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Reductive Cleavage of Allylic Ketals by an Arene-Catalysed Lithiation: A Simple and Direct Route to Masked Lithium Homoenolates

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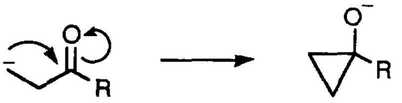
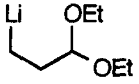
Abstract: The reaction of acrolein diethyl acetal **1** with an excess of lithium powder and a catalytic amount of 4,4'-di-*tert*-butylbiphenyl (DTBB; 2.5 mol %) in the presence of a carbonyl compound **2** in THF at 0°C leads, after hydrolysis with water, to the corresponding γ-coupling products **3** as a *Z/E* mixture, the *Z*-isomer being mainly the major one. When the final hydrolysis was carried out in acidic conditions (3 N hydrochloric acid) followed by treatment with silicon compounds of the type R_3SiNu in the presence of boron trifluoride etherate in dichloromethane at temperatures ranging between -78 and 20°C, the corresponding substituted tetrahydrofurans **4** were obtained. The same Barbier-type reaction applied to 2-cyclopentenone ethylene ketal **5** yields, after acid hydrolysis, the expected 3-substituted cyclopentanones **6**. In all cases overall yields are moderates.

INTRODUCTION

Homoenolate anions[1a] derived from carbonyl compounds are important intermediates in preparative organic chemistry as three-carbon homologating agents[1b], above all in homoaldol-type reactions[1c]. The corresponding lithiated species **I** are unknown due to their outstanding instability: even at low temperatures they decompose spontaneously giving the corresponding cyclopropanolates **II** through a fast intramolecular nucleophilic process[1]. Synthetic equivalents for lithium homoenolates[2] can be prepared mainly by the so called deffensive or offensive strategies[1c]. In the first case the most common procedure includes the protection of the carbonyl group, for instance in the intermediates **III** and **IV**[3]. In the offensive strategy an allylic anion bearing a heteroatom **V** (in equilibrium with both the α- and γ-lithiated species **VI** and **VII**, respectively) is usually prepared by deprotonation of the corresponding allylic precursors and used as a lithium homoenolate synthon[1c]. A problem inherent to the delocalised structure of the allylic anion **V** is its regioselectivity in the reaction with electrophilic reagents: in general, a mixture of both α- and γ-coupling products is always obtained[1c]. It is also interesting to note that homoenolate anions are intermediates with umpolung reactivity[4], namely *d*³ reagents following Seebach's nomenclature[5].



I II



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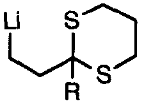

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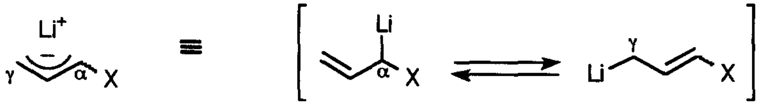


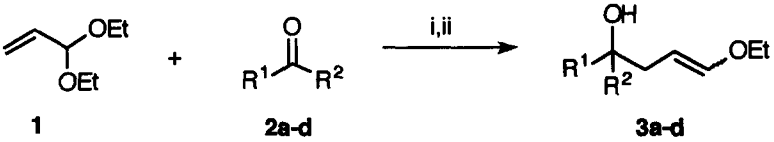
V VI VII

[X=OR, NR_2, SR, SiR_3, BR_2, ...]

On the other hand, and following our continuous interest on functionalised organolithium compounds[6], we have recently discovered that an arene such as naphthalene or 4,4'-di-*tert*-butylbiphenyl (DTBB) can catalyse lithiation reactions under very mild conditions, this mixture being even more effective than the corresponding lithium-arene[7]. Using this methodology it is possible to prepare very reactive organolithium compounds not only from halogenated precursors[8] but also from other starting materials such as sulphonates and sulfates[9], carbonyl derivatives[10], saturated heterocycles[11] and nitriles[12]. In this paper we apply the above described arene-catalysed lithiation to the preparation of lithium homoenolate equivalents following the offensive strategy (see *supra*) starting from α,β-unsaturated carbonyl compounds protected as the corresponding ketals.

RESULTS AND DISCUSSION

The reaction of acrolein diethyl acetal **1** with an excess of lithium powder (1:8 molar ratio) and a catalytic amount of DTBB (1:0.05 molar ratio; 2.5 mol %) in the presence of a carbonyl compound **2** (1:1.2 molar ratio; Barbier-type conditions) in THF at 0°C led, after hydrolysis with water, to the corresponding *Z/E* mixture of the γ-products in a totally regioselective manner (Scheme 1 and Table 1). When the lithiation was carried out at -40°C no reaction was observed. The same reaction in the presence of cyclohexanone **2d** at temperatures ranging between -40 and 20°C overnight gave the expected product **3d** with some lower yield and in a different *Z/E* ratio (Table 1, entry 4 and footnote d). The reaction has to be performed under Barbier-type reaction conditions in order to avoid decomposition of the allylic anionic intermediate of the type **V** (with X=OEt): when the starting material **1** was submitted to catalytic lithiation as above *in absence of the carbonyl compound* and after 30 min was treated with cyclohexanone gave, after hydrolysis, only a 5% yield (GLC) of the corresponding *Z/E* mixture (3/1) of product **3d**. It is interesting to note that, in spite of the fact that the yields are modest, only the γ-regioisomers **3a-d** were obtained[13]. Concerning not only the regiochemistry but also the stereochemistry observed, the general obtention of the *Z*-diastereoisomer as the major product can be rationalised by considering that the *Z*-configuration in the intermediate of the type **VII** (X=OEt) could be strongly stabilised by chelation with the ethoxy group (CIPE effect)[14].



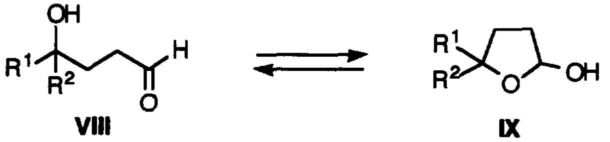
Scheme 1. *Reagents and conditions*: i, Li powder excess (1:8 molar ratio), DTBB cat. (1:0.05 molar ratio; 2.5 mol %), THF, 0°C; ii, H_2O.

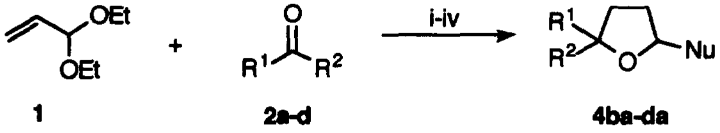
Table 1. Preparation of Hydroxyethers **3**

	Carbonyl compound			Product[a]		
Entry	no.	R^1	R^2	no.	yield (%)[b]	*Z/E*-ratio[c]
1	**2a**	Bu^t	H	**3a**	34	7/1
2	**2b**	Et	Et	**3b**	40	1/1
3	**2c**	Pr^i	Pr^i	**3c**	38	20/1
4	**2d**	$-(CH_2)_5-$		**3d**	41 (34)[d]	3/1 (9/1)[d]

[a] All products **3** (as a mixture of *Z/E* diastereoisomers) were >95% pure (GLC and 300 MHz ^1H NMR). [b] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the starting acetal **1**. [c] From 75 MHz ^{13}C NMR. [d] The reaction temperature was -40 to 20°C (overnight).

Since the acid hydrolysis of compounds of the type **3** gives a mixture of the corresponding γ-hydroxy-aldehyde **VIII** and the cyclic hydroxytetrahydrofurans (lactols) **IX**[3], we have combined this process with the silicon-promoted nucleophilic substitution of the hydroxy group in **IX**[15]. Thus, once compounds **3** were obtained as above, they were hydrolysed with 3 N hydrochloric acid and the crude **VIII+IX** mixture was treated with allyl-, cyano-trimethylsilane or triethylsilane in the presence of boron trifluoride-etherate[15] in dichloromethane at temperatures ranging between -78 and 20°C overnight: after hydrolysis with a saturated aqueous solution of sodium hydrogen carbonate, the expected products resulting from a hydroxy-allyl, hydroxy-cyano or hydroxy-hydrogen exchange were, respectively, isolated (Scheme 2 and Table 2). It is worthy to note that the overall yields (Table 2) for the tandem four steps shown in Scheme 2 are in the same rang that the corresponding ones in the preparation of compounds **3**; it would mean that steps iii and iv in Scheme 2 work with good yields. Actually, starting from compound **3d** the corresponding product **4da** was prepared in 85% isolated yield (Table 2, entry 5 and footnote d).





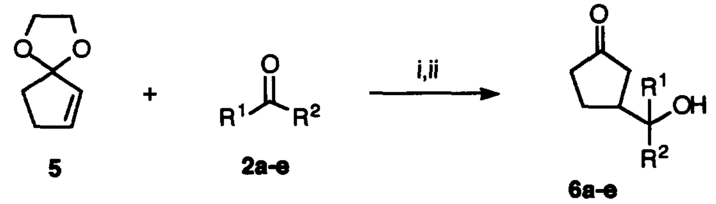
Scheme 2. ***Reagents and conditions***: i, Li powder excess (1:8 molar ratio), DTBB cat. (1:0.05 molar ratio; 2.5 mol %), THF, 0°C; ii, 3 N HCl, 20°C; iii, R_3SiNu, BF_3-OEt_2, CH_2Cl_2, -78 to 20°C; iv, $NaHCO_3$-H_2O.

Table 2. Isolation of Substituted Tetrahydrofurans **4**

Entry	Carbonyl[a] compound	R_3SiNu	Product[b] no.	Nu	yield (%)[c]
1	**2b**	$Me_3SiCH_2CH=CH_2$	**4ba**	$CH_2CH=CH_2$	43
2	**2c**	Et_3SiH	**4ca**	H	46
3	**2c**	Me_3SiCN	**4cb**	CN	44
4	**2c**	$Me_3SiCH_2CH=CH_2$	**4cd**	$CH_2CH=CH_2$	41
5	**2d**	$Me_3SiCH_2CH=CH_2$	**4da**	$CH_2CH=CH_2$	32 (85)[d]

[a] See Table 1. [b] All products **4** were >95% pure (GLC and 300 MHz ^1H NMR). [c] Isolated overall yield after column chromatography (silica gel, hexane/ethyl acetate) based on the starting acetal **1**. [d] Isolated overall yield based on the isolated vinyl ether **3d**.

Finally, we applied the methodology shown in Scheme 1 to the ethylene ketal derived from 2-cyclopentenone **5**, but carrying out the final hydrolysis under acidic conditions. In this case the cyclic geometry does not allow the formation of a cyclic hydroxyfuran of the type **IX**, so the corresponding hydroxyketones **6** were isolated in moderate yields (Scheme 3 and Table 3). In the case of using pivalaldehyde as electrophile, the expected mixture of *erythro/threo* diastereoisomers (*ca.* 1:1) was obtained (Table 3, entry 1 and footnote d).



Scheme 3. *Reagents and conditions*: i, Li powder excess (1:8 molar ratio), DTBB cat. (1:0.05 molar ratio; 2.5 mol %), THF, 0°C; ii, 2 N HCl, 20°C.

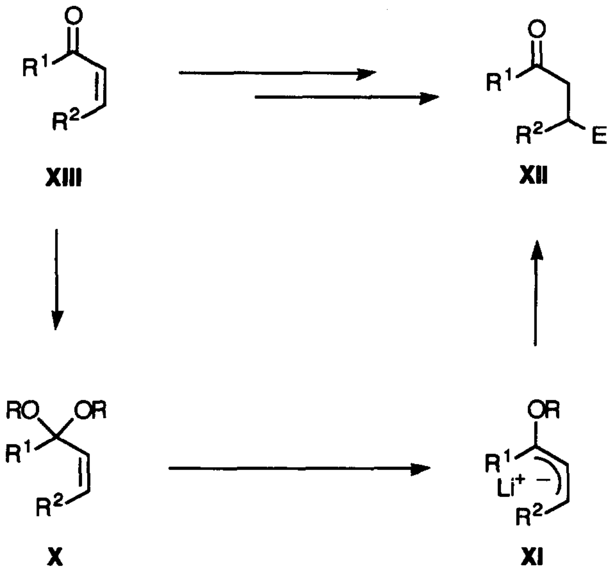
Table 3. Isolation of Hydroxyketones **6**

Entry	Carbonyl[a] compound	Product[b]	
		no.	yield (%)[c]
1	**2a**	**6a**	35[d]
2	**2b**	**6b**	40
3	**2c**	**6c**	33
4	**2d**	**6d**	35
5	**2e**	**6e**	36

[a] See Table 1; for starting compound **2e**: $R^1=R^2=Me$. [b] All compounds **6** were >95% pure (GLC and 300MHz ^1H NMR). [c] Isolated yield after column chromatography (silica gel, hexane/ethyl acetate) based on the starting ketal **5**. [d] A *ca.* 1:1 diastereoisomers mixture was obtained (from 75 MHz ^{13}C NMR).

CONCLUSIONS

From the results described in this paper we conclude that ketalised α,β-unsaturated compounds **X**, such as acrolein or 2-cyclopentenone) are adequate precursors for obtaining masked lithium homoenolates of the type **XI**, which by *in situ* reaction with carbonyl compounds (Barbier-type conditions) yield, after acid hydrolysis, β-substituted carbonyl compounds **XII**. If one considers the whole transformation **XIII**→**XII**, this methodology allows the introduction of an electrophile at the conjugate position of the starting material, this reaction being so the umpoled Michael process, which works with nucleophilic reagents. In addition, the *in situ* preparation of the allylic anion intermediate **XI** complements other synthetic routes for this species, which usually employ a deprotonation process[1c]. Finally, considering that α,β-unsaturated carbonyl compounds can be prepared from the corresponding saturated systems (tandem enolisation/selenation/oxidation) the route described here permits the β-substitution of a carbonyl compound by means of an electrophile.



EXPERIMENTAL PART

General.- For general information see reference 11c. High resolution mass spectra were measured in the corresponding service at the University of Zaragoza. Microanalysis was performed in the Microanalyses Service at the University of Alicante. The starting materials **1** and **5** as well as the silicon-containing reagents were commercially available (Aldrich, Fluka).

Preparation of Compounds **3a-d**. *General Procedure.*- To a blue suspension of lithium powder (112 mg, 16 mmol) and DTBB (30 mg, 0.11 mmol) in THF (5 ml) was slowly added (*ca.* 2 h) a solution of acrolein diethyl acetal **1** (320 μl, 2 mmol) and the corresponding carbonyl compound **2** (2.1 mmol) in THF (5 ml) at 0°C under argon. After the addition (the blue colour was recuperated indicating the end of the lithiation process), the resulting mixture was hydrolysed with water (20 ml), neutralised with a saturated aqueous solution of ammonium chloride and extracted with diethyl ether (2x20 ml). The organic layer was dried over anhydrous sodium sulfate and evaporated (15 Torr). The resulting residue was then purified by column chromatography yielding the pure title compounds. Yields and *Z/E* ratios are included in Table 1. Physical and spectroscopic data follow. In the case of compounds **3a** and **3c**, which could not be separated in their *Z* and *E* diastereoisomers, the ^{13}C NMR data were deduced from the *Z/E*-mixture; mass spectra were recorded in these cases by a tandem GLC-MS experiment.

(Z)-*1-Ethoxy-5,5-dimethyl-1-hexen-4-ol* [(*Z*)-**3a**]: R_f=0.75 (hexane/ethyl acetate: 7/3); ν_{max} (film) 3440 (OH), 3020, 1650 (HC=C), 1100, 1060 and 1040 cm^{-1} (C-O); δ_H 0.92 (9 H, s, Me_3C), 1.25 (3 H, t, *J*=7.1, *Me*CH_2), 1.98 (1 H, br s, OH), 2.15-2.23 (2 H, m, CH_2C=C), 3.22 (1 H, dd, *J*=8.0, 4.7, C*H*OH), 3.80 (2 H, q, *J*=7.1, CH_2O), 4.40-4.50 (1 H, m, HC=CO) and 6.10 (1 H, dt, *J*=6.2, 1.3, C=CHO); δ_C 15.2, 25.7 (3 C), 26.8, 34.75, 67.7, 79.7, 103.65 and 146.75; *m/z* 172 (M^+, <1%), 87 (48), 86 (100), 85 (19), 69 (42), 58 (47), 57 (90), 45 (16), 43 (22) and 41 (46) (Found: M^+, 172.145187. $C_{10}H_{20}O_2$ requires 172.146330).

(E)-*1-Ethoxy-5,5-dimethyl-1-hexen-4-ol* [(*E*)-**3a**]: R_f=0.75 (hexane/ethyl acetate: 7/3); δ_C 14.7, 25.75 (3 C), 27.6, 34.7, 64.7, 78.8, 100.6 and 148.8; *m/z* 172 (M^+, <1%), 87 (29), 86 (61), 85 (20), 69 (34), 58 (43), 57 (100), 45 (18), 43 (23) and 41 (50).

(Z)-*1-Ethoxy-4-ethyl-1-hexen-4-ol* [(*Z*)-**3b**]: R_f=0.46 (hexane/ethyl acetate: 7/3); ν_{max} (film) 3400 (OH), 3020, 1660 (HC=C) and 1100 cm^{-1} (C-O); δ_H 0.84 (6 H, t, *J*=7.3, 2x*Me*CH_2C), 0.93 (3 H, t, *J*=7.5, *Me*CH_2O), 1.43 (4 H, q, *J*=7.3, 2xMeCH_2C), 1.60 (1 H, br s, OH), 2.21 (2 H, dd, *J*=7.8, 1.1, CH_2C=C), 3.78 (2 H, q, *J*=7.5, CH_2O), 4.38 (1 H, td, *J*=7.8, 6.4, HC=CO) and 6.07 (1 H, dt, *J*=6.4, 1.1, C=CHO); δ_C7.9 (2 C), 9.95, 30.8 (2 C), 33.05, 71.05, 75.1, 101.25 and 146.75; *m/z* 172 (M^+, <1%), 143 (12), 97 (18), 87 (56), 86 (88), 69 (52), 58 (33), 57 (100), 55 (19), 45 (74), 43 (31) and 41 (35).

(E)-*1-Ethoxy-4-ethyl-1-hexen-4-ol* [(*E*)-**3b**]: R_f=0.42 (hexane/ethyl acetate: 7/3); ν_{max} (film) 3400 (OH), 3020, 1660 (HC=C) and 1100 cm^{-1} (C-O); δ_H 0.85 (6 H, t, *J*=7.0, 2x*Me*CH_2C), 1.04 (3 H, t, *J*=7.3, *Me*CH_2O), 1.26 (4 H, q, *J*=7.0, 2xMeCH_2C), 1.50 (1 H, br s, OH), 2.02 (2 H, dd, *J*=7.8, 1.1 CH_2C=C), 3.78 (2 H, q, *J*=7.3, CH_2O), 4.73 (1 H, dt, *J*=12.6, 7.8, HC=CO) and 6.24 (1 H, dt, *J*=12.6, 1.1, C=CHO); δ_C7.7 (2 C), 9.0, 30.6 (2 C), 36.75, 67.6, 74.0, 98.2 and 148.6; *m/z* 172 (M^+, <1%), 143 (10), 97 (15), 87 (61), 86 (59), 69 (44), 58 (53), 57 (86), 55 (16), 45 (100), 43 (39) and 41 (45).

(Z)-*1-Ethoxy-4-isopropyl-5-methyl-1-hexen-4-ol* [(*Z*)-**3c**]: R_f=0.88 (hexane/ethyl acetate: 3/2); ν_{max} (film) 3500 (OH), 3020, 1640 (HC=C), 1100 and 1040 cm^{-1} (C-O); δ_H 0.76, 0.78 (6 H, 2 d, *J*=5.8, 2x*Me*CH), 0.86 (3 H, t, *J*=7.0, *Me*CH_2O), 1.09, 1.14 (6 H, 2 d, *J*=7.0, 2x*Me*CH), 1.75-2.00 [5 H, m, $(CH)_2C(OH)CH_2$], 3.42 (2 H, q, *J*=7.0, CH_2O), 3.70 (1 H, td, *J*=7.0, 6.0, HC=CO) and 5.01 (1 H, d, *J*=6.0, C=CHO); δ_C 14.95, 17.6, 17.65, 18.05, 18.15, 25.9, 33.55, 34.0, 62.45, 65.75, 92.9 and 104.7; *m/z* 158 (M^+-42, 1%), 157 (12), 86 (48), 85 (16), 83 (12), 73 (11), 71 (72), 69 (13), 58 (21), 57 (38), 55 (33), 45 (16), 43 (100) and 41 (48) (Found: M^+-C_3H_7, 157.123149. $C_9H_{17}O_2$ requires 157.122855).

(E)-*1-Ethoxy-4-isopropyl-5-methyl-1-hexen-4-ol* [(*E*)-**3c**]: R_f=0.88 (hexane/ethyl acetate: 3/2); δ_C 15.15, 17.8, 17.85, 18.3, 18.4, 26.05, 33.45, 34.25, 58.05, 67.35, 99.55 and 101.05; *m/z* 158 (M^+-42, 2%), 157 (16), 115 (12), 111 (13), 86 (52), 85 (24), 83 (19), 73 (14), 71 (74), 69 (14), 59 (13), 58 (14), 57 (50), 55 (36), 45 (12), 43 (100) and 41 (66).

(Z)-*1-(3-Ethoxy-2-propenyl)cyclohexanol* [(*Z*)-**3d**]: R_f=0.40 (hexane/ethyl acetate: 4/1); ν_{max} (film) 3420 (OH), 3020, 1650 (HC=C) and 1100 cm^{-1} (C-O); δ_H 1.24 (3 H, t, *J*=7.1, Me), 1.25-1.75 (10 H, m, 5x ring CH_2), 1.78 (1 H, br s, OH), 2.24 (2 H, dd, *J*=7.8, 1.1, CH_2C=C), 3.80 (2 H, q, *J*=7.1, CH_2O), 4.45 (1 H, td, *J*=7.8, 6.4, HC=CO) and 6.12 (1 H, dt, *J*=6.4, 1.1, C=CHO); δ_C 15.25, 22.4 (2 C), 25.85, 37.4 (2 C), 36.35, 67.65, 71.9, 100.95 and 147.0; *m/z* 184 (M^+, 1%), 99 (41), 86 (100), 81 (64), 79 (10), 58 (40), 57 (39), 55 (31), 43 (20), 42 (10) and 41 (27) (Found: M^+, 184.146183. $C_{11}H_{20}O$ requires 184.146330).

(E)-*1-(3-Ethoxy-2-propenyl)cyclohexanol* [(*E*)-**3d**]: R_f=0.32 (hexane/ethyl acetate: 4/1); ν_{max} (film) 3400 (OH), 3020, 1680 (HC=C) and 1100 cm^{-1} (C-O); δ_H 1.25-1.70 (13 H, m with a t at 1.27,*J*=7.0, 5x ring CH_2, Me), 1.80 (1 H, br s, OH), 2.04 (2 H, dd, *J*=7.9, 0.8, CH_2C=C), 3.74 (2 H, q, *J*=7.0, CH_2O), 4.78 (1 H, dt, *J*=12.6, 7.9, HC=CO) and 6.12 (1 H, dt, *J*=12.6, 0.8, C=CHO); δ_C 14.65, 22.15 (2 C), 25.8, 37.05 (2 C), 40.5, 64.7, 70.65, 97.75 and 148.7; *m/z* 184 (M^+, <1%), 99 (47), 86 (100), 81 (70), 58 (38), 57 (34), 55 (24), 43 (13) and 41 (17).

Preparation of Compounds **4ba-da**.*General Procedure*.- Once the lithiation and *in situ* reaction with the corresponding carbonyl compound took place as it was above described for compounds **3**, the reaction mixture was hydrolysed with water (20 ml), acidified with 2 N hydrochloric acid and stirred for 2 h at room temperature. The resulting solution was extracted with diethyl ether (2x20 ml), the organic layer was dried over anhydrous sodium sulfate and evaporated (15 Torr). The resulting residue was then dissolved in dichloromethane (15 ml) and cooled at -78°C under argon. To the resulting solution was added the corresponding silicon reagent (4 mmol) and boron trifluoride etherate (6 mmol) and the mixture was stired at the same temperature for 1 h allowing the temperature to rise to 20°C overnight. The resulting mixture was hydrolysed with a saturated aqueous solution of sodium hydrogen carbonate and extracted with dichloromethane (2x20 ml). The organic layer was dried over anhydrous sodium sulfate and evaporated (15 Torr). The obtained residue was purified by column chromatography (silica gel, hexane/ethyl acetate) to give the pure title compounds. Yields are included in Table 2. Physical, analytical and spectroscopic data follow.

5-Allyl-2,2-diethyltetrahydrofuran (**4ba**): R_f=0.78 (hexane/ethyl acetate: 19/1); ν_{max} (film) 3060, 1630 (HC=C), 1070 and 1050 cm^{-1} (C-O); δ_H 0.78, 0.79 (6 H, 2 t, *J*=7.5, 2xMe), 1.35-1.65, 1.80-1.95 [8 H, 2 m, $(CH_2)_2COCH_2CH_2$], 2.08-2.18, 2.25-2.35 (2 H, 2 m, CH_2C=C), 3.80-3.95 (1 H, m, CHO), 4.90-5.05 (2 H, m, H_2C=C) and 5.65-5.85 (1 H, m, HC=C); δ_C8.55, 8.6, 31.0, 31.3, 31.4, 34.0, 40.6, 78.0, 85.65, 116.55 and 135.2; *m/z* 140 (M$^+$-28, 4%), 139 (43), 127 (26), 109 (34), 83 (11), 67 (30), 57 (100), 55 (24), 43 (10) and 41 (30) (Found: M$^+$-C_2H_5, 139.112968. $C_9H_{15}O$ requires 139.112290).

2,2-Diisopropyltetrahydrofuran (**4ca**): R_f=0.51 (hexane/ethyl acetate: 19/1); ν_{max} (film) 1100 and 1060 cm^{-1} (C-O); δ_H 0.78, 0.81 (12 H, 2 d, *J*=6.8, 4xMe), 1.59-1.64, 1.72-1.92 [6 H, 2 m, $(CH)_2COCH_2CH_2$] and 3.76 (2 H, t, *J*=6.8, CH_2O); δ_C 17.2 (2 C), 17.95 (2 C), 27.15, 27.95, 34.05 (2 C), 69.65 and 89.7; *m/z* 156 (M+, <1%), 98 (16), 83 (21), 71 (14), 70 (64), 69 (34), 67 (16), 59 (60), 58 (15), 57 (11), 56 (34), 55 (87), 53 (16), 43 (100), 42 (20) and 41 (30) (Found: M$^+$-CH_3, 141.128765. $C_9H_{17}O$ requires 141.127940).

5-Cyano-2,2-diisopropyltetrahydrofuran (**4cb**): R_f=0.40 (hexane/ethyl acetate: 19/1); ν_{max} (film) 2220 ($C\equiv N$), 1070 and 1040 cm^{-1} (C-O); δ_H 0.78, 0.81, 0.87, 0.89 (12 H, 4 d, *J*=6.8, 4xMe), 1.75-2.00, 2.10-2.35 [6 H, 2 m, $(CH)_2COCH_2CH_2$] and 4.57 (1 H, t, *J*=7.5, CHO); δ_C 17.1, 17.2, 17.8, 17.9, 27.6, 32.65, 33.2, 33.95, 67.15, 94.2 and 119.2; *M/z* 152 (M$^+$-29, <1%), 138 (100), 111 (16), 71 (14) and 43 (58) (Found: M$^+$-C_3H_7, 138.092346. $C_8H_{12}NO$ requires 138.091889).

5-Allyl-2,2-diisopropyltetrahydrofuran (**4cd**): R_f=0.88 (hexane/ethyl acetate: 19/1); ν_{max} (film) 3060, 1630 (HC=C), 1100 and 1050 cm^{-1} (C-O); δ_H 0.81, 0.83, 0.85, 0.88 (12 H, 4 d, *J*=6.9, 4xMe), 1.20-2.00 [6 H, m, $(CH)_2COCH_2CH_2$], 2.00-2.20, 2.37-2.50 (2 H, 2 m, CH_2C=C), 3.84-3.95 (1 H, m, CHO), 4.90-5.10 (2 H, m, H_2C=C) and 5.70-5.90 (1 H, m, HC=C); δ_C 17.4, 17.5, 18.15, 18.2, 28.3, 32.8, 33.65, 34.55, 40.35, 79.8, 89.8, 116.25 and 135.3; *m/z* 155 (M$^+$-41, 4%), 153 (62), 81 (14), 71 (100), 69 (15), 67 (37), 55 (18), 43 (99) and 41 (69) (Found: M$^+$-C_3H_7, 153.128123. $C_{10}H_{17}O$ requires 153.127940).

2-Allyl-1-oxaspiro[4.5]decane (**4da**): R_f=0.40 (hexane/diethyl ether: 19/1); ν_{max} (film) 3060, 1630 (HC=C), 1060 and 1010 cm^{-1} (C-O); δ_H 1.25-1.80 (14 H, m, 7x ring CH_2), 2.15-2.25, 2.30-2.45 (2 H, 2 m, CH_2C=C), 3.90-4.05 (1 H, m, CHO), 4.95-5.10 (2 H, m, H_2C=C) and 5.75-5.90 (1 H, m, HC=C); δ_C 23.75, 24.05, 25.65, 30.65, 35.7, 37.5, 38.5, 40.8, 77.15, 82.55, 116.4 and 135.15; *m/z* 140 (M$^+$-28, 4%), 139 (43), 127 (26), 109 (34), 83 (11), 67 (30), 57 (100), 55 (24), 43 (10) and 41 (30) (Found: M$^+$-C_3H_5, 139.111954. $C_9H_{15}O$ requires 139.112290).

Preparation of Compounds **6a-e**. *General Procedure* .- The same procedure as for compounds **3** was employed but using 2-cyclopentenone ethylene ketal **5** as starting material (instead of **1**) and stoping the reaction after the acid hydrolysis carrying out then the subsequent work up. The obtained residue was finally purified by column chromatography (silica gel, hexane/ethyl acetate) to yield the pure title compounds. Yields are included in Table 3. Physical, analytical and spectroscopic data follow.

3-(1-Hydroxy-2,2-dimethylpropyl)cyclopentanone (**6a**)[17]: R_f=0.64[17] (hexane/ethyl acetate: 4/5), mp 55-60°C (hexane/diethyl ether); ν_{max} (melted) 3420 (OH), 1720 (C=O) and 1090 cm^{-1} (C-O); δ_H (*ca.* 1:1 diastereoisomers mixture) 0.86, 0.89 (9 H, s, 3xMe), 1.80-2.40 (8 H, m, 3x ring CH_2, C*H*CH_2 and OH), 3.19 and 3.27 (1 H, 2 d, *J*=4.7, 2.2, respectively, CHO); δ_C 24.95, 26.45 (3 C), 26.55 (3 C), 28.6, 35.6, 35.65, 37.95, 38.0, 38.45, 38.75, 39.65, 44.3, 80.55, 81.05, 219.55 and 220.25; *m/z* 170 (M$^+$, 1%), 115 (13), 114 (20), 113 (32), 96 (21), 88 (25), 86 (48), 84 (51), 83 (59), 81 (10), 71 (52), 70 (24), 69 (23), 67 (26), 58 (42), 57 (100), 56 (11), 55 (34), 43 (24) and 41 (49) (Found: C, 69.1; H, 10.4. $C_{10}H_{18}O_2.0.2H_2O$ requires C, 69.09; H, 10.67).

3-(1-Ethyl-1-hydroxypropyl)cyclopentanone (**6b**): R_f=0.64 (hexane/ ethyl acetate: 1/4); ν_{max} (film) 3420 (OH), 1730 (C=O) and 1150 cm^{-1} (C-O); δ_H 0.84, 0.87 (6 H, 2 t, *J*=7.5, 7.4, respectively, 2xMe) and 1.25-2.40 (12 H, 5xCH_2, CH and OH); δ_C 7.8, 7.85, 22.75, 28.25, 29.45, 38.8, 39.2, 43.55, 74.45 and 219.5; *m/z* 170 (M$^+$, 1%), 155 (25), 141 (21), 137 (18), 123 (10), 98 (14), 95 (34), 87 (79), 85 (17), 83 (28), 81 (18), 69 (32), 67 (14), 57 (100), 55 (49), 53 (12), 45 (44), 43 (41), 42 (10) and 41 (34) (Found: M$^+$, 170.130127. $C_{10}H_{18}O_2$ requires 170.130680).

3-(1-Hydroxy-1-isopropyl-2-methylpropyl)cyclopentanone (**6c**): R_f=0.84 (hexane/ethyl acetate: 1/4); ν_{max} (film) 3480 (OH), 1720 (C=O) and 1170 cm^{-1} (C-O); δ_H 0.93, 0.97, 0.99, 1.00 (12 H, 4 d, *J*=7.1, 4xMe), 1.75-2.40 (9 H, m, 3xCH_2 and 3xCH) and 2.60 (1 H, br s, OH); δ_C 18.35, 18.8, 18.95, 19.0, 24.2, 34.6 (2 C), 38.3, 40.75, 41.45, 76.75 and 219.6; *m/z* 157 (M$^+$-41, 1%), 155 (100), 137 (13), 115 (19), 109 (21), 95 (34), 83 (97), 71 (39), 67 (15), 55 (50), 43 (70) and 41 (38) (Found: M$^+$-C_3H_7, 155.107858. $C_9H_{15}O_2$ requires 155.107205).

3-(1-Hydroxycyclohexyl)cyclopentanone (**6d**): R_f=0.67 (hexane/ethyl acetate: 1/4); ν_{max} (film) 3420 (OH), 1720 (C=O) and 1170 cm^{-1} (C-O); δ_H 1.20-1.90 and 1.90-2.60 (18 H, 2 m, all H); δ_C 21.8 (2 C), 22.6, 25.55, 35.5, 36.6, 38.75, 39.05, 46.6, 71.0 and 219.65; *m/z* 182 (M$^+$, 5%), 99 (100), 84 (15), 83 (33), 81 (54), 79 (13), 55 (30), 43 (10) and 41 (14).

3-(1-Hydroxy-1-methylethyl)cyclopentanone (**6e**)[18]: R_f=0.60 (hexane/ethyl acetate: 1/4); ν_{max} (film) 3400 (OH), 1720 (C=O) and 1140 cm^{-1} (C-O); δ_H 1.16, 1.21 (6 H, 2 s, 2xMe) and 1.95-2.35 (8 H, m, 3xCH_2, CH and OH); δ_C 23.7, 27.65, 28.45, 39.0, 40.0, 47.7, 70.75 and 219.5; *m/z* 142 (M$^+$, 4%), 127 (21), 109 (11), 85 (14), 84 (57), 83 (50), 81 (17), 69 (22), 59 (100), 55 (24), 43 (37) and 41 (17) (Found: M$^+$, 142.099842. $C_8H_{14}O_2$ requires 142.099380).

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