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TRIMETHYLSILYL TRIFLATE CATALYZED ALDOL-TYPE REACTION OF ENOL SILYL ETHERS AND ACETALS OR RELATED COMPOUNDS

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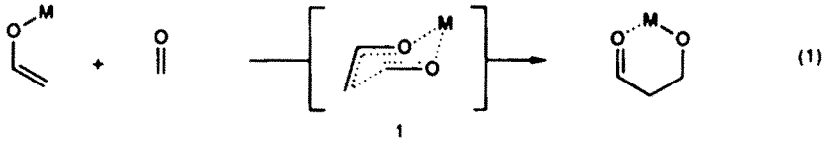
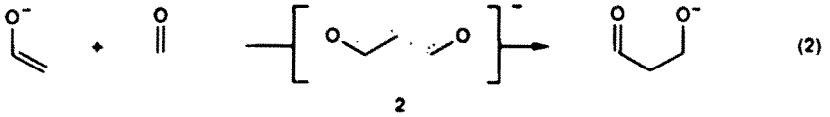
Abstract — Trimethylsilyl triflate with or without added hindered tertiary amines catalyzes directed condensation of enol trimethylsilyl ethers with acetals, orthoformate, or 2-acetoxytetrahydrofuran or -pyrans to give the corresponding β-alkoxy carbonyl compounds. Reaction of enol silyl ethers and carboxonium triflate ion-pair intermediates occurs via acyclic transition states and exhibits moderate to high erythro selectivity independent of the geometry (E/Z) of the enol silyl ethers.

Directed aldol reaction is one of the most fundamental carbon-carbon bond-forming reactions.[1] This reaction is capable of controlling stereochemistries of several contiguous asymmetric centers[2] and hence provides a powerful tool for syntheses of complex natural products.[3] Reactions of eq 1 (M = metallic species) are well precedented. In aprotic media, some preformed enolates having a Lewis acidic counter ion undergo nucleophilic reaction to carbonyl compounds via a six-membered pericyclic transition state 1 to give the β-oxido carbonyl products. Eq 2 is the combination of a "naked" enolate and unactivated carbonyl compound, while eq 3 represents reaction of a rather unreactive enolate toward a cationically activated carbonyl substrate (M = non-Lewis acidic atom, E^+ = cationic activating species). These condensations, unlike reactions of eq 1, are characterized by the absence of species that assemble the two oxygen atoms of the enolates and carbonyl compounds and, consequently, would



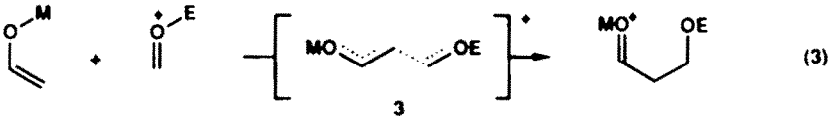
(1)

1



(2)

2



(3)

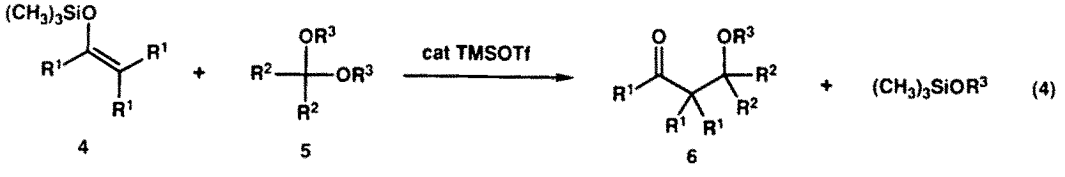
3

proceed via acyclic extended transition states, **2** and **3**, rather than cyclic structures. The anionic version, eq 2, has been exemplified by reaction of tris(dialkylamino)sulfonium (TAS)[4] or quaternary ammonium enolates.[5] Described herein is an example of the cationic alternant, eq 3.

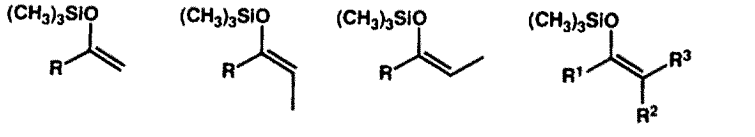
Trimethylsilyl triflate (TMSOTf), a super-reagent bearing a highly electron-withdrawing triflate moiety, can activate various oxygen-containing organic compounds through one-center (not multi-center) interaction at the electron-deficient silicon atom[6] and, in some cases, generates reactive ion-pair intermediates even in aprotic solvents. Indeed reaction of enol silyl ethers[7] and acetals or related compounds is catalyzed efficiently by TMSOTf, leading to the aldol-type products in a directed manner.[8] In addition, the stereochemical outcome is in contrast with those of ordinary aldol reactions of eq 1.

Aldol Reaction

As generalized by eq 4, reaction of enol trimethylsilyl ethers (**4**) and acetals (**5**), giving the aldol products (**6**), was accomplished by the use of TMSOTf as the catalyst (1—10 mol %). The condensation proceeded at temperatures as low as -100 to -78 °C in dichloromethane or 1,2-dichloroethane. The reaction in pentane, toluene, or ether was slow. The aldol products were stable under the reaction conditions and did not undergo β-elimination of alcohols, leading to α,β-unsaturated carbonyl compounds. Both open-chain and cyclic enol silyl ethers were usable. Besides acetals, certain orthoesters and acylals were employable as electrophiles. The results are summarized in Table I.



4 5 6



4a, R = C_6H_5
4b, R = t-C_4H_9

4c, R = C_6H_5
4d, R = H

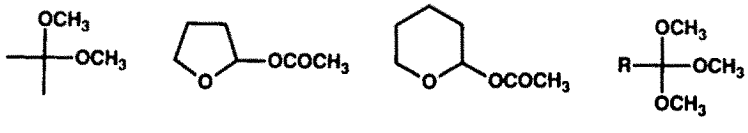
4e, R = C_6H_5
4f, R = t-C_4H_9
4g, R = t-C_4H_9S
4h, R = CH_3O

4i, R^1 = H; R^2 = R^3 = CH_3
4j, R^1 = R^2 = R^3 = CH_3

4k

4l, R^1 = R^2 = H
4m, R^1 = H; R^2 = CH_3
4n, R^1 = CH_3; R^2 = H

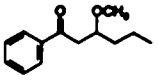
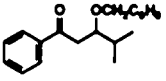
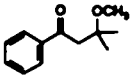
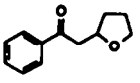
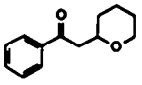
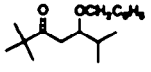
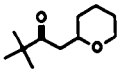
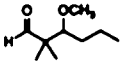
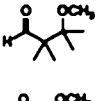
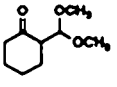
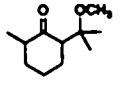
5a, R^1 = n-C_3H_7; R^2 = CH_3
5b, R^1 = i-C_3H_7; R^2 = CH_3
5c, R^1 = C_6H_5; R^2 = CH_3
5d, R^1 = i-C_3H_7; R^2 = $C_6H_5CH_2$
5e, R^1 = C_6H_5; R^2 = $C_6H_5CH_2$



5f **5g** **5h**

5i, R = H
5j, R = CH_3

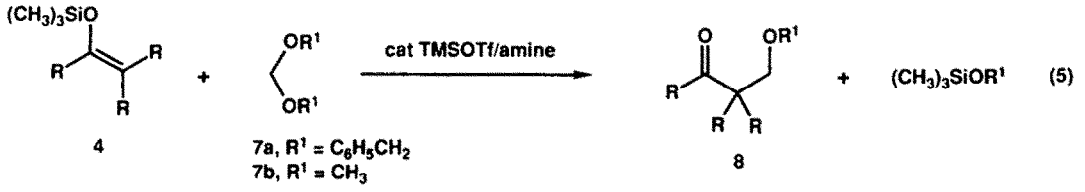
Table 1. The TMSOTf Catalyzed Reaction of Enol Silyl Ethers with Acetals[a]

enol silyl ether	acetal or related compound	product		
		structure	no.	% yield
4a	5a		6a	75
4a	5d		6b	73[b]
4a	5f		6c	96
4a	5g		6d	87
4a	5h		6e	81
4b	5d		6f	20[b,c]
4b	5h		6g	96
4l	5a		6h	75
4l	5f		6i	85
4j	5f		6j	87
4k	5f		6k	87
4l	5f		6l	87
4l	5l		6m	89
4m	5f		6n	93

[a] Reaction was carried out in the presence of 5 mol % TMSOTf in dichloromethane at -78 °C for 4—12 h. [b] Reaction using 10% TMSOTf. [c] Reaction for 19 h.

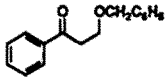
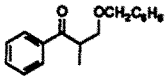
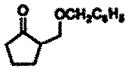
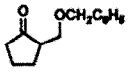
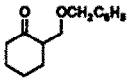
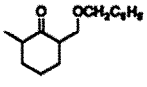
The ease with which the reaction occurs is sensitive to steric environment. For instance, reaction of the cyclic enol silyl ether **4l** or its 6-methyl derivative **4m** and acetone dimethyl acetal (**5f**) proceeded ordinarily but the 2-methylated analogue **4n** failed to give the condensation product; the latter was recovered without change in both independent and competitive experiments. Although trimethyl orthoformate (**5i**) reacted readily with **4l**, trimethyl orthoacetate (**5j**) did not afford the aldol product, partly because of decomposition of TMSOTf catalyst. When **4l**, **5j**, and TMSOTf were mixed in 1:1:1 ratio in dichloromethane at 25 °C, methyl acetate, methoxytrimethylsilane, and methyl triflate were formed in quantitative yields and **4l** was recovered without change.

Notably, formaldehyde acetals of type **7** were inert to the TMSOTf catalyzed reaction under the standard conditions. A simple solution of this problem, however, was obtained by addition of a sterically hindered tertiary amine to the reaction mixture. Thus reaction of eq 5 was effected in dichloromethane at room temperature by using an equimolar mixture (5—10 mol %) of TMSOTf and 2,6-



amine = 2,6-di-t-butylpyridine (**9a**) or dicyclohexylmethylamine (**9b**)

Table 2. The TMSOTf/Amine Catalyzed Reaction of Enol Silyl Ethers with Dialkoxymethanes[a]

enol silyl ether	dialkoxy-methane	added amine	product		
			structure	no.	% yield
4a	**7a**	**9a**		**8a**	92
4e	**7a**	**9a**		**8b**	77
4k	**7a**	**9a**		**8c**	76
4k	**7a**	**9b**		**8c**	65[b]
4l	**7a**	**9a**		**8d**	87
4l	**7b**	**9a**		**8e**	48
4m	**7a**	**9a**		**8f**	78

[a] Reaction was carried out with 5 mol % of the catalyst in dichloromethane at room temperature (12—22 °C) for 12—16 h. [b] Reaction was carried out with 1 mol % catalyst for 100 h.

di-t-butylpyridine (**9a**) or dicyclohexylmethylamine (**9b**) as a catalyst system. 2,6-Diphenylpyridine or diisopropylethylamine was less effective and unhindered pyridine or triethylamine was totally ineffective. The results are listed in Table 2. Benzyl group in the ketones (**8**, R = $C_6H_5CH_2$) was removed by hydrogenolysis over Pd/C catalyst. The hydroxymethyl and alkoxymethyl ketones are masked forms of synthetically useful α-methylene ketones. The TMSOTf/amine combined system also catalyzed the reaction of eq 4 proceeding at room temperature.

Reaction Mechanism

We consider that the aldol-type reaction is occurring by mechanism outlined by eq 6—9.[9] First, acetal oxygen gives an electron pair to the silicon atom in TMSOTf in a reversible fashion to form the complex **10** (eq 6).[10] This complex then undergoes fragmentation to generate the key carboxonium triflate ion pair, **11**, and alkoxytrimethylsilane (eq 7). The reactive carboxonium ion is trapped by the enol silyl ether **12** to give the adduct **13** (eq 8), which ultimately collapses into the β-alkoxy ketone **14** and TMSOTf catalyst (eq 9). Fragmentation of eq 7 is facilitated by electron-donating property of R^1 substituents and perhaps by relief of steric compression in **10**. Lack of reactivity of simple dialkoxymethanes of type **7** is thus easily understandable. When nucleophilic trapping of **11** (eq 8) is not rapid, **11** may collapse into the corresponding carbonyl compound and alkyl triflate (eq 10).

Operation of such mechanism was supported by ^1H and ^{13}C NMR study (Table 3). First, when benzaldehyde dimethyl acetal (**5c**) and TMSOTf were mixed in 1:1 ratio in dichloromethane-d_2 at 25 °C, production of benzaldehyde and methyl triflate (4% each) was detected. The remaining acetal **5c** (96%) exhibited broad signals at somewhat lower field, indicating the reversible nature of eq 6. In addition, an equimolar mixture of benzaldehyde and methyl triflate was found to generate a small amount (ca. 4%) of O-methylated benzaldehyde.[11] The signal assignment was confirmed by independent measurement of the spectra of these compounds and their mixtures under comparable conditions.

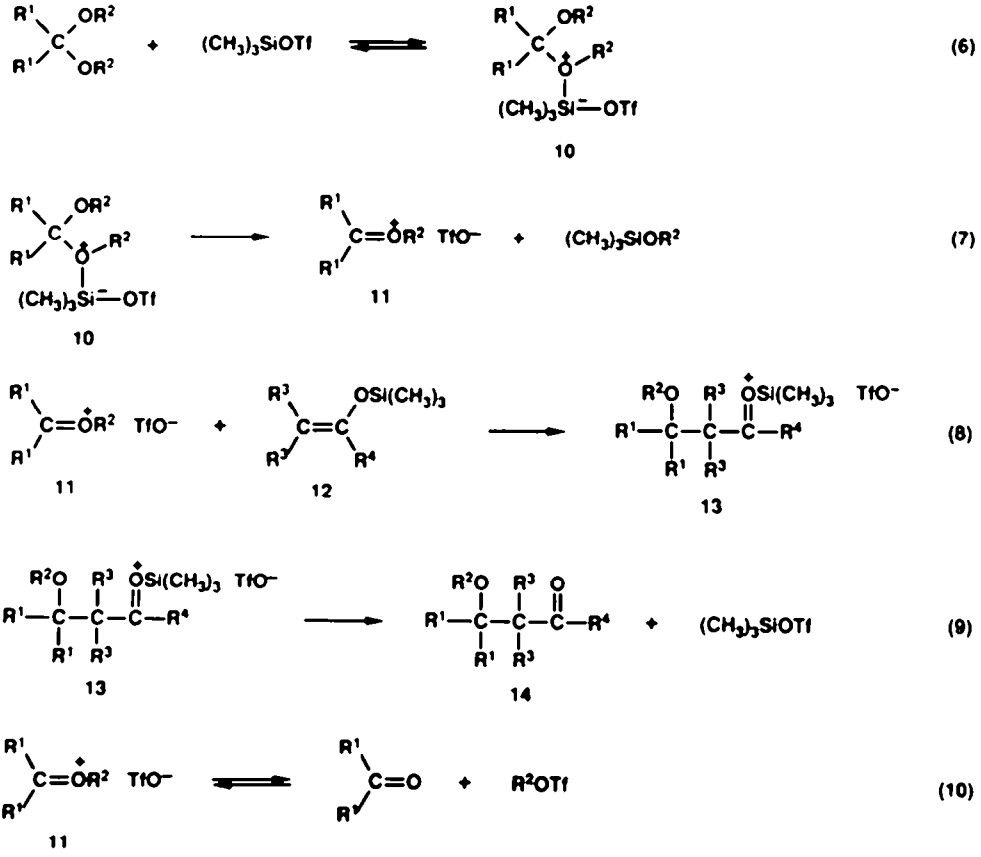


Table 3. ^1H and ^{13}C NMR Spectra[a]

compound or system	^{13}C signal	^{13}C δ/ppm (width)[b]	^1H signal	^1H distribution	^1H δ/ppm (width)[b]
$C_6H_5CH(OCH_3)_2$	$(CH_3O)_2\underline{C}H$	102.7 (6)	$(CH_3O)_2C\underline{H}$		5.31 (2)
	$\underline{C}H_3O$	51.9 (5)	$C\underline{H}_3O$		3.35 (1)
C_6H_5CHO	$\underline{C}HO$	191.5 (6)	$C\underline{H}O$		9.94 (2)
CH_3OTf	$\underline{C}H_3O$	61.4 (5)	$C\underline{H}_3O$		4.11 (2)
TMSOTf	$\underline{C}H_3Si$	0.3 (5)	$C\underline{H}_3Si$		0.47 (2)
$C_6H_5CH(OCH_3)_2$ and TMSOTf (1:1)	$C_6H_5\underline{C}HO$	191.7 (20)	$C_6H_5C\underline{H}O$	4%	9.93 (8)
	$C_6H_5\underline{C}H(OCH_3)_2$	105.8 (48)	$C_6H_5C\underline{H}(OCH_3)_2$	96%	5.43 (8)
	$\underline{C}H_3OTf$	61.4 (5)	$C\underline{H}_3OTf$	4%	4.11 (5)
	$C_6H_5CH(O\underline{C}H_3)_2$	52.1 (5)	$C_6H_5CH(OC\underline{H}_3)_2$	96%	3.28 (3)
	$(\underline{C}H_3)_3SiOTf$	-0.8 (5)	$(C\underline{H}_3)_3SiOTf$	96%	0.39 (10)
C_6H_5CHO and CH_3OTf (1:1)	$C_6H_5\underline{C}HO$	192.8 (20)	$C_6H_5C\underline{H}O$	96%	9.92 (5)
			$C_6H_5CH{=}\overset{+}{O}C\underline{H}_3$	4%	4.57 (4)
	$\underline{C}H_3OTf$	61.4 (4)	$C\underline{H}_3OTf$	4%	4.13 (4)
C_6H_5CHO and TMSOTf (1:1)	$C_6H_5\underline{C}HO$	192.6 (8)	$C_6H_5C\underline{H}O$	100%	9.90 (3)
	$(\underline{C}H_3)_3SiOTf$	0.0 (6)	$(C\underline{H}_3)_3SiOTf$	100%	0.38 (4)

[a] Measured on a JEOL GX-270 spectrometer in CD_2Cl_2 at 25 °C by using cyclohexane as an internal standard (C, δ = 26.4; H, δ = 1.36). [b] At half hight of the peak.

Addition of tertiary amines tends to decrease the reaction rate. Nevertheless, TMSOTf/hindered amine combined catalyst systems promote the reaction of otherwise unreactive dialkoxymethanes. Here the tertiary amines modify the reaction mechanism. As shown in eq 11, Si—OTf bond in the catalyst is cleaved by addition of a tertiary amine to form the silylated ammonium triflate, **15**,[12] acting as the actual silylating agent for the acetal substrate. Now the oxonium species **16** formed by eq 12, in comparison to **10**, has a much better leaving group and, even when R^1 is hydrogen, readily generates the carboxonium triflate **11** (eq 13) accomplishing the aldol reaction.

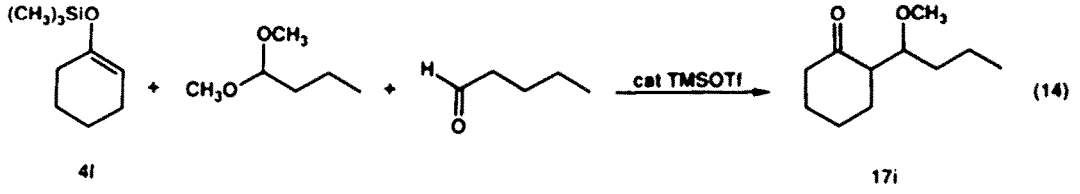
$$(CH_3)_3SiOTf + NR_3 \rightleftharpoons (CH_3)_3Si{-}\overset{+}{N}R_3\ TfO^- \quad (11)$$
15

$$(CH_3)_3Si{-}\overset{+}{N}R_3\ TfO^- \ (\mathbf{15}) + \underset{R^1}{\overset{R^1}{}}C(OR^2)_2 \longrightarrow \underset{R^1}{\overset{R^1}{}}C(OR^2)\overset{+}{O}(R^2)Si(CH_3)_3\ TfO^- + NR_3 \quad (12)$$
16

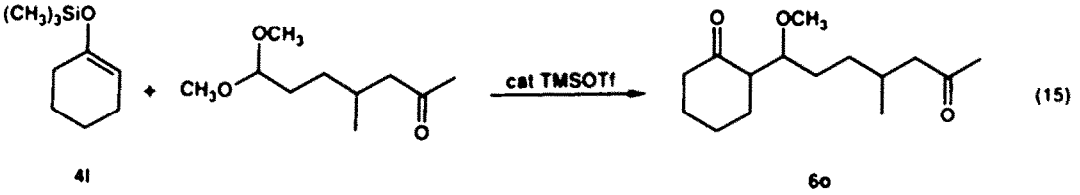
$$\underset{R^1}{\overset{R^1}{}}C(OR^2)\overset{+}{O}(R^2)Si(CH_3)_3\ TfO^- \ (\mathbf{16}) \longrightarrow \underset{R^1}{\overset{R^1}{}}C{=}\overset{+}{O}R^2\ TfO^- + (CH_3)_3SiOR^2 \quad (13)$$
11

Selectivities

Chemoselectivity. Ketones and alkanals did not react with enol silyl ethers in the presence of TMSOTf or a TMSOTf/9a mixture. Certain conjugated aldehydes such as benzaldehyde, (E)-2-hexenal, or cinnamaldehyde underwent TMSOTf-catalyzed condensation with 4l but only sluggishly.[9] For example, the reaction of benzaldehyde and 4l, leading to the aldol trimethylsilyl ether, appeared to be >100-fold slower than the reaction of the dimethyl acetal 5c and 4l.[13] As demonstrated by the intermolecular and intramolecular competition experiments of eq 14 and 15, the condensation is highly selective to acetals. Under such cationic conditions, acetal functionality is regarded as an activating group of carbonyl moiety rather than a protective group. Carbonyl compounds could have interaction with TMSOTf[6] to lead reversibly to pentacoordinate silicon species,[10] but such activation is not enough for ketones or alkanals to cause smooth reaction with weakly nucleophilic enol silyl ethers.[14] ^{13}C and ^{1}H NMR spectra of benzaldehyde, upon addition of an equimolar amount of TMSOTf, did not cause any significant change except some signal broadening (Table 3).



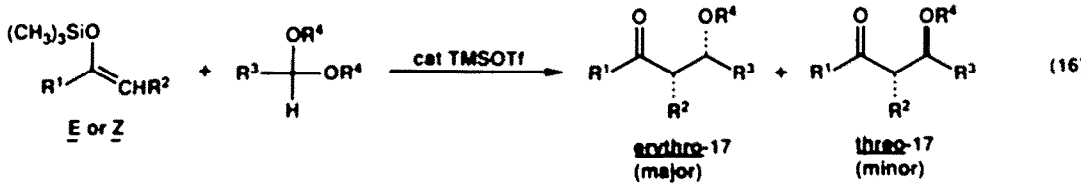
4l 17i (14)



4l 6o (15)

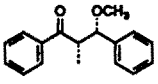
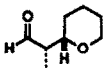
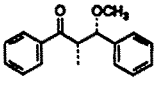
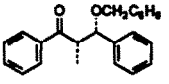
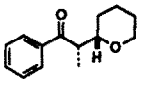
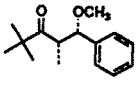
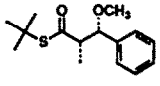
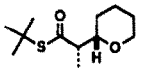
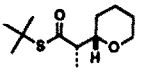
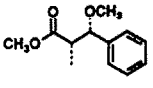
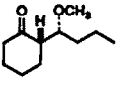
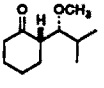
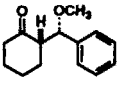
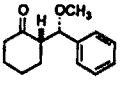
Regioselectivity. The absence of double-bond migration in enol silyl ethers allows for the regiospecific condensation at original sp^2-hybridized carbon. For example, a single product was obtained with 4m.

Stereoselectivities. Prochiral enol silyl ethers and carboxonium ions possess enantiofaces, and energy difference in their diastereomeric face-matching results in the formation of threo and erythro products (17) in unequal amounts (eq 16). As summarized in Table 4, the kinetic stereoselection of the present aldol reaction exhibited moderate to high erythro/threo ratios regardless of geometry (E or Z) of enol silyl ethers. The stereochemistries of the β-alkoxy carbonyl products were confirmed by O-alkylation of stereo-authentic aldol products. This general erythro-selection is in marked contrast to the ordinary aldol reaction of Lewis acidic metal coordinated enolates (eq 1) whose stereochemistry is defined by enolate geometry.[1,2] Addition of tertiary amines did not alter the steroselectivity, as consistent with the proposed mechanism.[15]



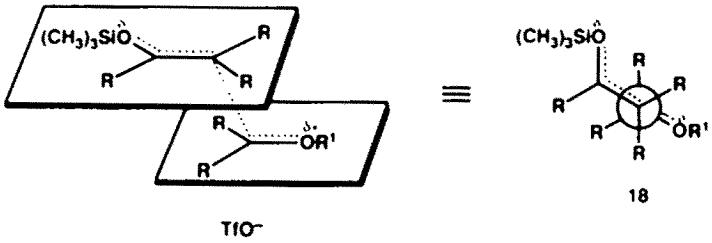
erythro-17 (major) + threo-17 (minor) (16)

Table 4. Erythro/Threo Selectivity in the TMSOTf Catalyzed Aldol Reaction[a]

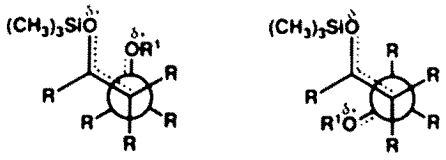
enol silyl ether	acetal or compound	product			
		major structure	no.	% yield	erythro:threo
4c	5c		17a	83	71:29
4d[b]	5h		17b	78	70:30
4e	5c		17a	97[c]	84:16[c]
4e	5e		17c	98[c]	76:24[c]
4e	5h		17d	91	62:38
4f	5c		17e	94	95:5
4g	5c		17f	92	78:22
4g	5h		17g	83	67:33
4g	5h		17g	79[d,e]	78:22[d]
4h	5c		17h	74	55:45
4l	5a		17i	91[c]	89:11[c]
4l	5b		17j	95[c]	86:14[c]
4l	5c		17k	89[c]	93:7[c]
4l	5c		17k	76[f]	75:25[f]

[a] Reaction was carried out with 5 mol % of TMSOTf in dichloromethane at -78 °C for 4–10 h. [b] A 65:35 mixture of the Z and E enol silyl ether. [c] Reaction using 1 mol % of TMSOTf. [d] Reaction in pentane. [e] Based on consumed starting material (49%). [f] A TMSOTf/2,6-di-t-butylpyridine mixture (5 mol %) as catalyst.

The unique stereoselection can be understood by assuming acyclic, extended transition structures.[9] In the reaction system there exists no ionic species capable of assembling enol silyl ethers and carboxonium ion simultaneously, removing the possibility of cyclic transition states. Among three possible structures, **18**–**20**, the anti conformer **18** would be the most favorable because the electrostatic repulsion of the positively charged oxygen atoms is minimized. Now as is seen in Scheme I, preference of

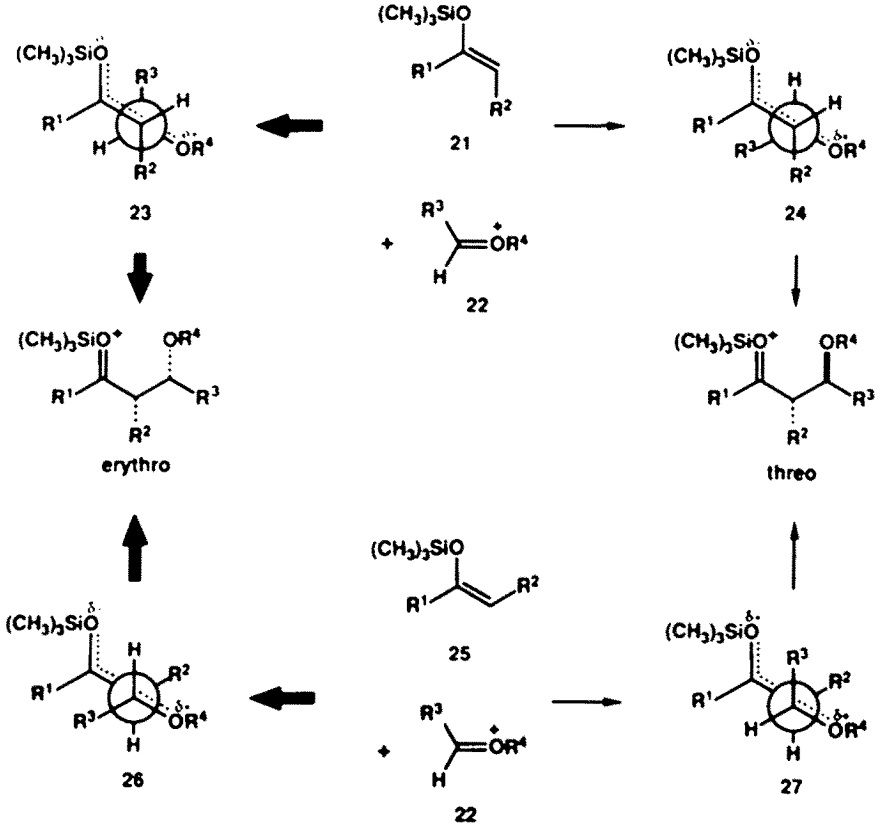


18



19 20

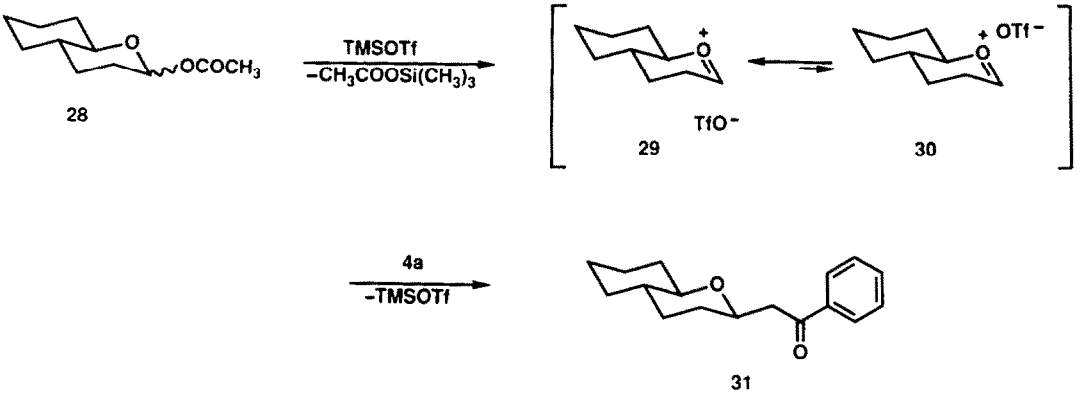
the erythro-generating transition structures is obvious. In the reaction of the E-enol silyl ether **21** and carboxonium ion **22**, the erythro transition state **23** arising from the re/si face matching is favored over the threo transition state **24** (re/re or antipodal si/si matching) which suffers significant nonbonded interaction between gauche R^2 and R^3 groups. With the Z-enol silyl ether **25**, for the same reason, the erythro transition state **26** is stabler than the threo form **27**.



Scheme I.

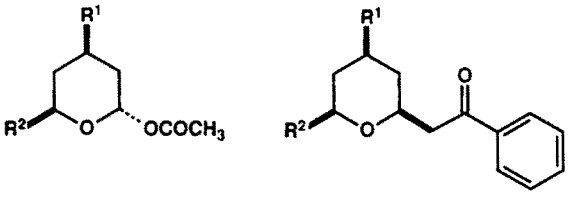
The erythro-selective aldol reaction is reminiscent of reaction of TAS enolates and aldehydes which is categorized into eq 2.[4] We have made a similar argument on the transition state structure, which coincides nicely with molecular orbital calculations on gas-phase reaction of an enolate and formaldehyde.[16] Closely related mechanisms have been adopted to explain the stereochemical outcome of some other cationic aldol condensations.[17]

Another characteristic steroselection was observed in reaction of certain chiral carboxonium intermediates possessing diastereofaces. Thus reaction of the bicyclic tetrahydropyranyl acetate **28** (equatorial/axial = 3:1)[18] and enol silyl ether **4a** catalyzed by TMSOTf produced the equatorial isomer **31** exclusively. This stereoselectivity is interpretable in terms of the preferred structure of the intermediary ion pair shown in Scheme II. When the possible diastereomeric ion pairs, **29** and **30**, are compared, the former having triflate in the α face is the more stablized by interaction between the C(2) vacant orbital and triflate anion through anomeric effect.[19] The α-ion pair **29** reacts with the enol silyl ether on the β-face via a half-boat transition state,[20] leading to the equatorial product **31**. Conformationally flexible acetate substrates, **32a** and **32b**, behaved similarly to afford the cis condensation products, **33a** and **33b**, respectively.[9]



28 29 30 31

Scheme II.



32a, $R^1 = CH_3$; $R^2 = H$
32b, $R^1 = H$; $R^2 = CH_3$

33a, $R^1 = CH_3$; $R^2 = H$
33b, $R^1 = H$; $R^2 = CH_3$

Conclusion

In the presence or absence of hindered tertiary amines, TMSOTf catalyzes aldol-type condensation of enol trimethylsilyl ethers and acetals (but not ketones and alkanals), orthoesters, acylals, etc. The reaction conditions are extremely mild (low temperatures, aprotic, nonbasic, and only very weak nucleophile present). The directed aldol reaction is irreversible and the β-alkoxy carbonyl compounds are kinetically determined. No β-elimination forming α,β-unsaturated carbonyl compounds takes place. The reaction proceeds by way of carboxonium triflate ion pairs generated from TMSOTf and acetals or related compounds. The electrophilic reaction toward enol silyl ethers occurs via acyclic, extended transition states and exhibits unique stereoselectivities, particularly, erythro selectivity independent of enol geometry.

Experimental

General.

Chemical shifts of ^1H NMR spectra were reported as δ values in parts per million relative to tetramethylsilane (δ = 0). As catalyst, trifluoromethanesulfonic acid-free TMSOTf was used. This was prepared by the standard procedure[21] and purified by distillation after stirring with ca. 3 vol% of triethylamine.[12c] Absence of triethylamine was confirmed by ^1H NMR. Enol silyl ethers (**4**) were synthesized by the standard procedures.[22b,23] Dimethyl and dibenzyl acetals (**5a**–**5e**) were prepared by acid catalyzed reaction of the corresponding aldehydes and ketones with alcohols. 2-Acetoxytetrahydrofuran (**5g**) and -pyran (**5h**) were obtained by acetylation (Ac_2O/pyridine) of the corresponding hemiacetals. 2-Acetoxytetrahydropyrans (**28**, **32a**, and **32b**) were synthesized by procedures described in references.[20a,24] Commercially available compounds were distilled before use.

General Procedures for Aldol-Type Condensation of Enol Silyl Ethers and Acetals.

Reaction of 1-Trimethylsiloxy-1-phenylethene (**4a**) with Butanal Dimethyl acetal (**5a**). To a solution of **4a** (0.20 g, 1.0 mmol) and **5a** (0.12 g, 1.1 mmol) in CH_2Cl_2 (3 ml) was added 0.1 M CH_2Cl_2 solution of TMSOTf (0.5 ml, 0.05 mmol) at -78 °C. After 10-h stirring, the mixture was poured into satd $NaHCO_3$ aqueous solution and extracted by CH_2Cl_2 (30 ml x 3). Combined extracts were passed through a short K_2CO_3 column and concentrated. Column chromatography on silica gel (30 g) eluting with a 10:1 mixture of petroleum ether and ether gave 3-methoxy-1-phenylhexan-1-one (**6a**, 0.15 g, 75%) as colorless oil.

Unless otherwise stated, results in Table 1 and Table 4 were obtained by similar reaction and workup procedures.

Reaction of 1-Trimethylsiloxycyclopentene (**4k**) with Dibenzyloxymethane (**7a**). To a mixture of **4k** (0.50 g, 3.2 mmol), **7a** (0.77 g, 3.1 mmol), and 2,6-di-*t*-butylpyridine (**9a**, 0.06 g, 0.3 mmol) in CH_2Cl_2 (6 ml) kept at 12 °C was added 0.1 M CH_2Cl_2 solution of TMSOTf (3 ml, 0.3 mmol). The mixture was stirred for 10 h and then worked up as described above. Chromatography on a silica-gel (30 g) column eluting with a 3:1 mixture of petroleum ether and ether gave 2-benzyloxymethylcyclopentanone (**8c**, 0.48 g, 76%) as colorless oil.

Results indicated in Table 2 were obtained by the similar procedures.

Confirmation of the Stereochemistries of β-Alkoxy Ketones.

Authentic β-alkoxy ketones were obtained by O-methylation or -benzylation of lithium alkoxides of the corresponding β-hydroxy ketones.[22] As shown in Table 5, although some kinetic discrimination was observed between the diastereomeric aldols, depending on the substrates, the good material balance and diastereomeric ratios indicate that no significant erythro/threo isomerization occurred during the reaction. A general procedure for the alkylation is illustrated by reaction as follows.

Methylation of erythro-2-Hydroxybenzylcyclohexanone (erythro-**34e**). Starting erythro-**34e** was obtained by reaction of the cyclohexanone lithium enolate with benzaldehyde followed by chromatographic separation.[22a] This aldol (96 mg, 0.47 mmol) was treated with 1.6 M hexane solution of *n*-butyllithium (0.28 ml, 0.45 mmol) in a 1:1 mixture of THF and ether (5 ml) at -78 °C for 10 min. To this was added methyl fluorosulfonate (0.52 ml, 0.50 mmol) and the mixture was stirred for an additional 1 h. The resulting mixture was diluted by addition of ether (30 ml) and washed with satd $NaHCO_3$ aqueous solution. After drying and concentrating the mixture in usual manner, the crude oil was subjected to column chromatography on silica gel (5 g). Eluting by a 10:1 mixture of petroleum ether and ethyl acetate afforded less polar erythro-2-methoxybenzylcyclohexanone (erythro-**17k**, 29 mg, 31%) as colorless oil, and subsequent elution by a 3:1 mixture of petroleum ether and ethyl acetate gave threo-**17k** (4 mg, 4%) together with erythro-**37e** (51 mg, 53% recovery).

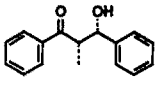
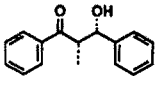
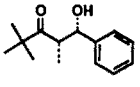
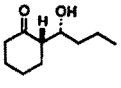
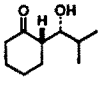
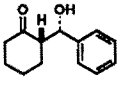
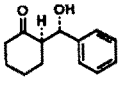
The stereochemistries of **17b**, **17d**, **17f**, **17g**, and **17h** were established by transformation from the known compouds as follows.

Methyl threo-3-Methoxy-2-methyl-3-phenylpropionate (threo-**17h**). threo-2-Methyl-1-phenyl-3-buten-1-ol which was obtained by $CrCl_2$ (2.44 g, 20 mmol) mediated condensation of benzaldehyde (0.53 g, 5 mmol) with 1-bromo-2-butene (1.40 g, 10 mmol)[25] was treated by NaH (8 mmol) in DMF (20 ml) followed by methyl iodide (1.5 ml) at 0 °C. Ozone was passed through an ethyl acetate solution of the above obtained methyl ether at -78 °C and then the mixture was treated with a mixture of 35% H_2O_2 (5 ml) and satd $NaHCO_3$ aqueous solution (10 ml) at 25 °C. After the mixture was acidified by addition of dil HCl, the organic layer was separated and evaporated. The residue was treated by ethereal solution of CH_2N_2 (30 ml), generated from N-methyl-N-nitrosourea (2g), and the crude product was subjected to column chromatography on silica gel (30 g) eluting with a 4:1 mixture of petroleum ether and ethyl acetate to give threo-**17h** (0.57 g, 55%).

Conversion of erythro-3-Methoxy-2-methyl-3-phenylpropionic Acid *t*-Butylthio Ester (erythro-**17f**) to erythro-**17h**. To a solution of the thio ester (**17f**, 47 mg) in CH_3OH (2 ml) was added $Hg(OCOCF_3)_2$ (0.2 g) at 0 °C. After 5-min stirring, the mixture was concentrated and the residue was subjected to preparative silica-gel TLC being developed with a 2:1 mixture of petroleum ether and ether. Methyl erythro-3-methoxy-2-methyl-3-phenylpropionate (erythro-**17h**, 15 mg, 40%) was obtained as colorless oil.

erythro-1-Phenyl-2-(tetrahydropyran-2-yl)propan-1-one (erythro-**17d**). To a THF (30 ml) solution of propiophenone lithium enolate prepared from propiophenone (2.71 g, 20 mmol) and LDA (21 mmol) was added 5-(tetrahydropyran-2-yloxy)pentanal (3.43 g, 20 mmol) at -78 °C. After 3 min, the mixture was worked up in usual manner. Silica-gel (100 g) column chromatography eluting with a 3:1 mixture of hexane and ethyl acetate gave an isomeric mixture of the corresponding β-hydroxy ketone (3.83 g,

Table 5. O-Alkylation of β-Hydroxy Ketones

β-hydroxy ketone **34**			β-alkoxy ketone **17**			recovered hydroxy ketone **34**	
structure	no.	ds purity[a]	no.	% yield	ds purity[a]	% yield	ds purity[a]
	**34a**	100	erythro-**17a**	24	81	67	80
	**34a**	100	erythro-**17c**	18	92	58	83
	**34b**	97	erythro-**17e**	27	93	37	81
	**34c**	98	erythro-**17i**	16	100	67	92
	**34d**	97	erythro-**17j**	17	100	55	95
	**34e**	100	erythro-**17k**	31	100	53	93
	**37f**	100	threo-**17k**	22	100	43	100

[a] Percent diastereomeric purity.

62%). This mixture was treated by pyridinium p-toluenesulfonate (50 mg) in boiling methanol (50 ml) followed by methanesulfonyl chloride (0.5 ml) in pyridine (15 ml) at 0 °C. After the usual workup, silica-gel (50 g) column chromatography eluting with a 20:1 mixture of chloroform and ethanol gave less polar methanesulfonyl diester (0.383 g) and more polar monoester (1.27 g). The latter was subjected to preparative silica-gel TLC and the plate was developed seven times by a 2.5:1 mixture of cyclohexane and THF to give the less polar erythro-methanesulfonate (96% isomeric purity) and the more polar threo isomer (89% purity) as colorless oil. ^{1}H NMR spectrum of the erythro isomer, upon irradiation of the neighboring methyl signal at δ 1.23, exhibited the C(2)-H signal at δ 3.45 as doublet with coupling constant of 3.7 Hz. The coupling constant of the threo-isomer was 6.7 Hz.

To a solution of the erythro-methanesulfonate (24 mg, 0.08 mmol) in THF (1 ml) was added 1 M THF solution of $LiAlH_4$ (0.04 ml) at -78 °C. After the usual workup, the organic residue was treated with 30% methanolic KOH in methanol (3 ml) followed by treatment with pyridinium chlorochromate (0.1 g) in CH_2Cl_2 (5 ml). TLC purification using a 2:1 mixture of petroleum ether and ether as solvent gave 95% stereoisomerically pure erythro-**17d** (14 mg, 89%) as colorless oil.

Conversion of 2-(Tetrahydropyran-2-yl)propanal (**17b**) to **17d**. A diastereomeric mixure of **17b** (7:3 ratio, 20 mg, 0.14 mmol) was mixed with 1 equiv of phenyllithium in ether (1 ml) at -78 °C and then with Jones reagent in acetone (2 ml) at 0 °C. A mixture of erythro- and threo-**17d** (75:25 ratio, 14 mg, 46%) was obtained by preparative TLC using a 2:1 petroleum ether/ether mixture as solvent.

Conversion of erythro-2-(Tetrahydropyran-2-yl)propanoic Acid t-Butylthio Ester (erythro-**17g**) to erythro-**17d**. A solution of the thio ester (**17g**) (27 mg, 0.12 mmol) in ether (1 ml) was treated with ethereal solution of phenyllithium (0.08 ml, 0.12 mmol) at -78 °C for 30 min. Workup by usual procedure followed by preparative TLC being developed with a 2:1 petroleum ether/ether mixture gave erythro-**17d** (6 mg, 22%) together with starting erythro-**17g** (11mg, 41% recovery). Neither threo-**17g** nor threo-**17d** was detected.

Chromatographic, Spectral, and Analytical Data of Products.

3-Methoxy-1-phenylhexan-1-one (**6a**). Liquid chromatography (LC): silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1680 cm^{-1}; ^{1}H NMR (CCl_4) 7.91 (m, 2H, aromatic), 7.40 (m, 3H, aromatic), 3.79 (m, 1H, CHO), 3.37 (s, 3H, CH_3O), 3.21 (dd, 1H, J = 16.6 and 6.4 Hz, CH_2CO), 2.75 (dd, 1H, J = 16.6 and 6.0 Hz, CH_2CO), 1.53 (m, 4H, CH_2), 0.92 (t, 3H, J = 6.3 Hz, CH_3); Ms m/z (rerative intensity) 71 (14), 77 (33), 105 (100), 173 (27), 184 (17), 191 (13), 206 (11). Found: C, 75.8;

H, 8.7%. Calcd for $C_{13}H_{18}O_2$: C, 75.7; H, 8.8%.

3-Benzyloxy-4-methyl-1-phenylpentan-1-one (6b). LC: silica gel, 7:1 petroleum ether/ether as eluant. IR (neat) 1683 cm^{-1}; ^1H NMR (CCl_4) 8.1–7.8 (m, 2H, aromatic), 7.5–7.3 (m, 3H, aromatic), 7.12 (brs, 5H, aromatic), 4.45 (s, 2H, CH_2Ph),4.2–3.9 (m, 1H, CHO), 3.5–2.7 (m, 2H, CH_2CO), 2.0 (m, 1H, CH), 1.00 (d, 6H, J = 6.4 Hz, CH_3). Found: C, 80.6; H, 7.9%. Calcd for $C_{19}H_{22}O_2$: C, 80.8; H, 7.9%.

3-Methoxy-3-methyl-1-phenylbutan-1-one (6c). LC: silica gel, 7:1 petroleum ether/ether as eluant. IR (neat) 1674 cm^{-1}; ^1H NMR (CCl_4) 7.92 (m, 2H, aromatic), 7.42 (m, 3H, aromatic), 3.15 (s, 3H, CH_3O), 3.02 (s, 2H, CH_2CO), 1.27 (s, 6H, CH_3). Found: C, 75.2; H, 8.5%. Calcd for $C_{12}H_{16}O_2$: C, 75.0; H, 8.4%.

1-Phenyl-2-(tetrahydrofuran-2-yl)ethan-1-one (6d). LC: silica gel, 7:1 petroleum ether/ether as eluant. IR (neat) 1680 cm^{-1}; ^1H NMR (CCl_4) 8.1–7.8 (m, 2H, aromatic), 7.6–7.2 (m, 3H, aromatic), 4.5–4.0 (m, 1H, CHO), 3.9–3.6 (m, 2H, CH_2O), 3.12 (dd, 1H, J = 15.6 and 5.4 Hz, CH_2CO), 2.85 (dd, 1H, J = 15.6 and 7.8 Hz, CH_2CO), 2.4–1.3 (m, 4H, CH_2). Found: C, 75.5; H, 7.4%. Calcd for $C_{12}H_{14}O_2$: C, 75.8; H, 7.4%.

1-Phenyl-2-(tetrahydropyran-2-yl)ethan-1-one (6e). LC: silica gel, 7:1 petroleum ether/ether as eluant. IR (neat) 1685 cm^{-1}; ^1H NMR (CCl_4) 8.1–7.8 (m, 2H, aromatic), 7.6–7.2 (m, 3H, aromatic), 4.1–3.4 (m, 3H, CHO and CH_2O), 3.25 (dd, 1H, J = 15.2 and 6.4 Hz, CH_2CO), 2.68 (dd, 1H, J = 15.2 and 7.6 Hz, CH_2CO), 2.0–1.2 (m, 6H, CH_2). Found: C, 76.2; H, 8.0%. Calcd for $C_{13}H_{16}O_2$: C, 76.4; H, 7.9%.

5-Benzyloxy-2,2,6-trimethylheptan-3-one (6f). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1708 cm^{-1}; ^1H NMR ($CDCl_3$) 7.18 (s, 5H, aromatic), 4.43 (s, 2H, CH_2Ph), 3.85 (ddd, 1H, J = 8.2, 6.1, and 4.3 Hz, CHO), 2.77 (dd, 1H, J = 16.0 and 8.2 Hz, CH_2CO), 2.25 (dd, 1H, J = 16.0 and 4.3 Hz, CH_2CO), 1.83 (m, 1H, CH), 1.08 (s, 9H, CH_3), 0.95 (d, 3H, J = 7.2 Hz, CH_3). Found: C, 77.9; H, 9.9%. Calcd for $C_{17}H_{26}O_2$: C, 77.8; H, 10.0%.

3,3-Dimethyl-1-(tetrahydropyran-2-yl)butan-2-one (6g). LC: silica gel, 4:1 petroleum ether/ether as eluant. IR (neat) 1705 cm^{-1}; ^1H NMR (CCl_4) 3.9–3.2 (m, 3H, CHO and CH_2O), 2.71 (dd, 1H, J = 16.3 and 7.0 Hz, CH_2CO), 2.21 (dd, 1H, J = 16.3 and 7.0 Hz, CH_2CO), 1.9–1.3 (m, 6H, CH_2), 1.03 (s, 9H, CH_3). Found: C, 71.8; H, 11.2%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%.

3-Methoxy-2,2-dimethylhexanal (6h). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 2700, 1722 cm^{-1}; ^1H NMR (CCl_4) 9.46 (s, 1H, HCO), 3.37 (s, 3H, CH_3O), 3.14 (t, 1H, J = 5.0 Hz, CHO), 1.8–0.8 (m, 7H, CH_2 and CH_3), 1.03 (s, 3H, CH_3), 0.98 (s, 3H, CH_3). Found: C, 68.5; H, 11.3%. Calcd for $C_9H_{18}O_2$: C, 68.3; H, 11.5%.

3-Methoxy-2,2,3-trimethylbutanal (6i). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 2700, 1715 cm^{-1}; ^1H NMR (CCl_4) 9.45 (s, 1H, HCO), 3.20 (s, 3H, CH_3O), 1.11 (s, 6H, CH_3), 1.01 (s, 6H, CH_3). Found: C, 65.8; H, 11.5%. Calcd for $C_8H_{16}O_2$: C, 66.0; H, 11.5%.

4-Methoxy-3,3,4-trimethylpentan-2-one (6j). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1698 cm^{-1}; ^1H NMR (CCl_4) 3.16 (s, 3H, CH_3O), 2.09 (s, 3H, $COCH_3$), 1.10 (s, 6H, CH_3), 1.07 (s, 6H, CH_3). Found: C, 68.4; H, 11.7%. Calcd for $C_9H_{18}O_2$: C, 68.3; H, 11.5%.

2-(2-Methoxypropan-2-yl)cyclopentanone (6k). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1739 cm^{-1}; ^1H NMR (CCl_4) 3.09 (s, 3H, CH_3O), 2.3–1.5 (m, 7H, CH and CH_2), 1.27 (s, 3H, CH_3), 1.12 (s, 3H, CH_3). Found: C, 69.2; H, 10.3%. Calcd for $C_9H_{16}O_2$: C, 69.2; H, 10.3%.

2-(2-Methoxypropan-2-yl)cyclohexanone (6l). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1708 cm^{-1}; ^1H NMR (CCl_4) 3.07 (s, 3H, CH_3O), 2.5–1.2 (m, 9H, CH and CH_2), 1.21 (s, 3H, CH_3), 1.14 (s, 3H, CH_3). Found: C, 70.3; H, 10.4%. Calcd for $C_{10}H_{18}O_2$: C, 70.5; H, 10.7%.

2-Dimethoxymethylcyclohexanone (6m). LC: silica gel, 7:1 petroleum ether/ether as eluant. IR (neat) 1711 cm^{-1}; ^1H NMR (CCl_4) 4.58 (d, 1H, J = 6.0 Hz, OCHO), 3.34 (s, 6H, CH_3O), 2.7–1.4 (m, 9H, CH and CH_2). Found: C, 63.0; H, 9.6%. Calcd for $C_9H_{16}O_3$: C, 62.8; H, 9.4%.

2-(2-Methoxypropan-2-yl)-6-methylcyclohexanone (6n). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1703 cm^{-1}; ^1H NMR (CCl_4) 3.13 (s, 3H, CH_3O), 2.7–2.2 (m, 2H, CHCO), 2.1–1.2 (m, 6H, CH and CH_2), 1.22 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 1.01 (d, 3H, J = 6.8 Hz, CH_3). Found: C, 71.6; H, 11.0%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%.

2-(1-Methoxy-4-methyl-6-oxoheptyl)cyclohexanone (6o). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1708 cm^{-1}; ^1H NMR (CCl_4) 3.55 (m, 1H, CHO), 3.27 (s, 2.4H, CH_3O), 3.21 (s, 0.6H, CH_3O), 2.5–1.2 (m, 14H, CH and CH_2), 2.04 (s, 3H, CH_3CO), 0.89 (d, 3H, J = 6.2 Hz, CH_3). Found: C, 70.5; H, 10.3%. Calcd for $C_{15}H_{26}O_3$: C, 70.8; H, 10.3%.

3-Benzyloxy-1-phenylpropan-1-one (8a). LC: silica gel, 5:1 petroleum ether/ether as eluant. IR (neat) 1683 cm^{-1}; ^1H NMR (CCl_4) 8.0–7.8 (m, 2H, aromatic), 7.6–7.0 (m, 3H, aromatic), 7.23 (s, 5H, aromatic), 4.48 (s, 2H, CH_2Ph), 3.82 (t, 2H, J = 6.9 Hz, CH_2O), 3.15 (t, 2H, J = 6.9 Hz, CH_2CO); Ms m/z (rerative intensity) 77 (50), 91 (50), 105 (100), 134 (70), 135 (100), 240 (2). Found: C, 80.0; H, 6.6%. Calcd for $C_{16}H_{16}O_2$: C, 80.0; H, 6.7%.

3-Benzyloxy-2-methyl-1-phenylpropan-1-one (8b). LC: silica gel, 10:1 petroleum ether/ether as

eluant. IR (neat) 1680 cm^{-1}; ^1H NMR (CCl_4) 8.0—7.7 (m, 2H, aromatic), 7.5—7.1 (m, 3H, aromatic), 7.18 (s, 5H, aromatic), 4.43 (s, 2H, CH_2Ph), 3.8—3.4 (m, 3H, CHO and CH_2O), 1.20 (d, 3H, J = 6.0 Hz, CH_3); Ms m/z (rerative intensity) 71 (35), 91 (65), 105 (100), 134 (20), 149 (80), 254 (2). Found: C, 80.5; H, 7.1%. Calcd for $C_{17}H_{18}O_2$: C, 80.3; H, 7.1%.

2-Benzyloxymethylcyclopentanone (**8c**). LC: silica gel, 3:1 petroleum ether/ether as eluant. IR (neat) 1738 cm^{-1}; ^1H NMR (CCl_4) 7.23 (s, 5H, aromatic), 4.43 (s, 2H, CH_2Ph), 3.58 (d, 2H, J = 3.5 Hz, CH_2O), 2.5—1.6 (m, 7H, CH and CH_2); Ms m/z (relative intensity) 91 (100), 97 (100), 107 (35), 204 (15). Found: C, 76.2; H, 7.8%. Calcd for $C_{13}H_{16}O_2$: C, 76.4; H, 7.9%.

2-Benzyloxymethylcyclohexanone (**8d**). LC: silica gel, 5:1 petroleum ether/ether as eluant. IR (neat) 1712 cm^{-1}; ^1H NMR (CCl_4) 7.23 (s, 5H, aromatic), 4.45 (s, 2H, CH_2Ph), 3.72 (dd, 1H, J = 9.0 and 4.8 Hz, CH_2O), 3.30 (dd, 1H, J = 9.0 and 7.5 Hz, CH_2O), 2.7—1.2 (m, 9H, CH and CH_2); Ms m/z (relative intensity) 91 (100), 218 (20). Found: C, 76.9; H, 8.5%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

2-Methoxymethylcyclohexanone (**8e**). LC: silica gel, 3:1 petroleum ether/ether as eluant. IR (neat) 1715 cm^{-1}; ^1H NMR (CCl_4) 3.62 (dd, 1H, J = 9.8 and 4.5 Hz, CH_2O), 3.27 (s, 3H, CH_3), 3.22 (dd, 1H, J = 9.8 and 8.0 Hz, CH_2O), 2.7—1.2 (m, 9H, CH and CH_2). Found: C, 67.4; H, 10.2%. Calcd for $C_8H_{14}O_2$: C, 67.6; H, 9.9%.

2-Benzyloxymethyl-6-methylcIohexanone (**8f**). LC: silica gel, 7:1 petroleum ether/ether as eluant. Less polar isomer (25% yield). TLC R_f 0.36 (5:1 petroleum ether/ether); IR (neat) 1708 cm^{-1}; ^1H NMR (CCl_4) 7.22 (s, 5H, aromatic), 4.45 (s, 2H, CH_2Ph), 4.0—3.1 (m, 2H, CH_2O), 2.7—1.3 (m, 8H, CH and CH_2), 0.95 (d, 3H, J = 6.3 Hz, CH_3). Found: C, 77.4; H, 8.5%. Calcd for $C_{15}H_{20}O_2$: C, 77.6; H, 8.7%. More polar isomer (49% yield). TLC R_f 0.31 (5:1 petroleum ether/ether); IR (neat) 1712 cm^{-1}; ^1H NMR (CCl_4) 7.22 (s, 5H, aromatic), 4.45 (s, 2H, CH_2Ph), 3.8—3.3 (m, 2H, CH_2O), 2.8—1.6 (m, 8H, CH and CH_2), 1.05 (d, 3H, J = 7.0 Hz, CH_3). Found: C, 77.5; H, 8.7%. Calcd for $C_{15}H_{20}O_2$: C, 77.6; H, 8.7%.

erythro-3-Methoxy-2-methyl-1,3-diphenylpropan-1-one (erythro-**17a**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.41 (5:1 petroleum ether/ether); IR (neat) 1675 cm^{-1}; ^1H NMR (CCl_4) 8.1—7.0 (m, 10H, aromatic), 4.36 (d, 1H, J = 8.2 Hz, CHO), 3.74 (dq, 1H, J = 8.2 and 7.8 Hz, CHCO), 3.18 (s, 3H, CH_3O), 1.31 (d, 3H, J = 7.8 Hz, CH_3). Found: C, 80.3; H, 7.2%. Calcd for $C_{17}H_{18}O_2$: C, 80.3; H, 7.1%.

threo-3-Methoxy-2-methyl-1,3-diphenylpropan-1-one (threo-**17a**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.37 (5:1 petroleum ether/ether); IR (neat) 1677 cm^{-1}; ^1H NMR (CCl_4) 8.1—7.0 (m, 10H, aromatic), 4.36 (d, 1H, J = 8.2 Hz, CHO), 3.9—3.6 (m, 1H, CHCO), 3.07 (s, 3H, CH_3O), 0.78 (d, 3H, J = 7.4 Hz, CH_3). Found: C, 80.5; H, 7.2%. Calcd for $C_{17}H_{18}O_2$: C, 80.3; H, 7.1%.

A Mixture of erythro- and threo-2-(Tetrahydropyran-2-yl)propanal (**17b**). LC: silica gel, 4:1 petro-leum ether/ether as eluant. IR (neat) 2730, 1725 cm^{-1}; ^1H NMR (CCl_4) 9.67 (m, 1H, HCO), 4.2—3.3 (m, 3H, CHO and CH_2O), 2.6—2.1 (m, 1H, CHCO), 2.0—1.3 (m, 6H, CH and CH_2), 1.08 (d, 2.1H, J = 7.0 Hz, CH_3), 1.04 (d, 0.9H, J = 7.4 Hz, CH_3). Found: C, 67.6; H, 10.0%. Calcd for $C_8H_{14}O_2$: C, 67.6; H, 9.9%.

A Mixture of erythro- and threo-3-Benzyloxy-2-methyl-1,3-diphenylpropan-1-one (**17c**). LC: silica gel, 10:1 petroleum ether/ether as eluant. IR (neat) 1680 cm^{-1}; ^1H NMR (CCl_4) 8.1—7.0 (m, 15H, aromatic), 4.7—3.7 (m, 4H, CH_2Ph, CHO, and CHCO), 1.37 (d, 2.6H, J = 7.5 Hz, CH_3), 0.84 (d, 0.4H, J = 7.4 Hz, CH_3). Found: C, 84.0; H, 6.7%. Calcd for $C_{23}H_{22}O_2$: C, 83.6; H, 6.8%.

erythro-2-(Tetrahydropyran-2-yl)-1-phenylpropan-1-one (erythro-**17d**). LC: silica gel, 5:1 petroleum ether/ether as eluant. TLC R_f 0.33 (10:1 petroleum ether/ethyl acetate); IR (neat) 1676 cm^{-1}; ^1H NMR (CCl_4) 8.0—7.8 (m, 2H, aromatic), 7.5—7.3 (m, 3H, aromatic), 3.94 (dm, 1H, J = 11.0 Hz, CHO), 3.6—3.2 (m, 3H, CHCO and CH_2O), 1.9—1.3 (m, 6H, CH_2), 1.20 (d, 3H, J = 6.6 Hz, CH_3). Found: C, 77.0; H, 8.3%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

threo-2-(Tetrahydropyran-2-yl)-1-phenylpropan-1-one (threo-**17d**). LC: silica gel, 5:1 petroleum ether/ether as eluant. TLC R_f 0.31 (10:1 petroleum ether/ethyl acetate); IR (neat) 1680 cm^{-1}; ^1H NMR (CCl_4) 8.0—7.8 (m, 2H, aromatic), 7.5—7.3 (m, 3H, aromatic), 3.83 (dm, 1H, J = 12.0 Hz, CHO), 3.7—3.2 (m, 3H, CHCO and CH_2O), 2.0—1.3 (m, 6H, CH_2), 1.06 (d, 3H, J = 6.8 Hz, CH_3). Found: C, 76.8; H, 8.4%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

erythro-1-Methoxy-2,4,4-trimethyl-1-phenylpentan-3-one (erythro-**17e**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.47 (5:1 petroleum ether/ether); IR (neat) 1708 cm^{-1}; ^1H NMR (CCl_4) 7.23 (s, 5H, aromatic), 4.11 (d, 1H, J = 10.0 Hz, CHO), 3.10 (dq, 1H, J = 10.0 and 6.3 Hz, CHCO), 3.00 (s, 3H, CH_3O), 1.17 (s, 9H, CH_3), 0.66 (d, 3H, J = 6.3 Hz, CH_3). Found: C, 77.2; H, 9.5%. Calcd for $C_{15}H_{22}O_2$: C, 76.9; H, 9.5%.

threo-1-Methoxy-2,4,4-trimethyl-1-phenylpentan-3-one (threo-**17e**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.41 (5:1 petroleum ether/ether); IR (neat) 1710 cm^{-1}; ^1H NMR (CCl_4) 7.18 (s, 5H, aromatic), 4.13 (d, 1H, J = 11.0 Hz, CHO), 3.2—3.0 (m, 1H, CHCO), 3.13 (s, 3H, CH_3O), 1.16 (d, 3H, J = 6.5 Hz, CH_3), 0.80 (s, 9H, CH_3). Found: C, 77.1; H, 9.4%. Calcd for $C_{15}H_{22}O_2$: C, 76.9; H, 9.5%.

erythro-3-Methoxy-2-methyl-3-phenylpropionic Acid t-Butylthio Ester (erythro-**17f**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.62 (5:1 petroleum ether/ether); IR (neat) 1680 cm^{-1};

^{1}H NMR (CCl_4) 7.25 (s, 5H, aromatic), 4.23 (d, 1H, J = 7.4 Hz, CHO), 3.18 (s, 3H, CH_3O), 2.70 (dq, 1H, J = 7.4 and 7.4 Hz, CHCO), 1.12 (s, 9H, CH_3), 1.08 (d, 3H, J = 7.4 Hz, CH_3). Found: C, 67.5; H, 8.5%. Calcd for $C_{15}H_{22}O_2S$: C, 67.6; H, 8.3%.

threo-3-Methoxy-2-methyl-3-phenylpropionic Acid t-Butylthio Ester (threo-**17f**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.60 (5:1 petroleum ether/ether); IR (neat) 1693 cm^{-1}; ^{1}H NMR (CCl_4) 7.23 (s, 5H, aromatic), 4.20 (d, 1H, J = 9.3 Hz, CHO), 3.0–2.4 (m, 1H, CHCO), 3.10 (s, 3H, CH_3O), 1.47 (s, 9H, CH_3), 0.78 (d, 3H, J = 6.2 Hz, CH_3). Found: C, 67.7; H, 8.4%. Calcd for $C_{15}H_{22}O_2S$: C, 67.6; H, 8.3%.

erythro-2-(Tetrahydropyran-2-yl)propionic Acid t-Butylthio Ester (erythro-**17g**). LC: silica gel, 15:1 petroleum ether/ether as eluant. TLC R_f 0.55 (10:1 petroleum ether/ether); IR (neat) 1680 cm^{-1}; ^{1}H NMR (CCl_4) 3.87 (dm, 1H, J = 12.0 Hz, CHO), 3.6–3.1 (m, 2H, CH_2O), 2.38 (dq, 1H, J = 9.0 and 6.8 Hz, CHCO), 2.0–1.3 (m, 6H, CH_2), 1.40 (s, 9H, CH_3), 1.10 (d, 3H, J = 6.8 Hz, CH_3). Found: C, 62.6; H, 9.6%. Calcd for $C_{12}H_{22}O_2S$: C, 62.6; H, 9.6%.

threo-2-(Tetrahydropyran-2-yl)propionic Acid t-Butylthio Ester (threo-**17g**). LC: silica gel, 15:1 petroleum ether/ether as eluant. TLC R_f 0.48 (10:1 petroleum ether/ether); IR (neat) 1680 cm^{-1}; ^{1}H NMR (CCl_4) 3.90 (dm, 1H, J = 12.4 Hz, CHO), 3.7–3.1 (m, 2H, CH_2O), 2.55 (dq, 1H, J = 7.0 and 7.0 Hz, CHCO), 2.0–1.3 (m, 6H, CH_2), 1.12 (s, 9H, CH_3), 1.03 (d, 3H, J = 7.0 Hz, CH_3). Found: C, 62.3; H, 9.9%. Calcd for $C_{12}H_{22}O_2S$: C, 62.6; H, 9.6%.

Methyl erythro-3-Methoxy-2-methyl-3-phenylpropionate (erythro-**17h**). LC: silica gel, 5:1 petroleum ether/ether as eluant. TLC R_f 0.61 (2:1 petroleum ether/ether); IR (neat) 1738 cm^{-1}; ^{1}H NMR (CCl_4) 7.20 (s, 5H, aromatic), 4.32 (d, 1H, J = 7.3 Hz, CHO), 3.43 (s, 3H, CH_3O), 3.18 (s, 3H, CH_3O), 2.62 (dq, 1H, J = 7.3 and 7.3 Hz, CHCO), 1.18 (d, 3H, J = 7.3 Hz, CH_3). Found: C, 69.5; H, 7.8%. Calcd for $C_{12}H_{16}O_3$: C, 69.2; H, 7.7%.

Methyl threo-3-Methoxy-2-methyl-3-phenylpropionate (threo-**17h**). LC: silica gel, 5:1 petroleum ether/ether as eluant. TLC R_f 0.52 (2:1 petroleum ether/ether); IR (neat) 1735 cm^{-1}; ^{1}H NMR (CCl_4) 7.23 (s, 5H, aromatic), 4.15 (d, 1H, J = 9.6 Hz, CHO), 3.66 (s, 3H, CH_3O), 3.11 (s, 3H, CH_3O), 2.9–2.3 (m, 1H, CHCO), 0.80 (d, 3H, J = 7.0 Hz, CH_3). Found: C, 68.9; H, 7.5%. Calcd for $C_{12}H_{16}O_3$: C, 69.2; H, 7.7%.

erythro-2-(1-Methoxybutyl)cyclohexanone (erythro-**17i**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.60 (7:1 petroleum ether/ethyl acetate); IR (neat) 1718 cm^{-1}; ^{1}H NMR (CCl_4) 3.62 (m, 1H, CHCO), 3.26 (s, 3H, CH_3O), 2.4–1.2 (m, 13H, CH and CH_2), 0.92 (t, 3H, J = 5.0 Hz, CH_3). Found: C, 71.7; H, 10.9%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%.

threo-2-(1-Methoxybutyl)cyclohexanone (threo-**17i**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.54 (7:1 petroleum ether/ethyl acetate); IR (neat) 1720 cm^{-1}; ^{1}H NMR (CCl_4) 3.52 (m, 1H, CHCO), 3.24 (s, 3H, CH_3O), 2.5–1.2 (m, 13H, CH and CH_2), 0.93 (t, 3H, J = 5.0 Hz, CH_3). Found: C, 71.5; H, 11.2%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%.

erythro-2-(1-Methoxy-2-methylpropyl)cyclohexanone (erythro-**17j**). LC: silica gel, 10:1 petrpleum ether/ether as eluant. TLC R_f 0.56 (10:1 petroleum ether/ethyl acetate); IR (neat) 1717 cm^{-1}; ^{1}H NMR (CCl_4) 3.5–3.3 (m, 1H, CHCO), 3.36 (s, 3H, CH_3O), 2.5–1.2 (m, 10H, CH and CH_2), 0.96 (d, 3H, J = 7.0 Hz, CH_3), 0.89 (d, 3H, J = 7.0 Hz, CH_3). Found: C, 71.6; H, 10.9%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%.

threo-2-(1-Methoxy-2-methylpropyl)cyclohexanone (threo-**17j**). LC: silica gel, 10:1 petrpleum ether/ether as eluant. TLC R_f 0.49 (10:1 petroleum ether/ethyl acetate); IR (neat) 1720 cm^{-1}; ^{1}H NMR (CCl_4) 3.4–3.2 (m, 1H, CHCO), 3.37 (s, 3H, CH_3O), 2.6–1.2 (m, 10H, CH and CH_2), 0.92 (d, 3H, J = 6.3 Hz, CH_3), 0.86 (d, 3H, J = 7.0 Hz, CH_3). Found: C, 71.5; H, 11.1%. Calcd for $C_{11}H_{20}O_2$: C, 71.7; H, 10.9%.

erythro-2-Methoxybenzylcyclohexanone (erythro-**17k**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.63 (10:1 benzene/ethyl acetate); IR (neat) 1707 cm^{-1}; ^{1}H NMR (CCl_4) 7.22 (s, 5H, aromatic), 4.27 (d, 1H, J = 3.9 Hz, CHO), 3.22 (s, 3H, CH_3O), 2.5–1.2 (m, 9H, CH and CH_2); Ms m/z (relative intensity) 77 (23), 91 (18), 121 (100), 186 (4), 203 (3), 218 (6). Found: C, 77.2; H, 8.2%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

threo-2-Methoxybenzylcyclohexanone (threo-**17k**). LC: silica gel, 10:1 petroleum ether/ether as eluant. TLC R_f 0.51 (10:1 benzene/ethyl acetate); IR (neat) 1712 cm^{-1}; ^{1}H NMR (CCl_4) 7.25 (s, 5H, aromatic), 4.51 (d, 1H, J = 7.0 Hz, CHO), 3.16 (s, 3H, CH_3O), 2.5–1.2 (m, 9H, CH and CH_2). Found: C, 76.9; H, 8.3%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

2-(Octahydrobenzopyran-2-yl)-1-phenylethan-1-one (**31**). LC: silica gel, 10:1 petroleum ether/ethyl acetate as eluant. IR (neat) 1682 cm^{-1}; ^{1}H NMR ($CDCl_3$) 7.96 (d, 2H, J = 8.8 Hz, aromatic), 7.56 (t, 1H, J = 8.8 Hz, aromatic), 7.48 (t, 2H, J = 8.8 Hz, aromatic), 4.26 (ddd, 1H, J = 7.6, 6.9, and 5.2 Hz, CHO), 3.43 (dd, 1H, J = 15.9 and 5.2 Hz, CH_2CO), 3.30 (dd, 1H, J = 15.9 and 7.6 Hz, CH_2CO), 3.23 (ddd, 1H, J = 10.4, 10.4, and 3.5 Hz, CHO), 2.1–1.0 (m, 13H, CH and CH_2). Found: C, 79.0; H, 8.6%. Calcd for $C_{17}H_{22}O_2$: C, 79.0; H, 8.6%.

cis-2-(4-Methyltetrahydropyran-2-yl)-1-phenylethan-1-one (**33a**). LC: silica gel, 3:1 petroleum ether/ether as eluant. IR (neat) 1690 cm^{-1}; ^{1}H NMR (CCl_4) 8.0–7.8 (m, 2H, aromatic), 7.5–7.2 (m, 3H, aromatic), 4.16 (m, 1H, CHO), 3.66 (m, 2H, CH_2O), 3.21 (dd, 1H, J = 14.0 and 6.0 Hz, CH_2CO), 2.75 (dd, 1H, J = 14.0 and 7.0 Hz, CH_2CO), 2.3–1.2 (m, 5H, CH and CH_2), 1.13 (d, 3H, J = 7.0 Hz, CH_3). Found: C, 76.9; H, 8.6%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

cis-2-(6-Methyltetrahydropyran-2-yl)-1-phenylethan-1-one (**33b**). LC: silica gel, 3:1 petroleum ether/ether as eluant. IR (neat) 1690 cm^{-1}; ^1H NMR (CCl_4) 8.0–7.8 (m, 2H, aromatic), 7.5–7.3 (m, 3H, aromatic), 4.33 (m, 1H, CHO), 3.92 (m, 1H, CHO), 3.22 (dd, 1H, J = 15.0 and 6.0 Hz, CH_2CO), 2.90 (dd, 1H, J = 15.0 and 7.6 Hz, CH_2CO), 1.9–1.2 (m, 6H, CH_2), 1.17 (d, 3H, J = 7.2 Hz, CH_3). Found: C, 76.8; H, 8.5%. Calcd for $C_{14}H_{18}O_2$: C, 77.0; H, 8.3%.

References and Notes

1. Review on directed aldol reactions: Mukaiyama, T. Org. React. **1982**, 28, 203.
2. Reviews on stereoselection in aldol reaction: (a) Heathcock, C. H. In Comprehensive Carbanion Chemistry; Durst, T.; E. Buncel, E., Eds.; Elsevier: Amsterdam, 1981; Vol. 2, Chapter 4; (b) Evans, D. A.; Nelson, J. V.; Taber, T. R. Top. Stereochem. **1982**, 13, 1; (c) Ito, Y.; Masamune, S.; Choy, W. J. Synth. Org. Chem. Jpn. **1983**, 41, 117; (d) Masamune, S. Heterocycles **1984**, 21, 107; (e) Heathcock, C. H. In Asymmetric Synthesis; Morrison, J. D., Ed.; Academic: Orlando, 1984; Vol. 3, pp 111-212; (f) Mukaiyama, T. Pure Appl. Chem. **1986**, 58, 505; (g) Braun, M. Angew. Chem., Int. Ed. Engl. **1987**, 26, 24.
3. Applications to synthesis of natural products: (a) Masamune, S.; Hirama, M.; Mori, S.; Ali, Sk. A.; Garvey, D. S. J. Am. Chem. Soc. **1981**, 103, 1568; (b) Masamune, S.; Lu, L. D.-L.; Jackson, W. P.; Kaiho, T.; Toyoda, T. J. Am. Chem. Soc. **1982**, 104, 5523; (c) Masamune, S.; Imperiali, B.; Garvey, D. S. J. Am. Chem. Soc. **1982**, 104, 5528; (d) Jackson, W. P.; Lu Chang, L. D.-L.; Imperiali, B.; Choy, W.; Tobita, H.; Masamune, S. In Strategies and Tactics in Organic Synthesis; Lindberg, T., Ed., Academic: Orlando, 1984; Chapter 5; (e) Heathcock, C. H.; Montgomery, S. H. Tetrahedron Lett. **1985**, 26, 1001; (f) Heathcock, C. H.; Young, S. D.; Hagen, J. P.; Pilli, R.; Badertscher, U. J. Org. Chem. **1985**, 50, 2095; (g) Evans, D. A.; Dow, R. L. Tetrahedron Lett. **1986**, 27, 1007; (h) Evans, D. A.; DiMare, M. J. Am. Chem. Soc. **1986**, 108, 2476.
4. (a) Noyori, R.; Nishida, I.; Sakata, J.; Nishizawa, M. J. Am. Chem. Soc. **1980**, 102, 1223; (b) Noyori, R.; Nishida, I.; Sakata, J. J. Am. Chem. Soc. **1981**, 103, 2106; (c) Noyori, R.; Nisida, I.; Sakata, J. J. Am. Chem. Soc. **1983**, 105, 1598; (d) Noyori, R. In Selectivity—a Goal for Synthetic Efficiency; Bartmann, W.; Trost, B. M., Eds., Verlag Chemie: Weinheim, 1983; pp 121-136.
5. (a) Kuwajima, I.; Nakamura, E. J. Am. Chem. Soc. **1975**, 97, 3257; (b) Kleshik, W. A.; Buse, C. T.; Heathcock, C. H. J. Am. Chem. Soc. **1977**, 99, 247; (c) Noyori, R.; Yokoyama, K.; Sakata, J.; Kuwajima, I.; Nakamura, E.; Shimizu, M. J. Am. Chem. Soc. **1977**, 99, 1265; (d) Kuwajima, I.; Nakamura, E.; Shimizu, M. J. Am. Chem. Soc. **1982**, 104, 1025; (d) Bellassoued, M.; Dubois, J.-E.; Bertounesque, E. Tetrahedron Lett. **1986**, 27, 2623.
6. (a) Noyori, R.; Murata, S.; Suzuki, M. Tetrahedron **1981**, 37, 3899; (b) Emde, H.; Domsch, D.; Feger, H.; Frick, U.; Gotz, A.; Hergott, H. H.; Hofmann, K.; Kober, W.; Krageloh, K.; Oesterle, T.; Steppan, W.; West, W.; Simchen, G. Synthesis **1982**, 1.
7. Reviews on synthetic utility of enol silyl ethers: (a) Rasmussen, J. K. Synthesis **1977**, 91; (b) Fleming, I. In Comprehensive Organic Chemistry; Jones, D. N., Ed., Pergamon: Oxford, 1979; Vol. 3, pp 584-592; (c) Fleming, I. Chimia **1980**, 34, 265; (d) Fleming, I. Chem. Soc. Rev. **1981**, 83; (e) Fleming, I. Bull. Soc. Chim. Fr. **1981**, II-7.
8. Preliminary reports: (a) Murata, S.; Suzuki, M.; Noyori, R. J. Am. Chem. Soc. **1980**, 102, 3248; (b) Murata, S.; Suzuki, M.; Noyori, R. Tetrahedron Lett. **1980**, 21, 2527; (c) Murata, S.; Noyori, R. Tetrahedron Lett. **1982**, 23, 2601.
9. The original postulate[6a,8] is modified as this.
10. For importance of pentacoordinate silicon species as reactive intermediates, see: (a) Damrauer, R.; DePuy, C. H.; Bierbaum, V. M. Organometallics **1982**, 1, 1553; (b) Bassindale, A. R.; Stout, T. J. Organomet. Chem. **1982**, 238, C41; (c) Sheldon, J. C.; Hayes, R. N.; Bowie, J. H. J. Am. Chem. Soc. **1984**, 106, 7711; (d) Corriu, R. J. P.; Gue'rin, C.; Moreau, J. J. E. Top. Stereochem. **1984**, 15, 43.
11. Perst, H. Oxonium Ions in Organic Chemistry; Verlag Chemie: Weinheim, 1971; pp 14-15.
12. (a) Chaudhary, S. K.; Hernandez, O. Tetrahedron Lett. **1979**, 99; (b) Hergott, H. H.; Simchen, G. Liebigs Ann. Chem. **1980**, 1718; (c) Murata, S.; Suzuki, M.; Noyori, R. Bull. Chem. Soc. Jpn. **1982**,

55, 247; (d) Bassindale, A. R.; Stout, T. J. Chem. Soc., Perkin Trans. 2 **1986**, 221; (e) Bassindale, A. R.; Lau, J. C.-Y.; Stout, T; and Taylor, P. G. J. Chem. Soc., Perkin Trans. 2 **1986**, 227.

13. Reaction of **4l** with benzaldehyde, (E)-2-hexenal, and cinnamaldehyde under the comparable conditions (5 mol % TMSOTf, dichloromethane, -78 °C, 6h) gave corresponding aldol silyl ethers in 11% (erythro:threo = 55:45), 13%, and 27% yields, respectively. In the presence of 5% TMSOTf/**9a**, reaction of **4l** with benzaldehyde in dichloromethane (20 °C, 18 h) gave trimethylsilyl ether of **34e** in 41% yield (erythro:threo = 42:58). Trifluoromethanesulfonic acid (TfOH) acts as an efficient catalyst for reaction of enol silyl ethers and aldehydes. For example, reactions of **4l** with 2-methylpropanal and benzaldehyde in the presence of 5 mol % of TfOH (CH_2Cl_2, -78 °C, 0.5 h) gave trimethylsilyl ethers of **34d** (82%, erythro:threo = 73:27) and **34e** (86%, erythro:threo = 69:31), respectively.
14. Reaction of carbonyl compounds with powerful nucleophiles proceeds through such hypervalent silicon intermediates. See: (a) Tsunoda, T.; Suzuki, M.; Noyori, R. Tetrahedron Lett. **1980**, 21, 1357; (b) Yoshimura, J.; Horito, S.; Hashimoto, H. Chem. Lett. **1981**, 375; (c) Suzuki, M.; Takada, H.; Noyori, R. J. Org.Chem **1982**, 47, 902.
15. Some decrease in selectivity in reaction of **4l** and **5c** by the use of TMSOTf/amine is perhaps due to higher temperature.
16. Houk, K. N.; Paddon-Row, M. N.; Rondan, N. G.; Wu, Y.-D.; Brown, F. K.; Spellmeyer, D. C.; Metz, J. T.; Li, Y.; and Loncharich, R. J. Science **1986**, 231, 1108.
17. (a) Mukaiyama, T.; Kobayashi, S.; Murakami, M. Chem. Lett. **1984**, 1759; (b) Mukaiyama, T.; Kobayashi, S.; Murakami, M. Chem. Lett. **1985**, 447; (c) Heathcock, C. H.; Hug, K. T.; Flippin, L. A. Tetrahedron Lett. **1984**, 25, 5973; (d) Heathcock, C. H.; Davidsen, S. K.; Hug, K. T.; Flippin, L. A.; J. Org. Chem. **1986**, 51, 3027.
18. In the absence of **4a**, the equatorial acetate underwent rapid stereomutation to give thermodynamically the more favorable axial isomer exclusively (10% TMSOTf, CD_2Cl_2, 25 °C).
19. (a) David, S.; Eisenstein, O.; Hehre, W. J.; Salem, L.; Hoffmann, R. J. Am. Chem. Soc. **1973**, 95, 3806; (b) Eisenstein, O.; Anh, N. T.; Jean, Y.; Devaquet, A.; Cantacuzène, J.; Salem, L. Tetrahedron **1974**, 30, 1717; (c) Rétey, J.; Robinson, J. A. Stereospecificity in Organic Chemistry and Enzymology; Verlag Chemie: Weinheim, 1982, pp 33-35.
20. (a) Chandrasekhar, S.; Kirby, A. J. J. Chem. Soc., Chem. Commum. **1978**, 171; (b) Kirby, A. J.; Martin, R. J. J. Chem. Soc., Chem. Commun. **1978**, 803; (c) Beaulieu, N.; Dickinson, R. A.; Delongchamps, P. Can. J. Chem. **1980**, 58, 2531; (d) Van Eikeren, P. J. Org. Chem. **1980**, 45, 4641; (e) Delongchamps, P. Stereoelectronic Effects in Organic Chemistry; Pergamon: Oxford, 1983; pp 34-39; (f) Chandrasekhar, S.; Kirby, A. J.; Martin, R. J. J. Chem. Soc., Perkin Trans 2 **1983**, 1619; (g) Kirby, A. J.; Martin, R. J. J. Chem. Soc., Perkin Trans 2 **1983**, 1627; (h) Kirby, A. J.; Martin, R. J. J. Chem. Soc., Perkin Trans 2 **1983**, 1633; (i) Hashimoto, S.; Hayashi, M.; Noyori, R. Tetrahedron Lett. **1984**, 25, 1379; (j) Noyori, R.; Hayashi, M.; Hashimoto, S. In Organosilicon and Bioorganosilicon Chemistry; Sakurai, H., Ed.; Ellis Horwood: Chichester, 1985; pp 213-218.
21. (a) Schmeisser, M.; Sartori, P.; Lippsmeier, B. Chem. Ber. **1970**, 103, 868; (b) Roesky, H. W.; Giere, H. H. Z. Naturforsch., B: Anorg. Chem., Org. Chem. **1970**, 25, 773; (c) Marsmann, H. C.; Horn, H.-G. Z. Naturforsch., B: Anorg. Chem., Org. Chem. **1972**, 27, 1448.
22. (a) House, H. O.; Crumrine, D. S.; Teranishi, A. Y.; Olmstead, H. D. J. Am. Chem. Soc. **1973**, 95, 3310; (b) Heathcock, C. H.; Buse, C. T.; Kleschick, W. A.; Pirrung, M. C.; Sohn, J. E.; Lampe, J. J. Org. Chem. **1980**, 45, 1066; (c) Structures of the aldol products were assumed by ^1H NMR analyses using $J_{threo} > J_{erythro}$ relationship.[2a]
23. House, H. O.; Czuba, L. J.; Gall, M.; Olmstead, H. D. J. Org. Chem. **1969**, 34, 2324.
24. (a) Anderson, C. B.; Sepp, D. T. Tetrahedron **1968**, 24, 1707; (b) Descotes, G.; Sinou, D.; Martin, J.-C. Bull. Soc. Chim. Fr. **1970**, 3730.
25. (a) Buse, C. T.; Heathcock, C. H. Tetrahedron Lett. **1978**, 1685; (b) Hiyama, T.; Kimura, K.; Nozaki, H. Tetrahedron Lett. **1981**, 22, 1037.