive towards the effect of the substituent in both solvents, whereas with methylenedimethyloxysulfurane the prevailing and most sensitive attack is the equatorial one.

The different stereochemical behavior might be ascribed either to different transition state energies,[20] either to a different balance between steric approach control and product development control.[21] A remarkable and interesting behavior was the different solvent effect we observed. With methylenedimethylsulfurane, the electronegativity of the substituent is more effectively transmitted in solvents of low polarity. Going from DMSO to C_6H_6 and from X=H to X=Br the rate increase was respectively 11 times (DMSO) to 20 times (C_6H_6) for ρ_{ax} and 7 times (DMSO) to 13 times (C_6H_6) for ρ_{eq}. The effect was opposite with methylenedimethyloxosulfurane: the maximum rate increase, going from X=H to X=Br was observed in DMSO. The rate drop was, respectively of 47 (DMSO) to 17 times (C_6H_6) for ρ_{ax}, and of 112 (DMSO) to 33 times (C_6H_6) for ρ_{eq}. To our knowledge, such a solvent effect was never encountered in the case of additions of other nucleophiles to the same substrates.

Additions to a trigonal centre occur at different reaction rates, one on each side of the molecule, and each one with its own controls. MO calculations will be necessary to construct a suitable transition state theory that takes into account at the same time changes in reactant, solvent, molecularity and so on, but a TS theory is precisely what is badly needed. Many questions are still far from being settled. Among other things, this

is a legacy of having considered diastereoselection mostly in terms of stereochemical ratios (k_{ax}/k_{eq}) and not in terms of kinetic relative rates of attack (k_{ax} or k_{eq}).

EXPERIMENTAL

General Remarks: Melting points were determined on a Mettler FP82HP apparatus and are uncorrected. HRMS were performed on a Bruker Spectrospin APEX TM 47e FT-IRC instrument. Micro analyses were carried out on a CE instrument EA 1110. IR spectra were recorded on a Perkin-Elmer 1600 Series FTIR. GC-MS analyses were performed with a GC-MS HP 5970 Chemstation Mass Selective Detector connected with an HP 5890 gas chromatograph using a capillary column coated with fluid methyl silicone (12.5 m, 0.2 mm i.d.). ^{1}H and ^{13}C NMR spectra ($CDCl_3$) were recorded respectively on a BRUKER AM-500 spectrometer and on a VARIAN XL 300 spectrometer. Chemical shifts are reported in parts per million (ppm) down field from TMS using residual $CDCl_3$ (7.27 ppm) for ^{1}H NMR and the middle resonance of $CDCl_3$ (77.0 ppm) for ^{13}C NMR spectrum as internal standard. GLC analyses were carried out on a Carlo Erba HRGC Mega Series 5300 apparatus using a 25 m, 0.25 mm i.d. fused silica capillary column (stationary phase CARBOWAX 20M), He flow = 0.5 mL/min. Reaction mixtures were eluted in the order (**1**, **1'**), (**2"**, **2**, **2'**), (**3**, **3"**, **3'**), (**4**, **4"**, **4'**), (**5**, **5"**, **5'**). All GLC analyses were carried out at an oven temperature of 160°C. The most suitable GLC conditions for the analyses of reaction mixtures of competition reactions between compounds (**1**) and (**2**) were: 160°C, 5 min, 25°C/min, 210°C, 20 min, that is initial oven temperature, isotherm time, temperature increase rate, final oven temperature; $T_{inj}=T_{det}$ = 230 °C. **1** and **1'** were detected during the initial isotherm. The separations by HPLC were performed on a Varian 9001 instrument equipped with a Varian RI-4 differential refractometer. Solvents were HPLC grade.

Starting materials: 2-Adamantanone is commercially available (Aldrich) and was used as such. Published procedures were used for the preparation of 5-phenyladamantan-2-one (**2**),[22] 5-methoxyadamantan-2-one (**3**),[23] 5-chloroadamantan-2-one (**4**) and 5-bromoadamantan-2-one (**5**).[24]

Preparation of reagents: Methylenedimethylsulfurane and methylenedimethyloxysulfurane in DMSO were prepared *in situ* according to the method of Corey and Chaykowsky.[10] Immediately before use, they were diluted (1:10) with the suitable amount of anhydrous C_6H_6 or THF.

Reactions: All reactions were performed at room temperature (22-25°C) for methylenedimethylsulfurane, and at 55°C (external bath) (80° for reactions in C_6H_6) for methylenedimethyloxysulfurane under a dry inert atmosphere (nitrogen or argon). All glassware was dried in an oven (*ca.* 150°C), carefully flame dried and cooled under dry inert atmosphere. Typically: in a 25 mL flask, equipped with magnetic stirrer, reflux condenser and dropping funnel by adding, under vigorous stirring to the substrate solution (0.2 mmol in 2 mL of the chosen anhydrous solvent, that is DMSO for conditions **a**) and **c**), or C_6H_6 for

conditions **b**) and **d**)), the appropriate ylides stoichiometric amount. The reaction mixtures were hydrolized with brine (after 10 to 30 min, depending on reaction times) and extracted three times with Et_2O. The ethereal solutions washed with brine, were combined, dried over Na_2SO_4, filtered and evaporated. Reactions in the solid state were performed in a 10 mL dry flamed flask. Typically: 2 mmol of starting material were rapidly introduced and stirred with 4 mmol of powdered KOH and 4 mmol of trimethylsulfonium iodide (or trimethyloxysulfonium iodide). Reaction times and temperature varied for each substrate. We report in parenthesis reaction times and the external bath temperatures for each substrate: **1** (90 min, 115°C); **2** (60 min, 115°C); **3** (60 min, rt); **4** and **5** (10 min, 60°C).

Competition experiments: Four flasks (10 or 100 mL for competition experiments in more diluted conditions) were equipped with a magnetic stirrer and connected by means of a four-point star-rotating receiver to a graduate burette, gas inlet and $CaCl_2$ tube. Each flask contained an equimolecular amount of **1** and **2** or, **3**, **4** and **5**, depending on the chosen partner for each particular experiment (0.2 mmol in all), dissolved in 2 mL of anhydrous solvent. The suitable, conveniently diluted (0.1-0.05 M) ylide was rapidly added to the substrates mixtures under vigorous stirring. It was not possible to perform competition experiments in which all substrates were present simultaneously due to peaks overlapping in the GLC trace. The reaction mixtures were quenched and worked up as previously described.

Identification, isolation and characterization of the diastereomeric epoxides: For this purpose, we performed the reactions on each substrate, on a larger scale, allowing the reaction to go to completion. Following work up, the crude reaction mixtures were separated into their components by HPLC and the purity of each compound was tested by GLC. Besides physical chemical properties, we report the most suitable HPLC solvent composition and the elution order of compounds from each mixture. As formerly stated, we could not isolate compound (**2'**) from compound (**2"**). We report only the still lacking data.

Diastereomeric mixture of **2'** and **2"**: *m/z* (%): 241(M^{+1}, 3), 240(M^+, 15), 155(6), 122(100), 107(10), 91(21), 77(9). ^{1}H NMR δ: 7.48-7.28 (m, 5H, PhH), 2.81 (s, 2H $CH_{2eq}O$); 2.79 (s, 2H, $CH_{2ax}O$) 2.30-1.70 (m, 12H); 1.66 (br m, 1H, H7).

Purification by HPLC (Hexane/EtOAc=85/15), gave, in order, **3"** and **3'**. **Compound** (**3'**): white viscous oil; HRMS: found 194.1303. $C_{12}H_{18}O_2$ requires 194.1307; ν_{max}($CHCl_3$) 2930, 2860, 1260, 1095, 910 cm^{-1}; m/z(%): 194(M^+, 4), 137(2), 109(100), 91(18), 77(11); ^{1}H NMR δ: 3.34(s, 3H, -OCH_3), 2.76 (s, 2H, $CH_{2ax}O$), 2.06 (br d, 2H, $H8_{ax}$, $H10_{ax}$, *J*=12.5 Hz), 1.96 (br d, 2H, $H4_{ax}$, $H9_{ax}$, *J*=12 Hz), 1.92-1.90 (m, 6H), 1.71 (br d, 2H, $H8_{eq}$, $H10_{eq}$, *J*=12 Hz), 1.65 (br m 1H, H7); ^{13}C NMR (300 MHz) δ: 71.08 (C5); 63.70 (C2); 54.41 (CH_2O); 48.29 (OCH_3); 40.98 (C6); 38.14, 37.79 (C1,3); 35.82 (C4,9); 31.69 (C7); 29.80, 29,28 (C8,10). **Compound** (**3"**): white viscous oil; HRMS: found 194.1310. $C_{12}H_{18}O_2$ requires 194.1307; ν_{max}($CHCl_3$) 2940, 1290, 1085, 790 cm^{-1}; m/z (%): 195(M^{+1}, 2), 194(M^+, 18), 166(26), 109(100), 94(28), 73(24); ^{1}H NMR δ: 3.34(s, 3H, -OCH_3), 2.77 (s, 2H, $CH_{2eq}O$), 2.19 (br d, 2H, $H4_{ax}$,

$H9_{ax}$, *J*=11.5 Hz), 1.87-1.83 (m, 8H), 1.76 (br d, 2H, $H8_{eq}$, $H10_{eq}$, *J*=12 Hz), 1.70 (br m 1H, H7); ^{13}C NMR (300 MHz) δ: 71.34 (C5); 64.02 (C2); 54.98 (CH_2O); 48.40 (OCH_3); 40.45 (C6); 39.91, 39.78 (C1,3); 37.07, 36.51 (C4,9); 33.99 (C7); 30.69, 30.31 (C8,10).

Purification by HPLC (Hexane/EtOAc=80/20), gave, in order, **4'** and **4"**. **Compound** (**4'**): pale yellow oil; HRMS: found 186.0815. $C_{10}H_{15}OCl$ requires 186.0811; $\nu_{max}(CHCl_3)$ 2940, 1225, 1200, 1026, 960, 830; m/z(%): 200(M^{+2}, 8), 198(M^+, 27) 163(100), 121(19), 91(24), 77(11); ^1H NMR δ: 2.77 (s, 2H, $CH_{2ax}O$); 2.37 (br d, 2H, $H4_{ax}$, $H9_{ax}$, *J*=12 Hz); 2.31-2.29 (m, 6H); 2.08 (br d, 2H, $H8_{ax}$, $H10_{ax}$, *J*=12.5 Hz), 1.79 (br d, 2H, $H8_{eq}$, $H10_{eq}$, *J*=12.5 Hz), 1.64 (br m 1H, H7); ^{13}C NMR (300 MHz $CDCl_3$) (δ) 66.34 (C5); 62.77 (C2); 54.82 (CH_2O) 47.16 (C6); 46.38 (C4,9); 38.22 (C1,3); 33.13 (C8,10); 30.16 (C7). **Compound** (**4"**): pale yellow oil; HRMS: found 186.0814. $C_{10}H_{15}OCl$ requires 186.0811; $\nu_{max}(CHCl_3)$ 2940, 1260, 1200, 910, 760; m/z(%): 200(M^{+2}, 9), 198(M^+, 27), 169(12), 163(100), 122(20), 121(12), 91(33), 77(14); ^1H NMR δ: 2.77 (s, 2H, $CH_{2eq}O$); 2.53 (br d, 2H, $H4_{ax}$, $H9_{ax,}$ *J*=12 Hz); 2.27 (br m, 4H); 2.18 (br d, 2H, $H4_{eq}$, $H9_{eq,}$ *J*=12.5 Hz); 1.93 (br d, 2H, $H8_{ax}$, $H10_{ax}$, *J*=11.5 Hz), 1.85 (br d, 2H, $H8_{eq}$, $H10_{eq}$, *J*=13 Hz), 1.68 (br m 1H, *H7*); ^{13}C NMR (300 MHz) 66.80 (C5); 62.90 (C2); 54.77 (CH_2O); 47.60 (C6); 45.29 (C4,9); 39.25 (C1,3); 35.38 (C8,10); 30.78 (C7).

Purification by HPLC (Hexane/EtOAc=85/15), gave, in order, **5'** and **5"**. **Compound** (**5'**): white needles, mp 156-157 °C; *Anal*. Calcd for $C_{10}H_{18}O_2$: C, 70.53; H, 10.66. Found: C, 70.50; H, 10.68; ν_{max} ($CHCl_3$) 2935, 1450, 1265, 1230, 1210, 800, 710 cm^{-1}; m/z(%): 244(M^{+2}, 4). 242(M^+, 4); 163(100); 105(13); 91(24); 79(18); ^1H NMR δ: 2.78 (s, 2H, $CH_{2ax}O$), 2.57 (br d, 2H, $H4_{ax}$, $H9_{ax}$, *J*=12 Hz), 2.52-2.50 (m, 6H), 2.13 (br d, 2H, $H8_{ax}$, $H10_{ax}$, *J*=12.5 Hz), 1.83 (br d, 2H, $H8_{eq}$, $H10_{eq}$, *J*=12.5 Hz), 1.61 (br m 1H, H7);^{13}C NMR (300 MHz) δ: 64.00 (C5); 62.80 (C2); 54.82 (CH_2O) 48.65 (C6); 47.96 (C4,9); 39.15 (C1,3); 33.11 (C8,10); 31.01 (C7). **Compound** (**5"**): white viscous oil; *Anal*. Calcd for $C_{10}H_{18}O_2$: C, 70.53; H, 10.66. Found: C, 70.49; H, 10.65; ν_{max} ($CHCl_3$) 2930, 1260, 1225, 1200, 1020, 955, 810; m/z(%): 244(M^{+2}, 3), 242(M^+, 3), 163(100); 121(9), 105(10), 91(26), 79(13); ^1H NMR δ: 2.76 (s, 2H, $CH_{2eq}O$), 2.74 (br d, 2H, $H4_{ax}$, $H9_{ax}$, *J*=12.5 Hz), 2.48 (br m, 4H), 2.40 (br d, 2H, $H4_{eq}$, $H9_{eq}$, *J*=12.5 Hz), 1.98 (br d, 2H, $H8_{ax}$, $H10_{ax}$, *J*=12 Hz), 1.90 (br d, 2H, $H8_{eq}$, $H10_{eq}$, *J*=12 Hz), 1.65 (br m 1H, H7); ^{13}C NMR (300 MHz) δ: 63.90 (C5); 62.20 (C2); 54.36 (CH_2O); 48.60 (C6); 46.29 (C4,9); 39.56 (C1,3); 34.85 (C8,10); 31.07 (C7).

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