Asymmetric synthesis involving silicon

Thesis

ASYMMETRIC SYNTHESIS INVOLVING SILICON

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This thesis is dedicated to my parents

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SYNOPSIS

Several different types of optically active, synthetically useful, silylated diols (17 pairs) have been prepared by asymmetric dihydroxylation of the corresponding allyl and vinylsilanes using Sharpless catalysts. Chiral analysis of these silyl diols was carried out by ^{1}H NMR methods in the presence of $Eu(hfc)_3$. Enantiomeric purity of some of these silyl diols is greater than 90% e.e.

Synthetically more useful, optically active trimethylsilylepoxides, trimethylsilyl amino alcohols and aziridines have been isolated by a multi-stage chirality transfer from their precursor diol involving no racemization. The main routes for these chirality transfers were via silylated cyclic sulphite or sulphate intermediates and via silylated cyclic ortho esters and halohydrin derivatives. The reactions of these silylated species can be very regioselective, such as the ring opening of epoxysilanes by azide ion, leading exclusively to a single regioisomer. Similarly, the deoxygenation of vicinal silyl diols has been observed without loss of the silyl group.

Chiral analysis of trimethylsilyl amino alcohols and aziridines (with enantiomeric excesses of up to 95%) have been carried out by ^{13}C NMR methods in the presence of $Eu(hfc)_3$.

Asymmetric epoxidation of allyl and vinylsilanes without polar groups have been investigated using manganese (III) salen complexes as a catalyst. A number of axial ligands of the salen complexes has been studied and some of these axial ligands were very effective to influence the reactivity of the catalyst, *cis* / *trans* ratio of the silyl epoxides and enantioselectivity of the epoxidation. Several different types of allyl and vinylsilanes have been epoxidized enantiomerically using this catalytic method.

Enantiomeric excesses of epoxides were determined by Chiradex G-PN column. Some of these silyl epoxides had e.e. of greater than 95%.

Abbreviations

ADH	Asymmetric dihydroxylation
AD-mix-α	Mixture of dihydroquinine based osmium asymmetric dihydroxylation catalyst and cooxidants
AD-mix-β	Mixture of dihydroquinidine based osmium asymmetric dihydroxylation catalyst and cooxidants
AE	Asymmetric epoxidation
Ar	Aromatic
BINAP	2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl
BHPC	1-Benzyl-3-hydroxypyridinium chloride
BQC	*N*-Benzylquininium chloride
br	Broad
vbr	Very broad
^{13}C-^{1}H COSY 2D	Carbon 13 proton two dimensional correlated spectroscopy
CADH	Catalytic asymmetric dihydroxylation
Cat.	Catalyst
COD	1,5-Cyclooctadiene
CSAs	Chiral solvating agents
CLSRs	Chiral lanthanide shift reagents
CDAs	Chiral phosphorus derivatising agents
chxn	*trans*-1,2-Diaminocyclohexane
cis-TOE	*cis*-1-Trimethylsilyl-1-octene

cis-THE	*cis*-1-Trimethylsilyl-1-heptene
cis-5DCEN	*cis*-5-Decene
cis-T2NE	*cis*-1-Trimethylsilyl-2-nonene
Cy	Cyclohexyl
d	Doublet
dd	Doublet of doublets
dt	Doublet of triplets
DCM	Dichloromethane
DIBALH	Diisobutylaluminium hydride
DHQD	Dihydroquinidine
DHQ	Dihydroquinine
DHQD-CLB	Dihydroquinidine 4-Chlorobenzoate
DHQ-CLB	Dihydroquinine 4-Chlorobenzoate
$(DHQD)_2$-PHAL	Bisdihydroquinidine -9-*O*-phthalazine ether
$(DHQ)_2$-PHAL	Bisdihydroquinine -9-*O*-phthalazine ether
$(DHQD)_2$-PYR	2.5-Diphenyl-4,6-bis(9-*O*-dihydroquinidinyl)pyrimidine
$(DHQ)_2$-PYR	2.5-Diphenyl-4,6-bis(9-*O*-dihydroquinyl)pyrimidine
DET	Diethyl tartrate
DEPT	Distortionless enhancement polarisation transfer
DIOP	2,3-*O*-Isopropylidene-2,3-dihydroxy-1,4-bis(diphenyl-phosphino) butane
DMAP	4-*N*,*N*-dimethylamino-pyridine
DMF	Dimethyl formamide
δ_H	Proton chemical shift

δ_C	Carbon 13 chemical shift
e.e.	Enantiomeric excess
$Eu(hfc)_3$	Tris[3-(heptafluoropropylhydroxymethylene)-(+)-camphorato] europium (III)
eq.	Equivalent
Et	Ethyl
H^1-H^1 COSY 2D	Proton proton two dimensional correlated spectroscopy
HPLC	High performance liquid chromatography
g	Gram
glc	Gas liquid chromatography
FAB	Fast atom bombardment
FT-IR	Fourier transform infrared spectroscopy
IMD	Imidazole
J	Coupling constant in Hertz
M	Metal, or mass of molecule in mass spectrometry
Me	Methyl
MOP	Monodentate phosphine ligand
MTPA	α-Methoxy-α–(trifluoromethyl)phenyl acetic acid
m	Multiplet for NMR
m	Medium for FT-IR
ml	Milli (10^{-3}) litre
mmol	Milli mole
mol	Mole
ms	Middle to strong absorption in the infra red spectrum

m/z	Mass to charge
NMI	*N*-Methylimidazole
NMO	*N*-Methylmorpholine *N*-oxide
NMR	Nuclear magnetic resonance
NOE	Nuclear overhauser enhancement
PPTS	Pyridinium *p*-toluenesulphonate
Py	Pyridine
Pm	Pyridinium
Pybox-i-Pr	2,6-Bis-[4'-*(S)*-isopropyloxalin-2'-yl]pyridine
Pybox	2,6-Bis(oxazolinyl)pyridine
PPNO	4-Phenylpyridine *N*-oxide
PTC	Phase transfer catalyst
q	quartet
R	Alkyl or aryl residue
RT	Room temperature
salen	Complexes containing *N,N'*-ethylenebis(salicylidene aminato) ligands
s	Strong absorption in the infra red spectrum
vs	Very strong absorption in infra red spectrum
µl	Micro (10^{-6}) liter
υ_{max}	Wavenumber (cm^{-1})
tart	Tartrate
t, tert	Tertiary
t	Triplet

tt	Triplet of triplets
THF	Tetrahydrofuran
TMSCl	Chlorotrimethylsilane
TMS	Trimethylsilyl, or tetramethylsilane
TMEDA	*N,N,N',N'*-Tetramethylethylenediamine
TON	Turnover number of catalyst
trans-PTP	*trans*-1-Phenyl-3-trimethylsilylpropene
trans-TOE	*trans*-1-Trimethylsilyl-1-octene
w	Weak absorption in the infra red spectrum
vw	Very weak absorption in the infra red spectrum

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Introduction

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§ 1.1 Introduction to Asymmetric Synthesis

Asymmetric synthesis has evolved in just over twenty years from an academic curiosity into one of the most intensely studied synthetic methodologies. Leading research groups in both academic and industrial laboratories are now concentrating a large amount of effort in this area. An asymmetric synthesis may be defined as a synthesis in which an achiral unit in an ensemble of substrate molecules is converted into a chiral unit such that the possible stereoisomers are formed in unequal amounts. In the simplest case an achiral substrate is converted into an unequal mixture of the two enantiomers of a chiral product containing only one stereogenic unit. The ultimate goal is obviously to achieve the highest possible proportion of the desired enantiomer, that is to maximise the enantioselectivity. The most commonly used measure of the extent of enantioselectivity achieved is the

enantiomeric excess (e.e.). This is defined as the proportion of the major enantiomer (A) less that of the minor enantiomer (B) and is commonly expressed as a percentage:

$$\mathbf{e.e.\% = 100[(A-B)/(A+B)]}$$

Special mention should be made of the two extreme values of the e.e.. An e.e. of 100% corresponds to an enantiomerically pure compound, that is, no B is formed. A reaction which gives a product of 100% e.e. is called enantiospecific. Since this represents an ideal situation which is rarely attainable in practice, the term enantioselective should generally be used. An e.e. of 0% corresponds to a 1:1 mixture of enantiomers know as a racemic mixture or racemate.

§ 1.2 Methodologies of Asymmetric Synthesis

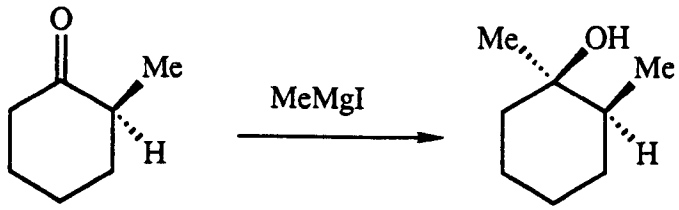
The ultimate source of chirality in all asymmetric syntheses is nature. The chiral compounds which occur in nature provide an enormous range and diversity of possible starting materials. To be useful in asymmetric synthesis, most importantly, they must be capable of exerting a high degree of stereocontrol in the required reactions by means of steric hindrance, chelation or other specific effects. Secondly, they should be cheap and readily available in high enantiomeric purity.

A unit within a molecule which gives rise to the existence of stereoisomers is called a stereogenic unit. The chirality of most chiral molecules is associated with the presence of one or more stereogenic units although it is important to note that the presence of a stereogenic unit is not in itself a sufficient condition for chirality. This main factor is that the molecule should not be superimposable on its mirror image.

As mentioned above, asymmetric synthesis involves the formation of a new stereogenic unit in the substrate, under the influence of another chiral group, ultimately derived from a naturally occurring compound. The known methods of asymmetric synthesis can be conveniently divided into four major classes, depending on how this influence is exerted.

1.2.1 Substrate-controlled Methods

This method is regarded as a first-generation method. An example is provided in scheme 1.1 which shows the addition of a methyl Grignard reagent to *(S)*-2-methylcyclohexanone (1) to give (2) in which addition to the carbonyl group is influenced by the adjacent stereogenic centre according to Cram's rule[1]



(1) (2)

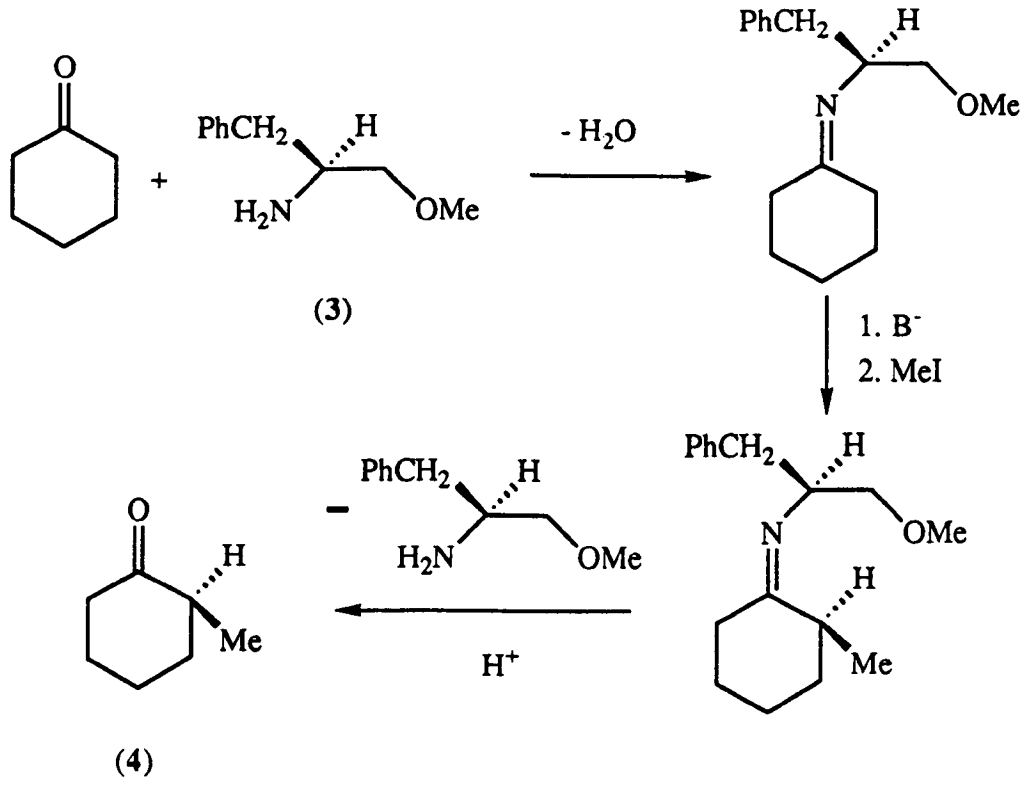
Scheme 1.1

Generally speaking, this reaction is controlled by a stereogenic unit already present in the chiral substrate. The formation of the new stereogenic unit most often occurs by reaction of an achiral reagent at a diastereotopic site controlled by a nearby stereogenic unit. A homochiral product cannot be formed from an achiral substrate by this method. If we represent that part of the substrate which reacts as S, the chiral directing group as G, the reagent as R, the product as P-G and the chirality by *, then:

$$S\text{-}G^{*} \xrightarrow{R} P^{*}\text{-}G^{*}$$

1.2.2 Auxiliary-controlled Methods

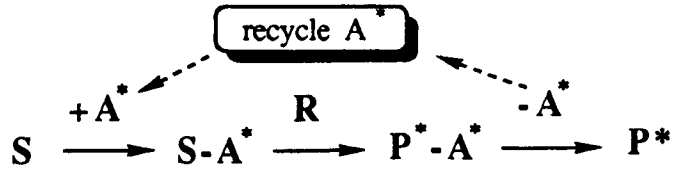
Most of the recent asymmetric synthetic methods introduced over the last 20 years are auxiliary-controlled methods (called second-generation methods). A specific example is that of the methylation of cyclohexanone[2], to give (4) in 77% e.e., via its imine formed with



Scheme 1.2

the methyl ether of *(S)*-phenylalaninol (3), as shown in Scheme 1.2.

This approach is similar to the first-generation method, in that control is again achieved intramolecularly by a chiral group in the substrate. The difference is that the directing group, the 'chiral auxiliary', is now deliberately attached to an achiral substrate in order to direct the reaction and can be removed once it has served its purpose. In this way a homochiral product can be obtained from an achiral substrate. Retaining the same symbols as earlier and representing the auxiliary by A, we have:

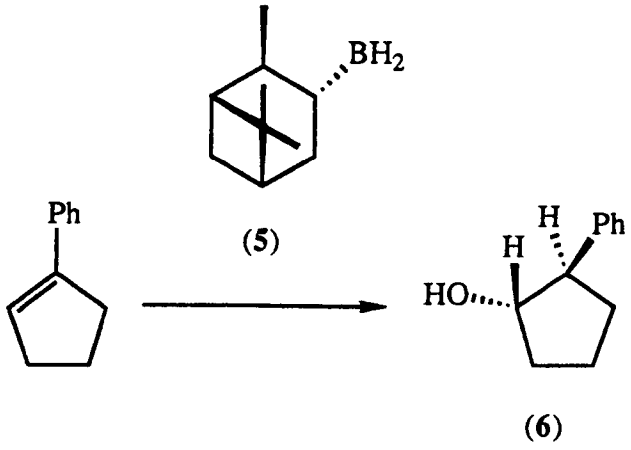


1.2.3 Reagent-controlled Methods

This method is also called the third-generation method. This is distinguished from the first- and second-generation methods by the fact that the asymmetry derives from a chiral reagent, rather than from the starting material or an auxiliary and the control is intermolecular.

$$S \xrightarrow{R^*} P^*$$

This is obviously an attractive procedure but the range of reactions for which effective chiral reagents exist is somewhat limited at present. An example is provided by the hydroboration of 1-phenylcyclopentene[3], using isopinocamphenyl-borane (5) derived from (+)-α-pinene, to give alcohol (6) with two adjacent stereogenic centres (100% e.e.).



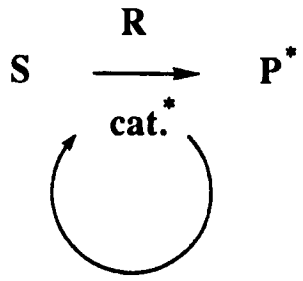
(6)

Scheme 1.3

1.2.4 Catalyst-controlled Methods

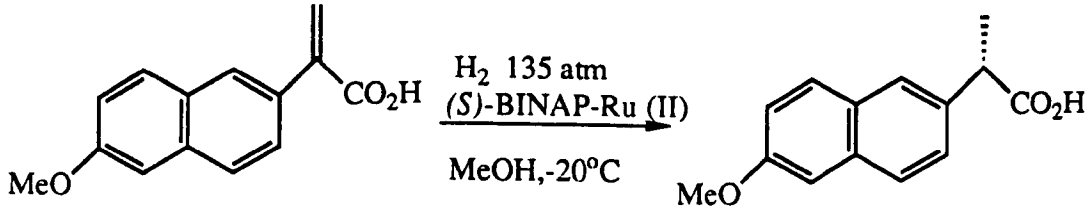
In contrast to the previously mentioned three classes, this approach (the fourth-generation method), does not require an enantiomerically pure compound in stoichiometric amounts. The amounts of catalyst required can be defined by the molar ratio of the substrate to the catalyst (**S/C ratio**). By definition the catalyst can be reused again and again in the same

reaction, so called **turnover**, and can be recovered at the end of the reaction. The turnover number (**TON**) can be defined as the number of product moles produced by one mole of catalyst during 18 hours. In fourth-generation methods, a chiral catalyst is used to direct the conversion of an achiral substrate directly into a chiral product with an achiral reagent. Again the control is intermolecular:



The advantages of fourth- over first- and second-generation methods are two-fold: the choice of starting material is far wider, since it need no longer come from a chiral pool. Secondly, there is no need to dedicate two extra steps to the installation and removal of a chiral auxiliary. The chiral catalysts may include naturally occurring optically active alkaloids and their quaternary amine salts, optically active amino alcohols, transition metal complexes with chiral ligands, enzymes and so on. Some examples are described below.

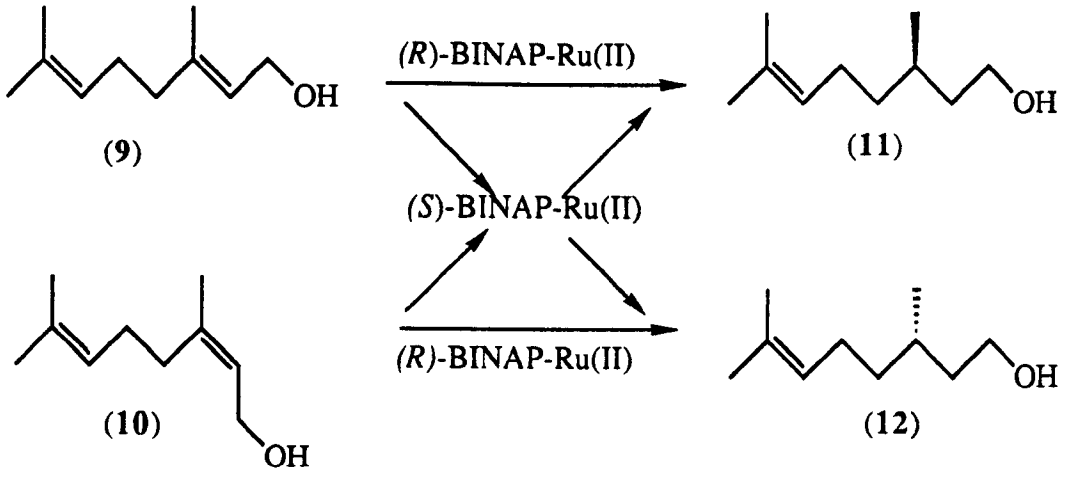
Noyori-Takaya's new-generation of asymmetric hydrogenation catalysts,[4-8] so called 'Noyori process', has been successfully used in Industry. Noyori catalysts are chiral diphosphine-Ru (II) complexes. The Ru (II) catalyst systems have been used with a variety of functionalized olefins and ketones[6, 9-12] such as the asymmetric hydrogenation of (**7**) to give *(S)*-naproxen (**8**), a potent anti-inflammatory drug, with S/C=10,000 and 97% e.e. in 92% yield (Scheme 1.4). Similarly asymmetric hydrogenation of the allylic alcohols (**9**) and (**10**) yielded the primary alcohols(**11**) and (**12**), with 92-99% e.e. and S/C=50,000 (Scheme 1.5).[13]



(7) (8) 97% e.e.

(S)-Naproxen

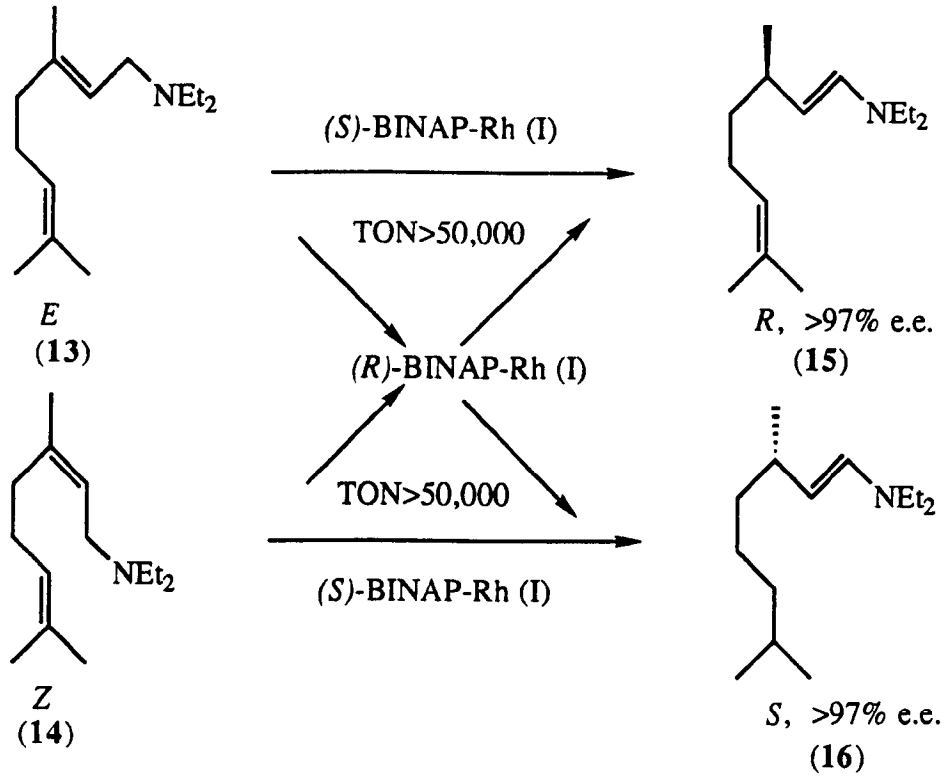
Scheme 1.4



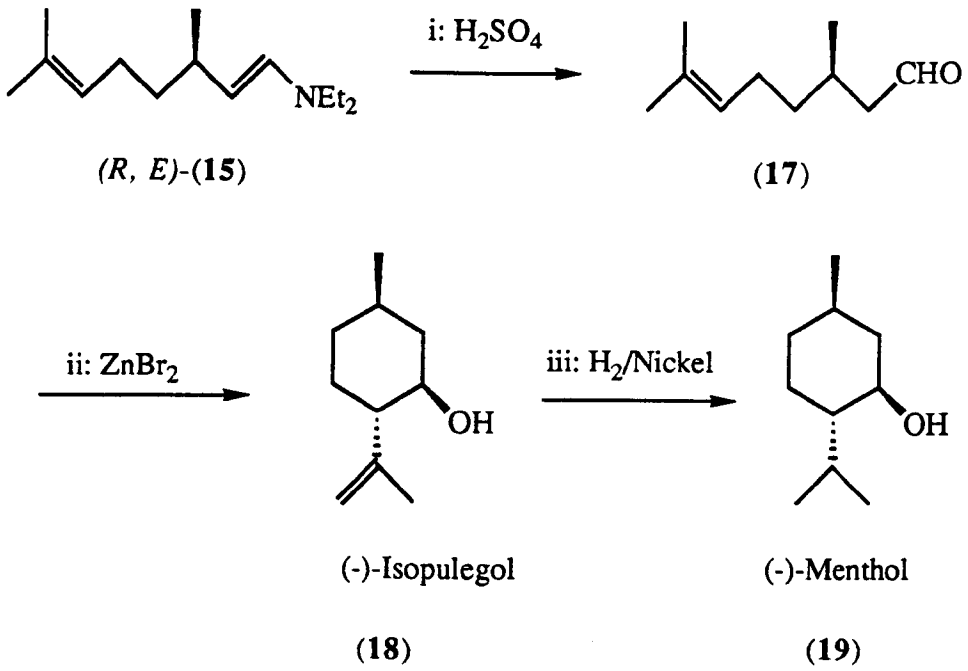
Scheme 1.5

Asymmetric isomerization of allylamines has been applied to the large-scale commercial synthesis of *l*-menthol using the 'Takasago process'.[14-16] This involves a bis(BINAP) rhodium (I) complex, $[Rh(BINAP)_2]^+$, as the catalyst as shown in Scheme 1.6. The (*R*, *E*)-enamine (**15**) was made by asymmetric isomerization of (**13**) with an optimum TON of greater than 50,000 to 400,000, and with a high stereoselectivity. Since BINAP enantiomers are obtained easily together with both *(E)-N,N*-diethylgeranylamine (**13**) and *(Z)-N,N*-diethylnerylamine (**14**), this stereochemical reaction provides the following economical advantages:

(1) the option of taking the starting material either from a natural resource (renewable terpene) or from petroleum,



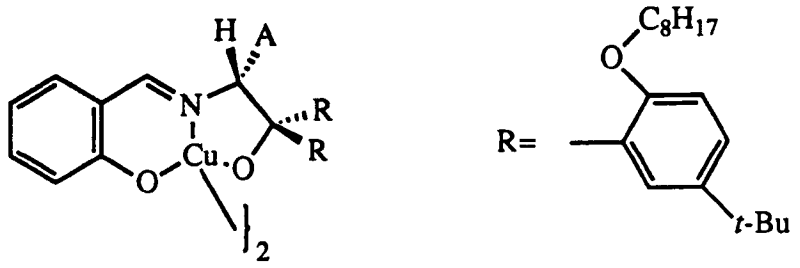
Scheme 1.6



Scheme 1.7

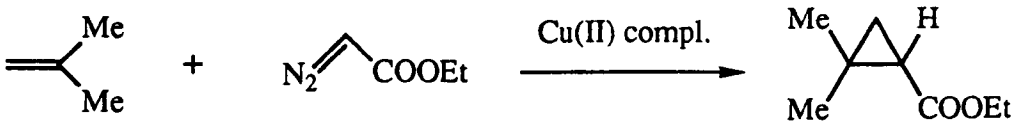
(2) easy access to both enantiomers of citronellal (**17**) from a single intermediate; (+)-citronellal (**17**) on further reaction gives (-)-isopulegol and (-) - menthol.

Another example is asymmetric intermolecular cyclopropanation using a copper (II)-Schiff base catalyst.



(**20**) (R)-Cu (II) complex

When A=Me, the carbinol substituents (R) were the bulky 5-*tert*-butyl-2-(n-octyloxy)phenyl group. Optimum enantioselectivities for the intermolecular cyclopropanation reaction were achieved with the catalytic use of the corresponding copper (II) complex (**20**) (Aratani catalyst),[17] in both enantiomeric forms. One of the specific applications of the Aratani catalyst is the commercial production of *(S)*-2,2-dimethylcyclopropane carboxylate (**23**), the "Sumitomo process," which is employed for the production of cilastatin, an *in vivo* stabilizer of the antibiotic imipenem.



(**21**) (**22**) 92% e.e. (**23**)

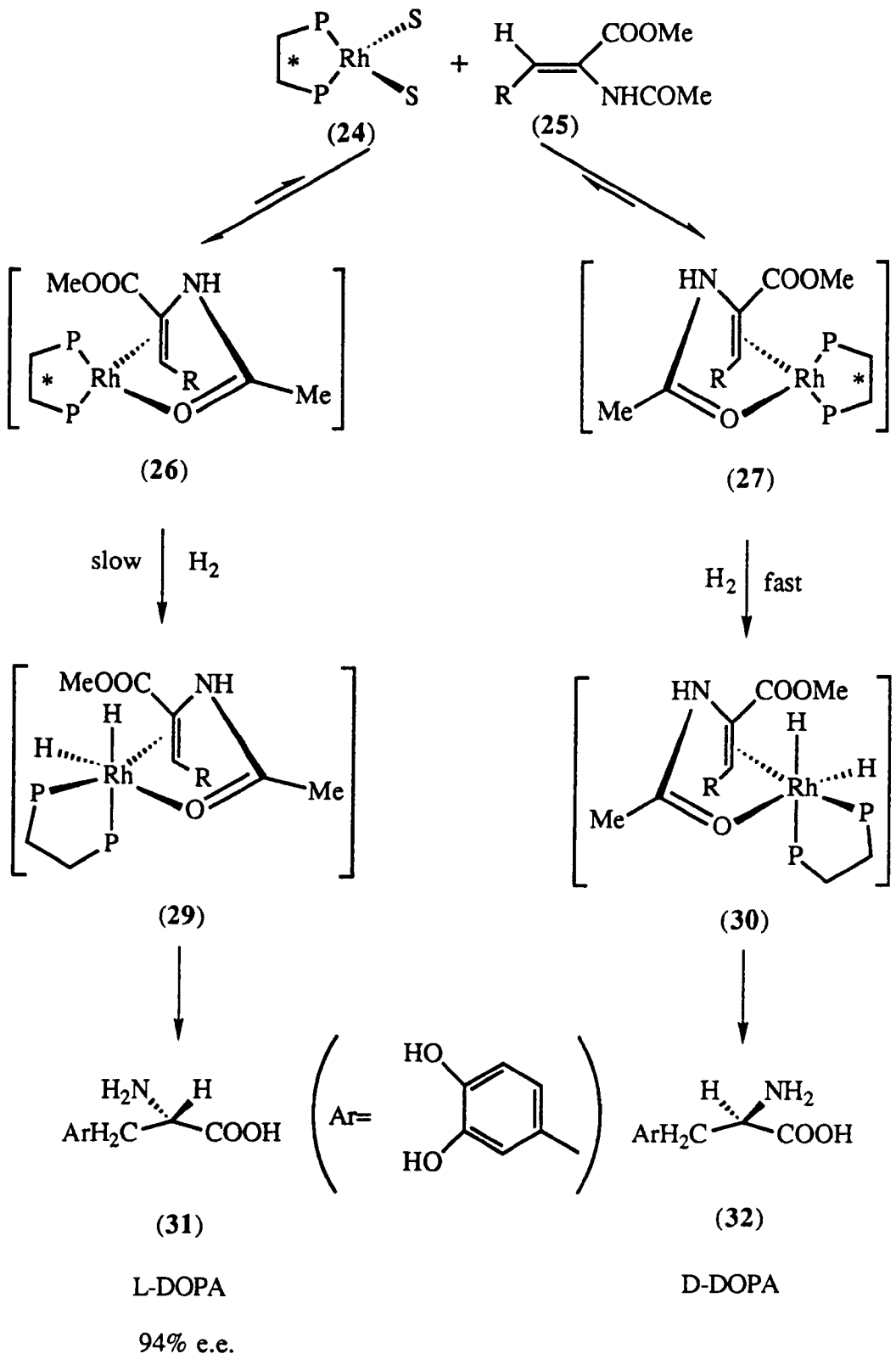
Scheme 1.8

§ 1.3 Homogeneous Chiral Catalysis

1.3.1 Recent Advances and Significance

Homogeneous chiral catalysis using transition metal complexes provides an important class of asymmetric synthesis using fourth generation methods. Homogeneous chiral catalysis has made significant advances through the development of substrate-catalyst interactions and the chiral recognition of substrate structures. Knowles' outstanding "Monsanto process," established in the early 1970s for the asymmetric synthesis of L-DOPA, was based on the interactions between the multifunctionalized substrate, a N-acetyldehydroamino acid, and a chiral diphosphine-rhodium catalyst as shown in Scheme 1.9.[18] However, the new-generation asymmetric hydrogenations based on chiral diphosphine-ruthenium catalysts can now be applied to simple acrylic acids with exceptionally high enantioselectivity, as demonstrated in Scheme 1.4. The Sharpless oxidation of allylic alcohols,[19] extensively developed in the 1980s, requires a hydroxyl functionality to anchor the substrate to the titanium catalyst. In sharp contrast to this, the recently developed Sharpless asymmetric dihydroxylation[20] and Jacobsen's epoxidation[21] work extremely well with unfunctionalized alkenes. This has involved the rational design of chiral catalysts, that bring about extremely high enantioselectivities without the assistance of a huge protein backbone.

In some cases, the new chiral catalysts have a beautiful C_2 symmetry and in other cases a fascinating dissymmetry. It is breath-taking to realize that such simple and beautiful small molecules can compete, practically and efficiently, with the highly sophisticated enzymes



Scheme 1.9

that nature has created. This provides encouragement for synthetic organic chemists to continue to expend their efforts to design and develop highly efficient homogeneous chiral catalysts.

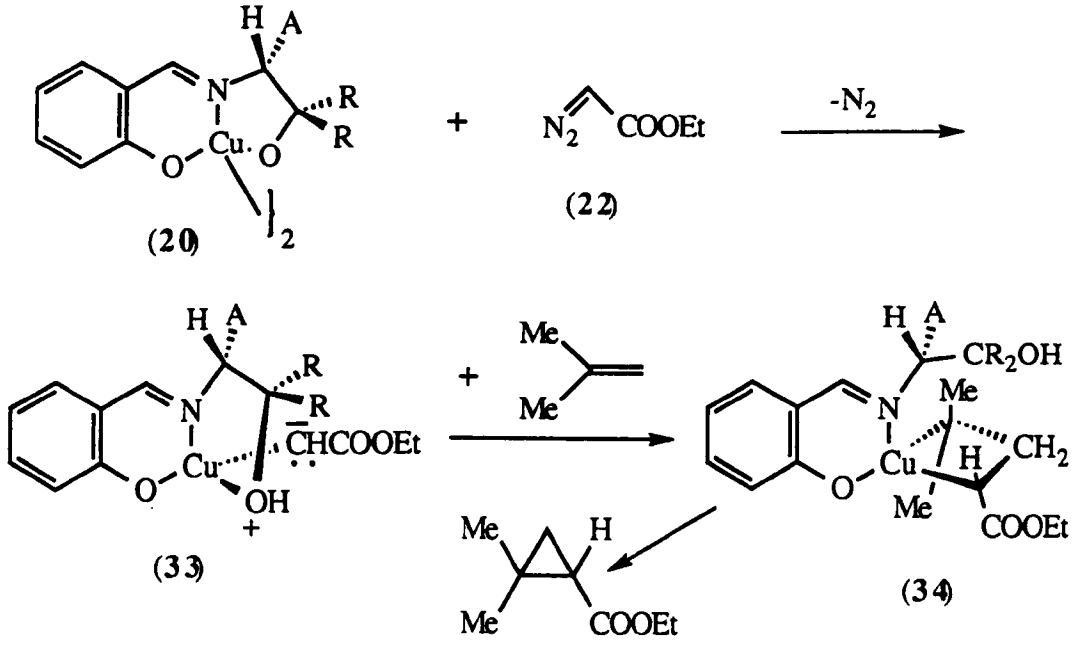
The current development of "chiral drugs" is spawning a new technology known as "chirotechnology," and a new industry may well emerge in the near future in the same way that the biotechnology industry has developed. Sharpless dihydroxylation and Jacobsen's epoxidation have been licensed to Sepracor, one of the newly emerging "chirotechnology" companies that provides a supply of new enantiomeric intermediates.

1.3.2 Mode of Action of Homogeneous Chiral Catalysis

Homogeneous catalysts can be tailor-made by ligand variation thus achieving high specificity and turnover at low temperature. Ideally, the catalyst complex should be stable in more than one coordination number and, through fine-tuning of chemical bond strength (variation of the ligands), capable of holding a substrate molecule selectively but not too tightly.

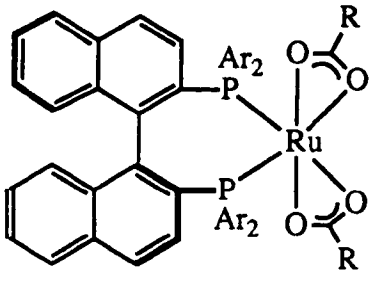
In the case of homogeneous chiral catalysis, the asymmetric environment of the complex is provided by the specially chosen optically active ligands which coordinate with the central metal. The mode of action of homogeneous chiral catalysis may be outlined as follows:

(I) *The coordination of the reaction partners to a transition metal bring them into close proximity, thus promoting the reaction under the influence of the chirality of the ligands.* As an example, the mechanism of the reaction shown in Scheme 1.8[17] is presented in Scheme 1.10.



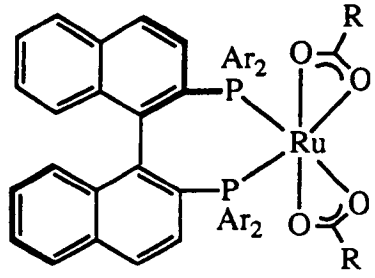
Scheme 1.10

(II) *Through coordination to a transition metal, a reaction partner can become activated for subsequent reactions under the control of the chiral ligands.* For example, Scheme 1.11 shows the Noyori process.[4 a]



Λ-*(S)*-Ru(II)

(35')

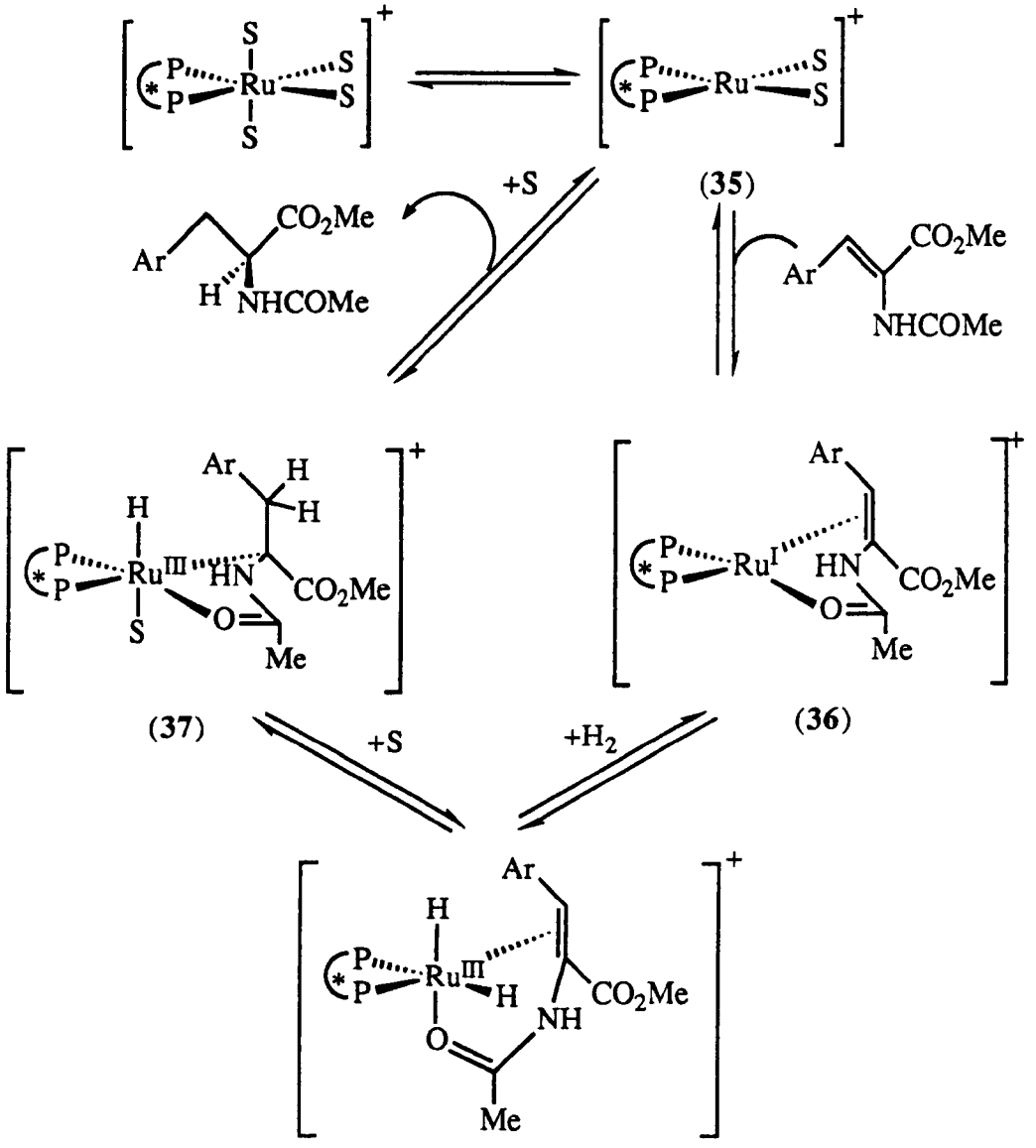


Δ-*(R)*-Ru(II)

(35")

The mechanism of these remarkable reductions is believed to be as follows: in solution the complex (35') [4 a] or (35") [4 a] is in equilibrium with a four-coordinate square-planar form (35). [4 b] The doubly bonded substrate coordinates to this species largely on one enantiotopic face, as a result of the extremely asymmetric environment of metal nucleus. (Note the importance of the polar group as a ligand.) Hydrogen undergoes oxidative

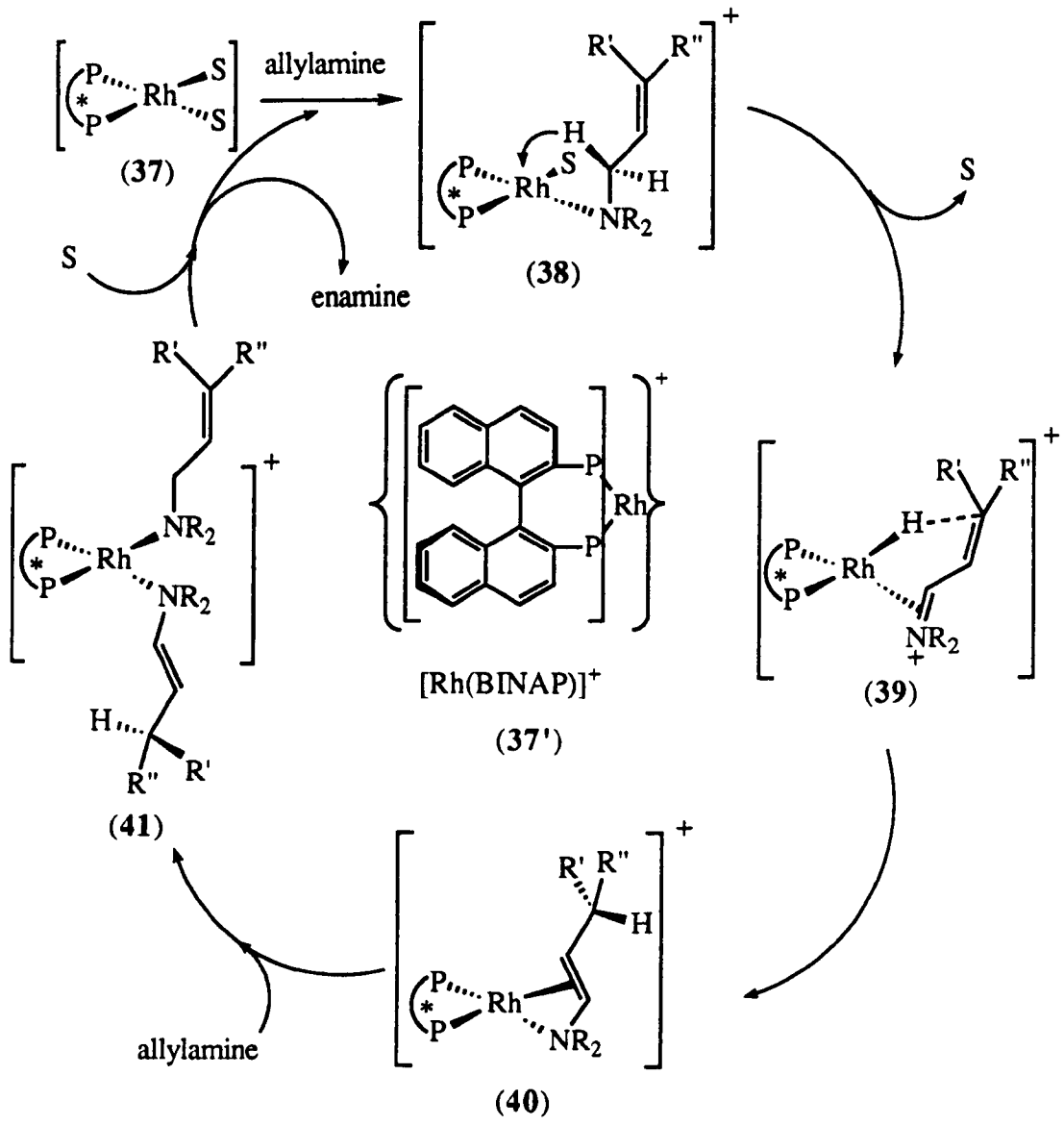
addition to the complex (**36**) at this point, and this is followed by hydrogen transfer from the metal to alkene, resulting in a σ-bonded complex. The catalytic cycle is completed by both hydrogens being delivered to the complexed face of the alkene, which explains why the alkene geometry is so crucial.



Scheme 1.11

(III) *The coordination of an organic substrate to a transition metal can facilitate nucleophilic attack under the influence of the chirality of ligands.* The catalytic cycle for the Takasago process[14-16] for the asymmetric isomerization of allylamines is presented in Scheme 1.12. The key step is the migration of the hydride from the α to the γ position.

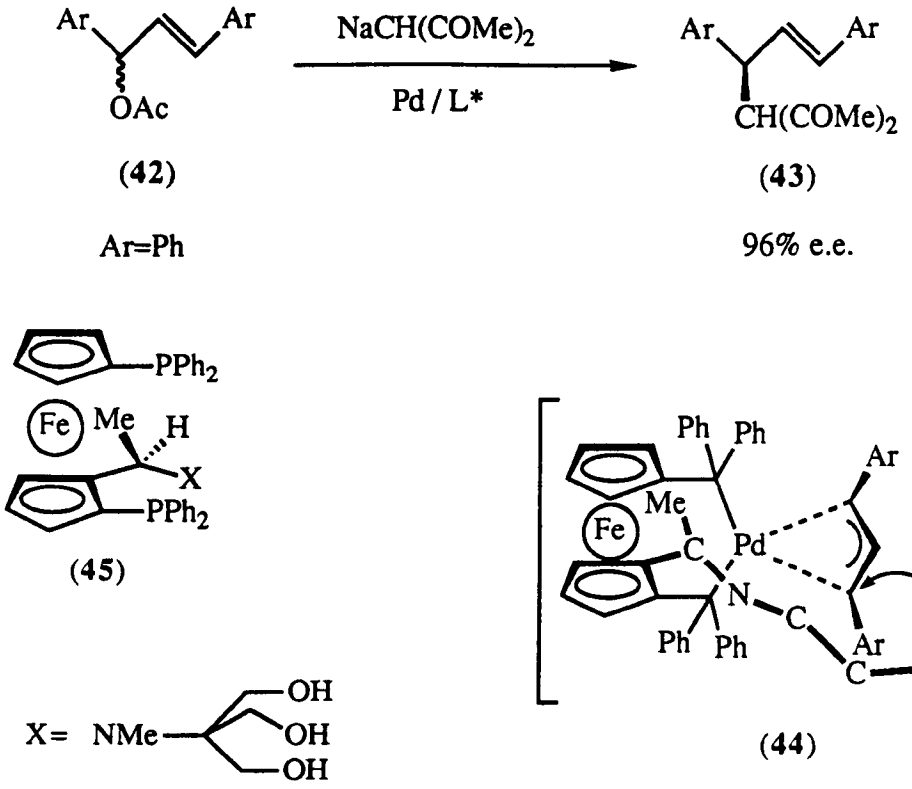
It is thought that the hydride in the α position attacks the central rhodium(I) (**38**) and then migrates to the γ position (**39**).



Scheme 1.12

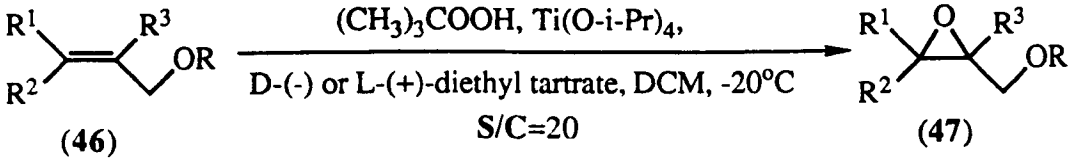
(IV) *The organic substrate coordinated to a transition metal can be fixed and activated to attack by a nucleophile which is specifically controlled by the pendant arm of the chiral ligand.* An example of this is asymmetric allylic substitution, forming a chiral carbon centre (**43**) from an allylic substrate (**42**) via the transition state (**44**) (Scheme 1.13).[22] The chiral ferrocenylphosphine (**45**), which contains hydroxyl groups on the pendant side

chain, catalyses the reaction between 1,3-diphenyl-2-propenyl acetate (42) and sodium acetylacetonate with a selectivity of 96% e.e..



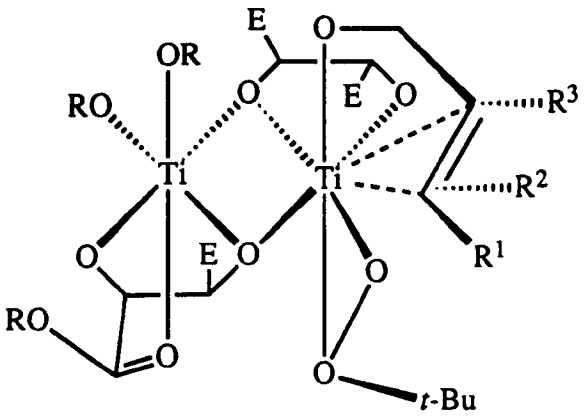
Scheme 1.13

(V) *The organic substrate coordinated to a metal centre can be fixed by a hydroxy group or an alkoxy group, activated and then oxidized in a chiral complex.* The Katsuki-Sharpless asymmetric epoxidation,[19] Scheme 1.14, is an example as shown below. The key to this remarkable enzyme-like enantioselectivity lies in the complex formed from the titanium salt and the tartrate.[19] It is believed to have the structure (48). Under the reaction conditions ligand exchange occurs rapidly with the oxidant (Bu^tOOH) and the allylic alcohol. In the highly asymmetric environment of the binuclear titanium complex, the complexed hydroperoxide is forced to approach from the *Si-* face (with (+)-DET) or *Re-* (with (-) -DET), due to the presence of the bulky ester groups. It should be noted, however, that the exact nature of the substrate/catalyst complex is still controversial.



(46) (47)

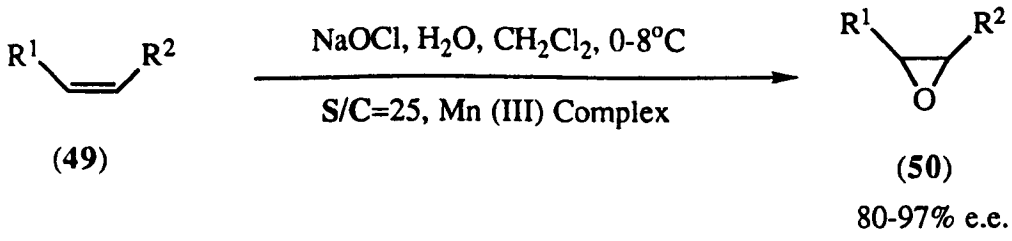
R= H, alkyl, aryl. 90-99% e.e.



(48)

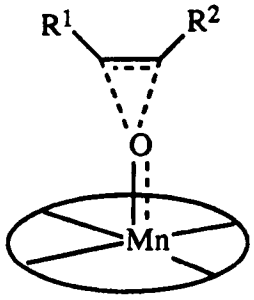
Scheme 1.14

(VI) *In the oxo transfer oxidation catalysts, the facial approach of the oxo groups on the high oxidation state transition metal complex to the unsaturated organic substrate, can be controlled by the extremely asymmetric ligands by either dipole-dipole or dipole-induced-dipole interactions.* The Sharpless asymmetric dihydroxylation and Jacobsen's epoxidation, are regarded as the most important recent advances in this area. Jacobsen's epoxidation is shown in Scheme 1.15. The Mn(III) catalyst (**52**)[21] is oxidized by sodium hypochlorite to the Mn (V) oxygen bearing complex (**51**). When the alkene approaches the oxo group on the complex (**51**), it is spontaneously oxidized. As a result of the influence of the chiral ligands, the epoxides are formed enantioselectively.



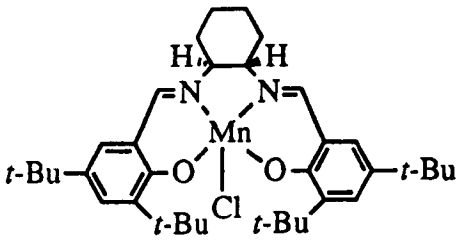
(49) (50)

80-97% e.e.



Mn (V)

(51)



(1S,2S)

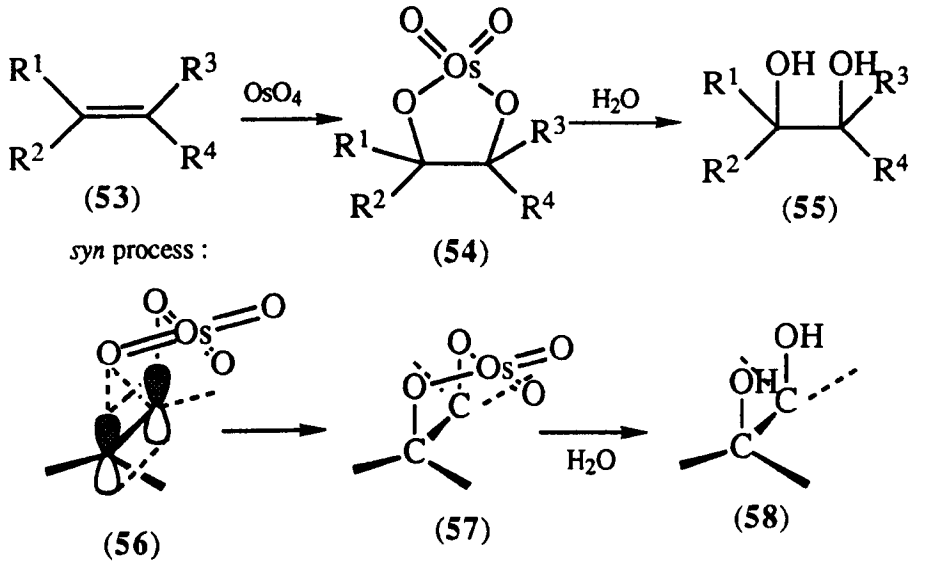
Mn(III) salen complex

(52)

Scheme 1.15

§ 1.4 Asymmetric Dihydroxylation (ADH) of Alkenes

The reaction of osmium tetroxide with alkenes is perhaps one of most reliable and selective transformations in organic chemistry. The ability to stereospecifically place two hydroxyl groups in a hydrocarbon framework accounts for the popularity of the osmium tetroxide dihydroxylation in organic chemistry (Scheme 1.16).



Scheme 1.16

Hoffmann[23] was the first to show that osmium tetroxide could be used catalytically in the presence of a secondary oxygen donor such as sodium or potassium chlorate for the *cis*-dihydroxylation of alkenes. Criegee[24] found that osmium tetroxide could also be used in stoichiometric amounts and that the resultant osmate ester could be hydrolyzed reductively to give insoluble osmium salts, or hydrolyszed oxidatively to regenerate osmium tetroxide. Later, several other oxidizing agents were employed in combination with osmium tetroxide for the catalytic oxidation of alkenes including hydrogen peroxide, [26] *t*-butyl hydroperoxide,[27-29] *N*-methylmorpholine *N*-oxide,[28-30] oxygen,[31] sodium periodate,[32, 33] sodium hypochlorite,[34] and potassium ferricyanide[35] *etc.*

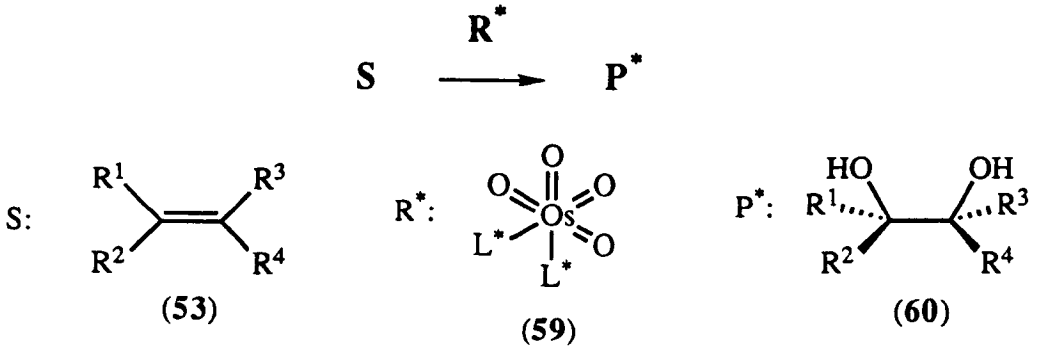
Criegee's discovery in the 1940's[24,25] that, the presence of a tertiary amine led to a dramatic rate enhancement in the osmylation of alkenes laid the foundation for the development of asymmetric reactions. Since then, many tertiary amines have been used and several of these complexes have been isolated and characterized. Over 40 years later, chiral nucleophilic ligands such as quinidine, quinine, and their derivatives. have been used to accelerate the formation of osmium (VI) complexes, and have resulted in the enantioselective oxidation of olefins to vicinal diols.

1.4.1 Development of the Methodology of Asymmetric Dihydroxylation of Alkenes

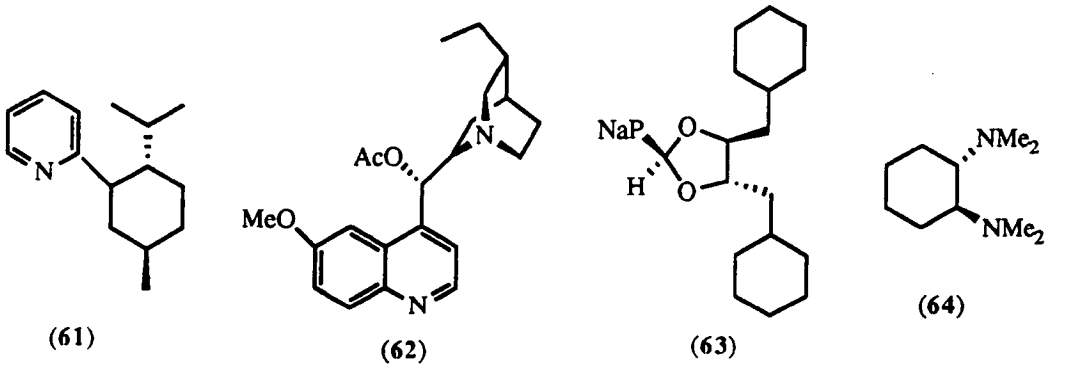
Great progress has been achieved in this area. The approaches fall into two categories: third generation methods and the fourth-generation methods, depending on the type of chiral ligand employed.

1.4.1.1 Asymmetric Dihydroxylation of Alkenes Using Third-generation Methods

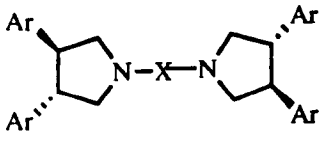
Complexes derived from osmium tetroxide with chiral diamines and aminoalcohols (Figure 1.1) do not undergo catalytic turnover, but serve as chiral reagent which control the asymmetric dihydroxylation of alkenes (Scheme 1.17). This is a third generation method.



Scheme 1.17

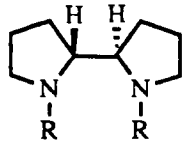


Hentges & Sharpless[36] Yamada & Narasaka[37] Tokles & Snyder[38]



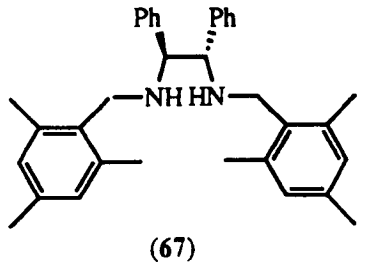
(65)

Tomioka, Nakajima & Koga[39]



(66)

Hirama, Oishi & Ito[40]

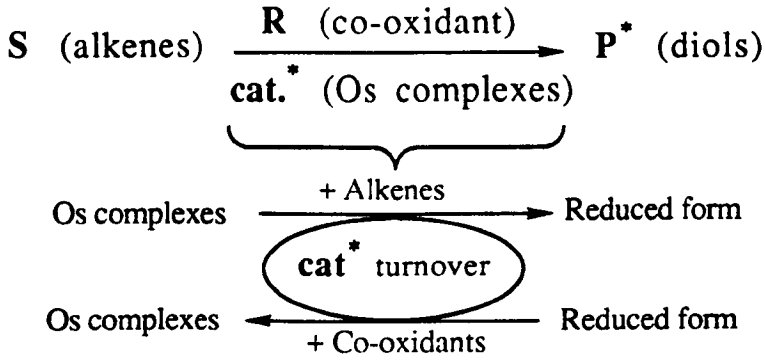


(67)

Corey and coworkers[41]

Figure 1.1

1.4.1.2 Asymmetric Dihydroxylation of Alkenes Using Fourth-generation Methods



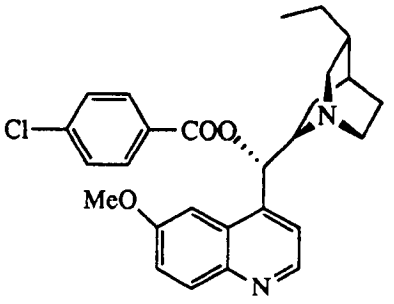
Scheme 1.18

Complexes of osmium tetroxide formed with globular proteins,[42, 43] or alkaloids such as quinuclidine, dihydroquinidine (DHQD), dihydroquinine (DHQ) and its derivatives have been found to be very effective catalysts for the oxidation of variety of alkenes. Figure 1.2 lists most of the chiral ligands used so far in the catalytic asymmetric dihydroxylation (CADH) of alkenes. These fourth-generation methods are illustrated in Scheme 1.18.

The catalytic asymmetric dihydroxylation of alkenes began in 1973 when Kokubo *et. al.* [43] used a globular protein-bovine serum albumin (BSA)-2-phenylpropane-1,2-diolatodioxo-osmium (VI) complex to catalyse ADH of alkenes. It was shown by spectroscopic methods that the osmium tetroxide is bound to BSA through the amine

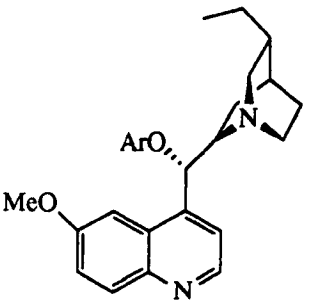
residue. α-Methylstyrene gave its product diol with 68% e.e. (*S*-configuration) using *t*-butyl hydroperoxide as co-oxidant at 25°C. Other olefins such as 1-octene, and *trans*-β-methylstyrene gave relatively lower optical purities of the diol with the *S*-configuration.

A major breakthrough in the catalytic asymmetric dihydroxylation of alkenes was reported by Sharpless and coworkers in 1988. [44] The combination of dihydroquinidine 4-chlorobenzoate (**68**) as a chiral ligand [36] with *N*-methylmorpholine *N*-oxide as the co-oxidant in aqueous acetone was found to give efficient catalytic turnover affording optically active diols (20-88% e.e.) from alkenes in excellent yields (80-95%). Other derivatives of DHQD and DHQ were examined in order to improve the enantiomeric excess of the diol products. The 4-chlorobenzoate derivatives of dihydroquinidine (DHQD-CLB)



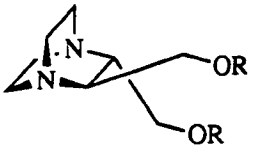
(**68**)

Sharpless et. al. [44]



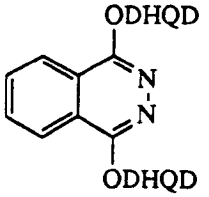
(**69**)

Sharpless et. al. [45, 46]



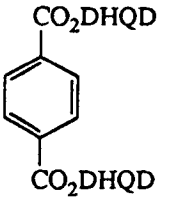
(**70**)

Hirama et. al. [47]



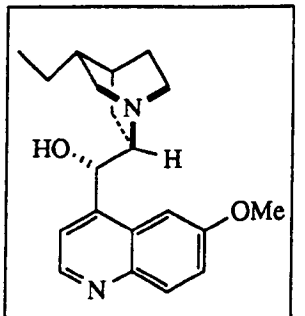
(**71**)

Sharpless et. al.[20]



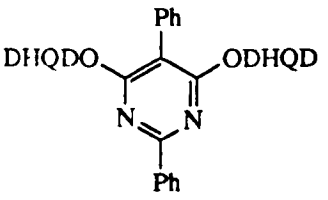
(**72**)

Lohray & Bhushan[48]



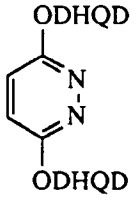
(**73**)

Dihydroquinidine (DHQD)



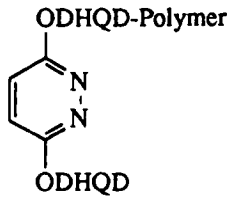
(74)

Sharpless et. al. [49]



(75)

Sharpless et. al. [50]



(76)

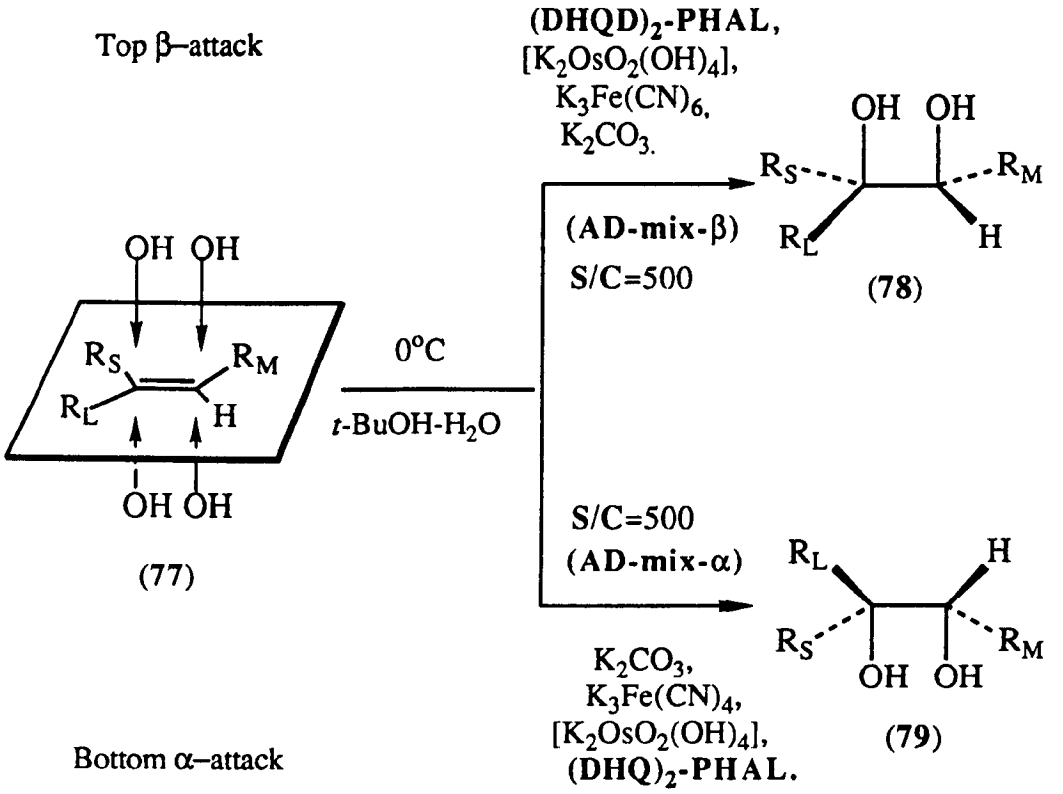
Lohray et. al. [51]

Figure 1.2

and dihydroquinine (DHQ-CLB) were found to afford the opposite optical antipodes of the diols with high optical purity (>90% e.e.) [52] . Although several aryl substituted alkenes afforded high optical purities of the corresponding diols, the alkyl substituted olefins resulted in a considerably lower (20%) optical purity. Even lower enantiomeric excesses were obtained with *cis* or cyclic alkenes (4-10% e.e.).

To improve the enantioselectivity of the reaction of dialkyl substituted alkenes, over 250 different cinchona alkaloid derivatives were screened for the stoichiometric asymmetric dihydroxylation. The aryl ethers of DHQD were found to be excellent ligands for dialkyl substituted olefins. [45, 46] A number of aryl ethers of DHQD were also examined as chiral ligands for the ADH reaction of several terminal, di-and trisubstituted alkenes. The highest enantioselectivity was obtained with 9-*O*-(9'-phenanthryl)-dihydroquinidine (**69a**) and 9-*O*-(4'-methyl-2'-quinolyl)-dihydroquinidine (**69**b). [46] The use of potassium ferricyanide as the co-oxidant was also examined [53, 54, 55] in cases where slow addition [56, 57, 58] of the olefin is not required and the reaction can be carried out at room temperature. Under these conditions, the diols were obtained in 85-90% yield with essentially the same enantioselectivity as that obtained in the stoichiometric reaction.

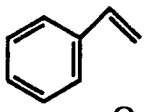
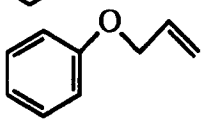
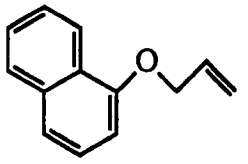
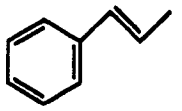
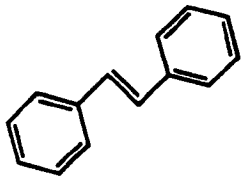
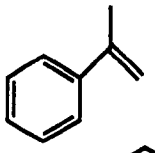
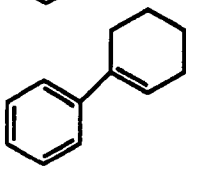
Hirama et. al.[47] have used C_2-symmetric diazabicyclo[2,2,2]octanes (**70**) as chiral ligands in the osmium tetroxide catalysed ADH reaction of alkenes. Although the enantiomeric excess of the diols is less than 41%, they observed a change in the diastereofacial selectivity of the alkenes with increasing steric constraint of the chiral controller.



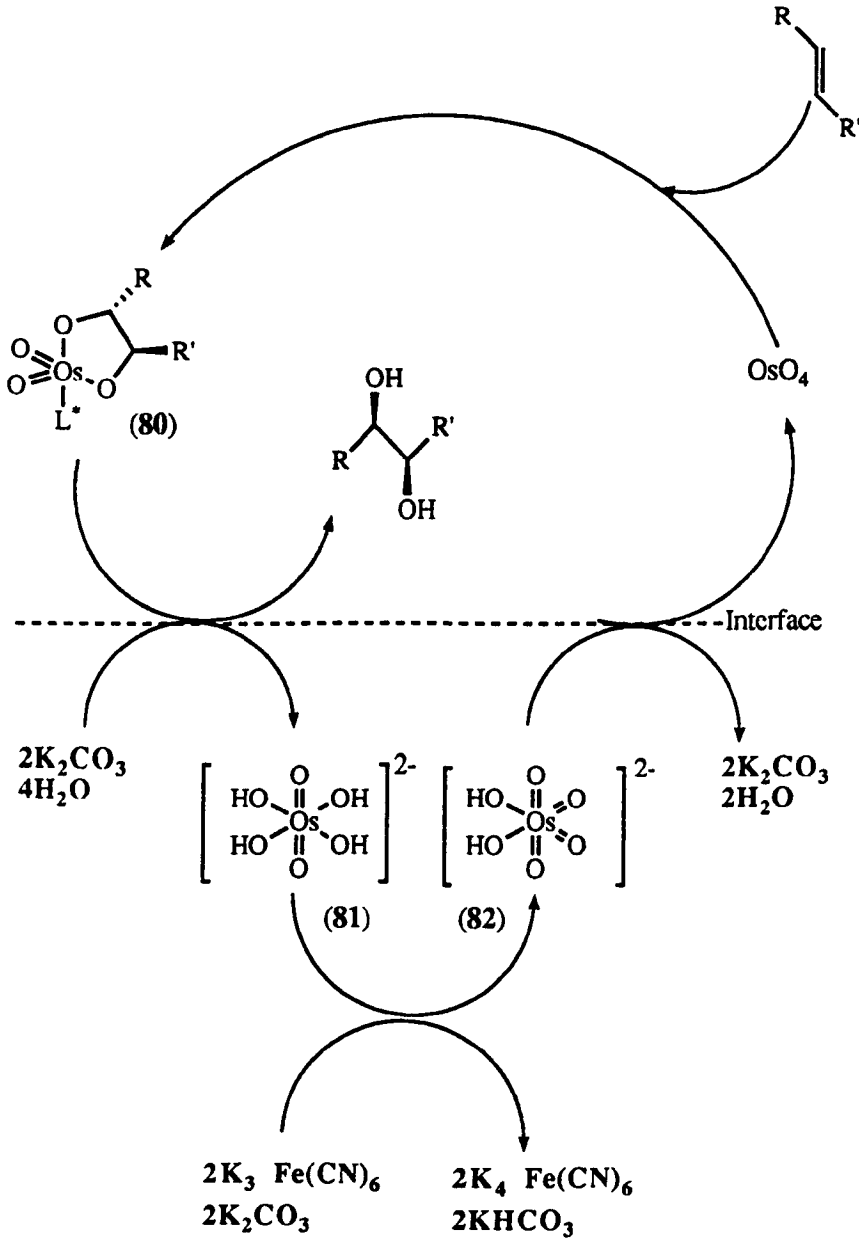
Scheme 1.19

Sharpless *et. al.*[20] (Scheme 1.19) and Lohray *et. al.*[48] have developed C_2-symmetric ligands derived from cinchona alkaloids. Bisdihydroquinidine (**72**) and bisdihydroquinine esters,[48] (**72**) have been found to be excellent chiral ligands for the CADH of most *trans*-disubstituted alkenes. Sharpless's use of bisdihydroquinidine and bisdihydroquinine ethers of 1,4-phthalazine ($DHQD_2$-PHAL)[20] (**71**) as chiral ligands, combined with potassium ferricyanide as the secondary oxidant, has attained the highest selectivity of any asymmetric dihydroxylation of alkenes. Using this approach, great

Table 1.1

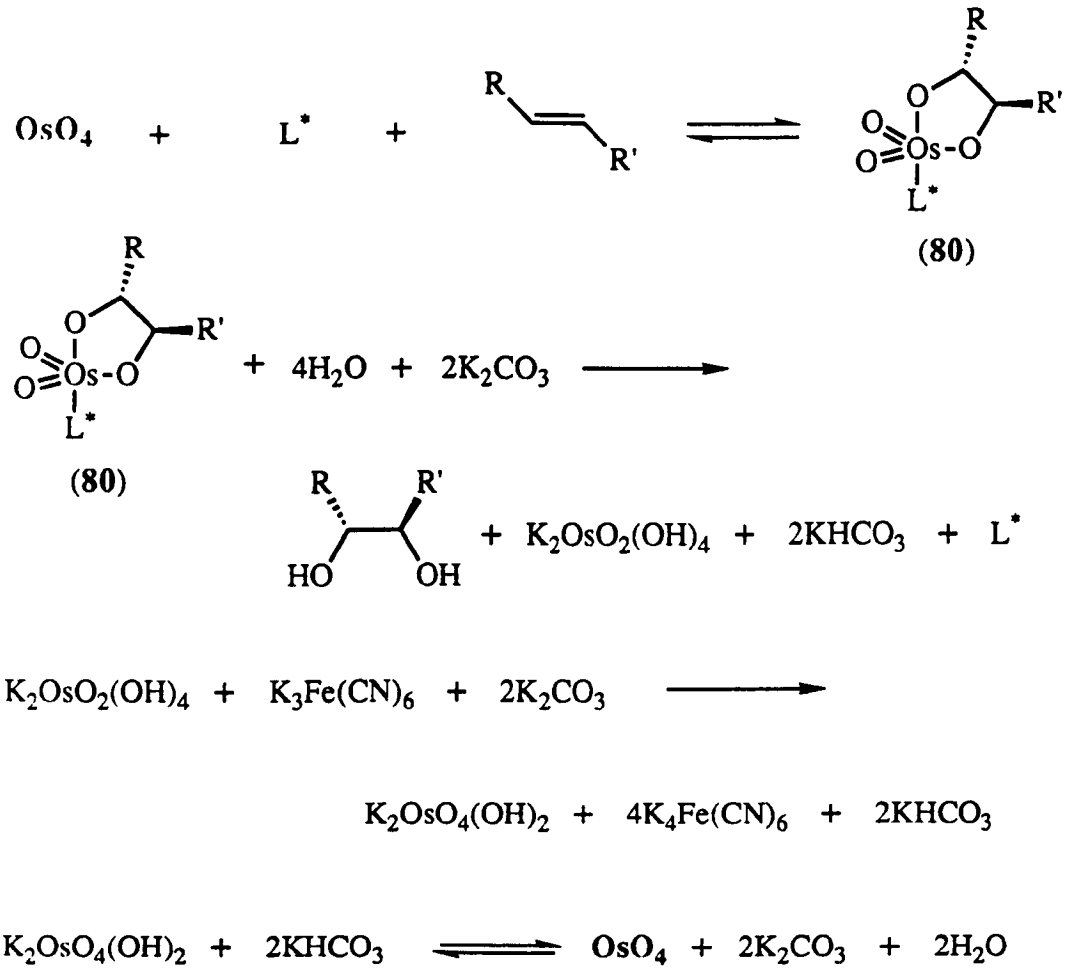
	alkenes	% e.e. of the resulting diols	
		(68) DHQD-CLB / DHQ-CLB	**(71)** $(DHQD)_2$-PHAL / $(DHQ)_2$-PHAL
1		73/74	97 / 97
2			88 / 77
3		-/60	91 / 88
4		79/-	97 / 93
5			99 / 96
6		-/91	- / 97
7		91/95	97 / 95
8			94 / 93
9		91/-	99 / 97
10			98 / 95

improvements have been achieved *in the enantiomeric excess of the diols obtained from many alkenes (Table 1.1), including monosubstituted alkenes.



Scheme 1.20

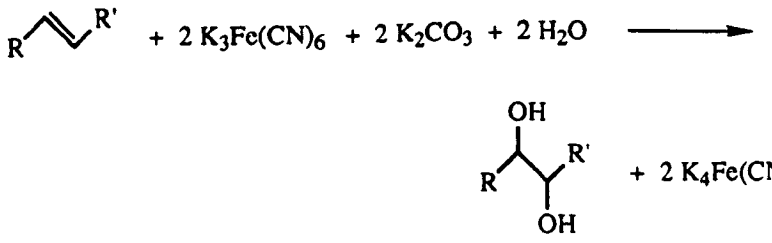
Hexacyanoferrate (III) has been used as a co-oxidant in the osmium catalysed reactions for studies of the kinetics and mechanism of various redox reactions.[59] The use of $K_3Fe(CN)_6$-K_2CO_3 as the co-oxidant in the ADH reaction substantially improved the enantiomeric excess of all the diols without the slow addition of alkenes at room temperature.



Scheme 1.21

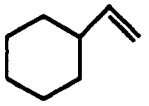
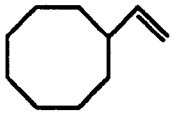
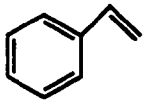
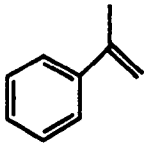
When $K_3Fe(CN)_6$-K_2CO_3 is used as the co-oxidant, the reaction takes place in both the organic phase and the aqueous phase as shown in Scheme 1.20. The turnover of osmium tetroxide follows the Scheme 1.21. The overall reaction is a redox reaction as shown in equation 1, which shows that during the catalytic cycle both the oxygens of the diol are provided by water.

After an initial screen by Sharpless and co-workers [31] involving variously substituted pyrimidines, it was found that 2,5- diphenyl-4,6-bis(9-*O*-dihydroquinidyl)pyrimidine (**74**) gave 92% e.e. for 3,3-dimethyl-1-butene, a poor substrate (only 64% e.e. for ligand **72**). Evaluation of (**74**) with other mono-substituted terminal olefins quickly revealed its superiority (Table 1.2).



1

Table 1.2

	olefin	% e.e. and configuration of the diol. (74) $(DHQD)_2$-PYR / $(DHQ)_2$-PYR*	% e.e. and configuration of the diol. (71) $(DHQD)_2$-PHAL
1		89,† *R* / 76, *S*	84,*R*
2		92,† *R* / 87, *S*	64, *R*
3		93,† *R* / -	80, *R*
4		96,† *R* / -	88, *R*
5		94,† *R* / 87, *S*	87, *R*
6		80, *R* / -	97,†*R*
7		69, *R* / -	94,† *R*
8		88, *R*,*R* / -	98,† *R*,*R*
9		87, *R* / -	98,† *R*

* $(DHQD)_2$-PYR: 2.5-diphenyl-4,6-bis(9-*O*-dihydroquinidinyl)pyrimidine (**74**), $(DHQ)_2$-PYR: 2.5-diphenyl-4,6-bis(9-*O*-dihydroquinyl)pyrimidine. † best result of e.e..

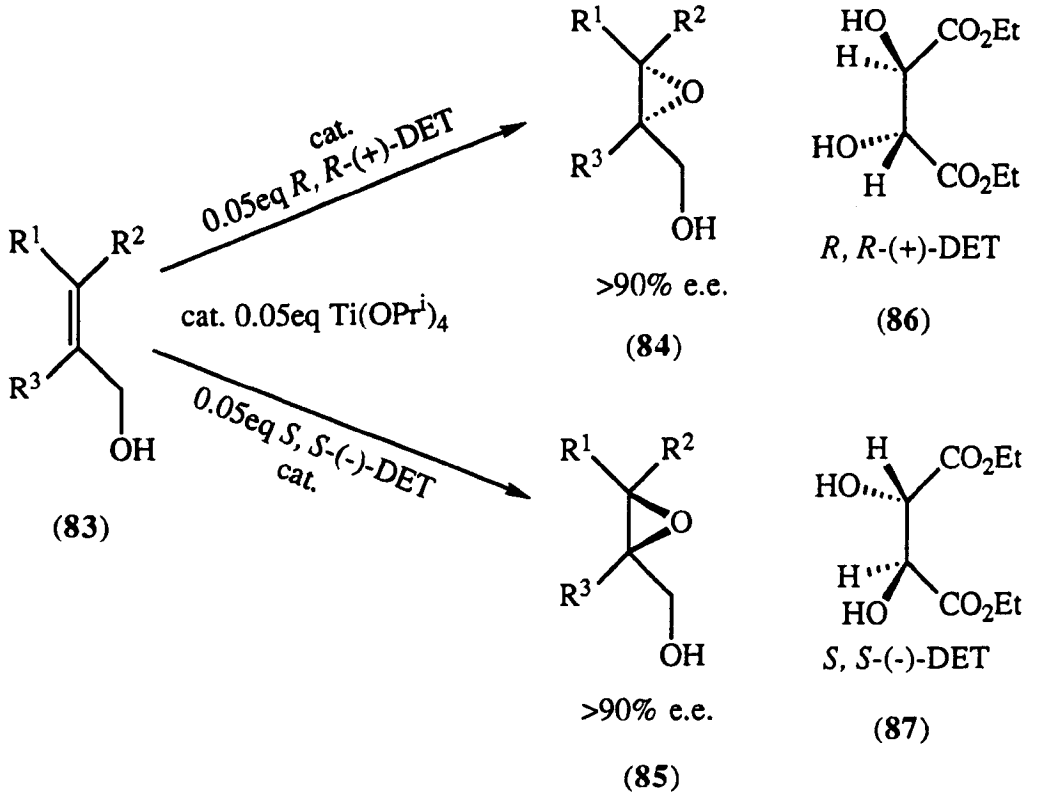
§ 1.5 Asymmetric Epoxidation of Alkenes

1.5.1 Asymmetric Epoxidation via the Substrate Bound to Central Metal

Epoxidation is a popular reaction in organic synthesis because the epoxide group is readily opened to produce 1,2 functionality in a stereospecific manner. Epoxidation is also attractive in the context of asymmetric synthesis, as it can create two contiguous chiral centres in one reaction. Efforts to achieve asymmetric induction in the epoxidation of olefins began in 1965 with a report by Henbest that a low level of enantioselectivity (8%) was achieved using percamphoric acid. [60, 61] A useful level of asymmetric induction remained an elusive goal for 15 years until Katsuki and Sharpless reported that the combination of a titanium (IV) alkoxide, an optically active tartrate ester, and t-butyl hydroperoxide was capable of epoxidizing a wide variety of allylic alcohols in good yield and with an enantiomeric excess usually greater than 90% and predictable configuration, as illustrated in Scheme 1.22.

d^0 Titanium (IV) alkoxides, while not the most active epoxidation catalysts known, are able to promote the reaction of olefins with alkyl hydroperoxides to produce epoxides in high yield and with high selectivity. [62-65] They, like other good epoxidation catalysts, such as vanadium (V), molybdenum (VI), and tungsten (VI), are characterized as being Lewis acids, existing in their highest oxidation state, that is, d^0, having low redox potential [62,63] and being labile to alkoxide ligand substitution. [66-68] They are also hydrolytically unstable, tending to form polymeric hydrates when exposed to water. One of the important differences between titanium (IV) alkoxides and most other highly active catalysts, is that the titanium species have four covalently bound alkoxide ligands whereas others do not. According to the mechanism of asymmetric epoxidation proposed by Sharpless and co-workers[65], the metal catalyst is a dimer consisting of two dialkyl tartrates or tartramides covalently bound through hydroxylic functions to two titaniums(**48**). The

epoxidation of allylic alcohols on the d^0 titanium templates proceeds more rapidly and under milder conditions than the epoxidation of olefins lacking nearby hydroxyl group.[69-78]. This effect is much more pronounced in metal-catalyzed reactions than peracid oxidations



Scheme 1.22

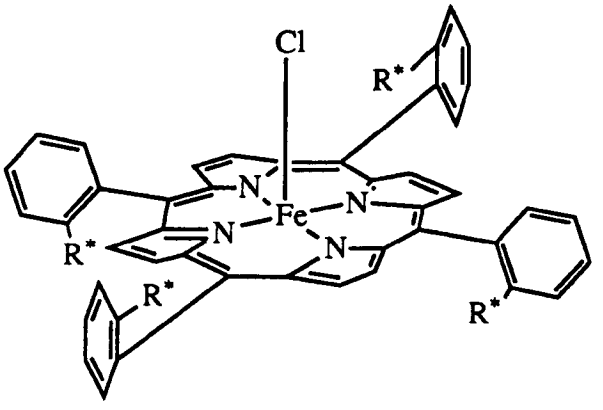
due to the propensity of high-valent transition metals to form covalent metal-oxygen bonds rapidly. The epoxidation step therefore proceeds in a unimolecular fashion, with both allylic alcohol and hydroperoxide bound to the metal centre. It has been estimated that the change from intermolecular to intramolecular reaction(a reduction in kinetic order by one) results in a favourable change in $T\Delta S^*$ by ~5 kcal/mol, corresponding to a rate acceleration of ~1000-fold at 25°C.[79]

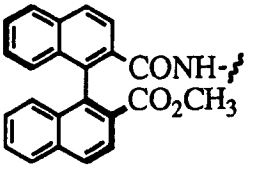
1.5.2 Asymmetric epoxidation of alkenes without an OH group

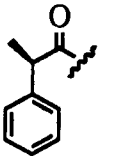
Alkenes without an OH group can be intermolecularly epoxidized by a metal catalyst, even though the alkenes bear no functionality to coordinate to the catalyst. In this case only the steric and electronic properties of the double bond undergoing epoxidation are relevant to the enantioselectivity of these reaction, the pool of potential substrates becomes extremely broad.

1.5.2.1 Asymmetric epoxidation of alkenes using P450-model oxo transfer catalysts

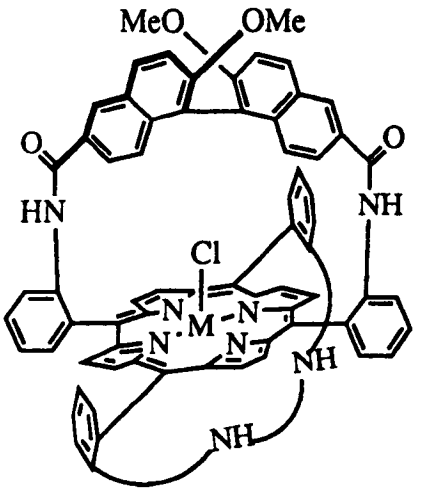
Fe(III) porphyrin complexes are models for cytochrome P-450. [80] Indeed, P450-model oxo transfer catalysts are capable of epoxidizing non polar group attached simple alkenes to corresponding epoxides. However, chiral porphyrin monooxygenase model systems have received the greatest attention thus far as potentially viable asymmetric epoxidation catalysts. The first example of asymmetric epoxidation of simple alkenes was reported in 1983 by Groves and Meyers[81] using chiral porphyrin complexes (**88**) and (**89**). More recently, Groves has investigated the chemistry of the vaulted binaphthyl derivatives (**90**) and (**91**). [82] Several other groups have pursued the design and synthesis of chiral porphyrin derivatives bearing conformationally restricted bridging ligands. The resulting



(**88**) R*= 

(**89**) R*= 

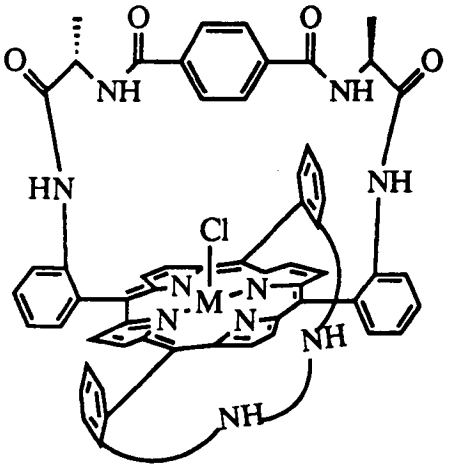
Groves and Meyers.[81]
up to 51% e.e.



(**90**) M=Fe

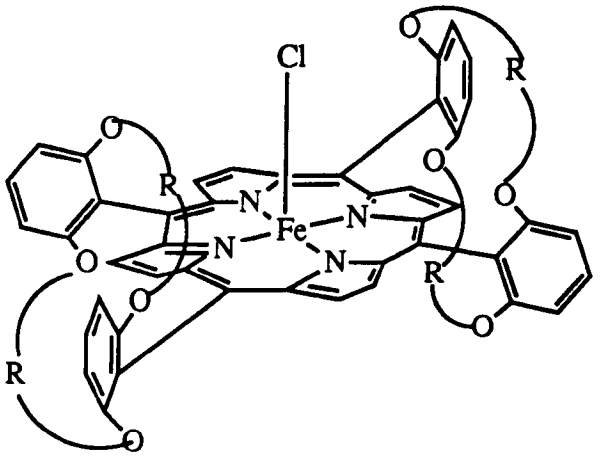
(**91**) M=Mn

Groves and Viski[82]
39-58% e.e.,
up to 72% e.e. (9% yield)

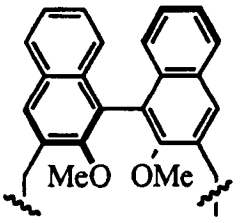


(**92**)

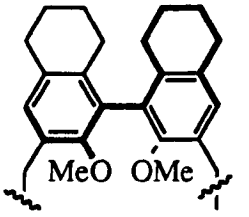
Mansuy, Battoni, Renaud, and Guerin[83]
up to 50% e.e.



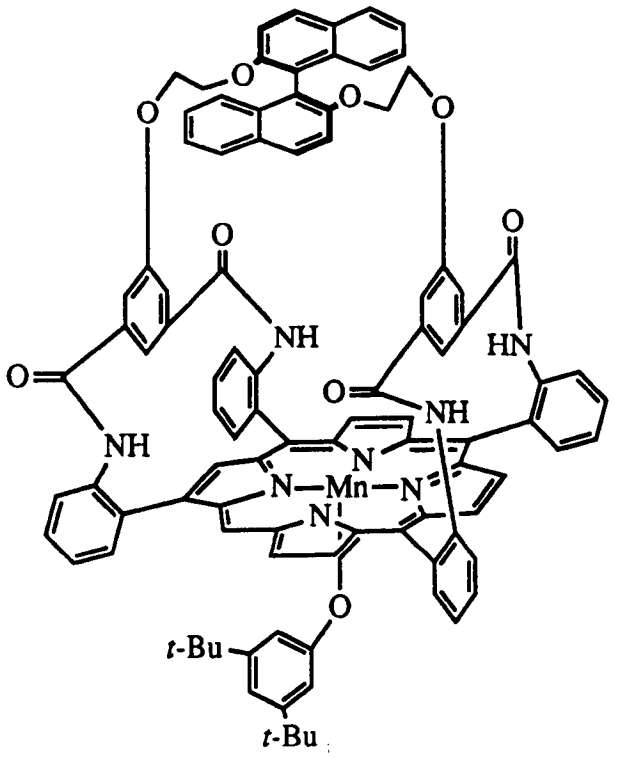
(**93**) R=



(**94**) R=



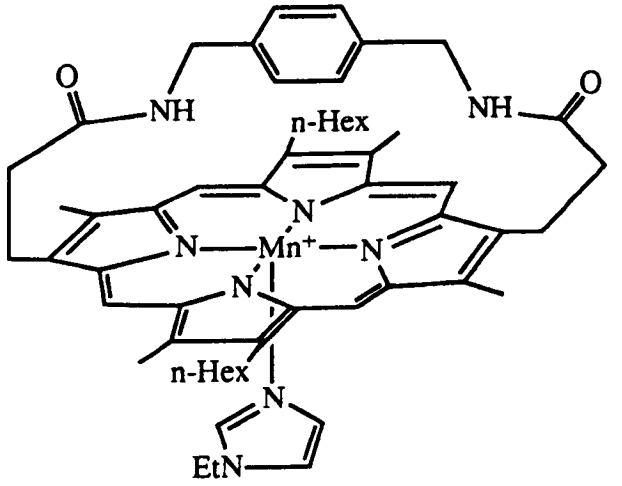
Naruta, Tani, Maruyama[84],
Naruta, Tani, Ishihara, Maruyama[85,86],
up to 89% e.e.



(**95**)

Collman, Zhang, Hembre, Brauman,[87]

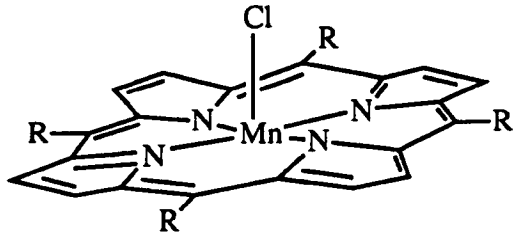
up to 13% e.e.



(**96**)

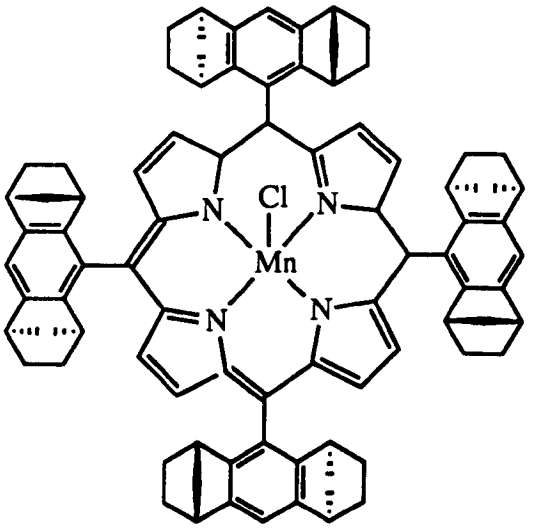
Konishi, Oda, Nishida, Aida, Inoue,[88]

up to 58% e.e.



(**97**) R = Binap

O'Malley, Kodadek,[89]
up to 40% e.e.



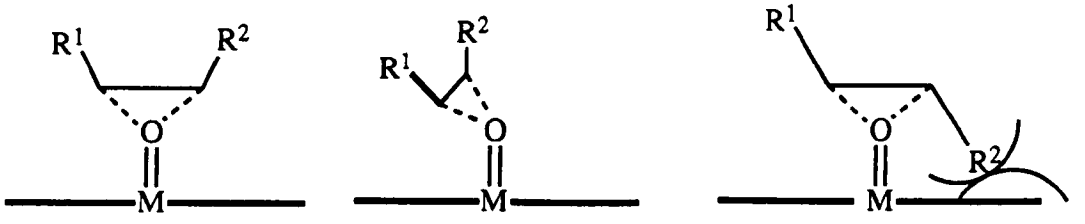
(98)

Halterman, Jan,[90]

Up to 76% e.e.

complexes include Mansuy's Figure 1.3 "basket handle" porphyrin (**92**) [83], Naruta's "twin coronet" porphyrin (**93**) and (**94**) [84-6], Collman's "picnic basket (**95**) [87], Inoues's "strapped" porphyrin (**96**) [88], O'Malley and Kodadek's "chiral wall" porphyrin (**97**) [89], and Halterman and Jan's porphyrin catalyst (**98**).[90] Usually, iodosylarenes have been used as cooxidant.

To account for the observed selectivities and for the general observation that *cis* olefins are more reactive than *trans* olefins, Groves proposed a transition state model for oxygen atom transfer involving side-on approach of the olefin to the putative iron-oxo intermediate (Scheme 1.23). Although the precise angle of alkene approach to the oxo intermediate remains open to some controversy[91-3], the side-on approach and variants thereof has gained wide acceptance and has provided an extremely useful model for the design of other



Scheme 1.23 Side-on approach model for oxygen transfer illustrating the less-hindered approach of *cis*-alkenes to the metal oxo moity. The porphyrin ligand is symbolized by the heavy line.

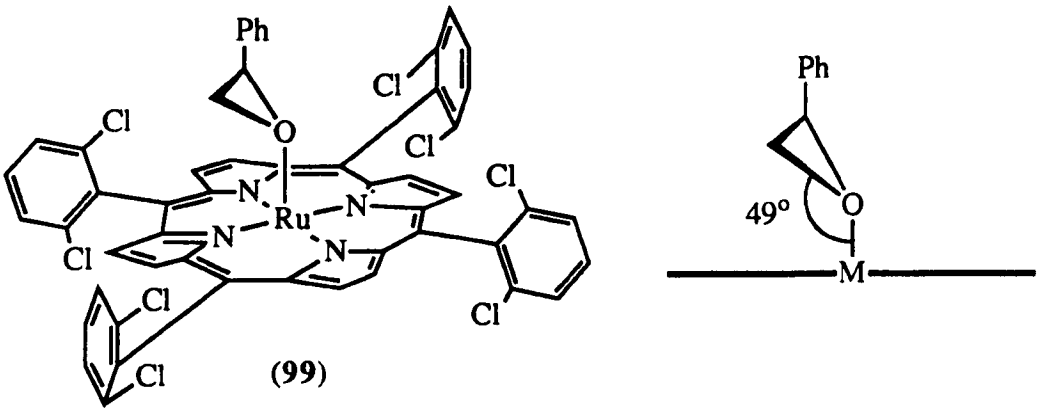


Figure 1.4 Schematic representation of the coordination of epoxide to a Ru(II)-porphyrin complex, as exhibited in the X-ray crystal structure of (**99**).

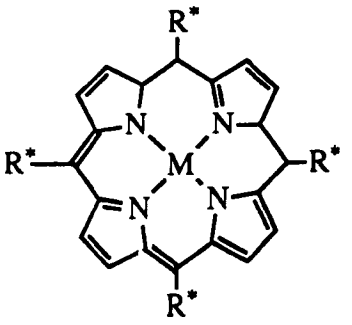
chiral porphyrin derivatives. The X-ray crystal structure of the Ru(II) porphyrin/styrene oxide complex (**99**) has been interpreted as lending indirect physical support to the side-on approach model (Figure 1.4).[94]

Since these porphyrin complexes are obtained by multistep synthesis in extremely low overall yields, high catalyst turnovers are essential if such systems are to be synthetically viable. To limit catalyst degradation, substrates have typically been employed in large excess relative to the iodosylarene derivative, and conversion to product has been limited to below 30%. Several practical problems associated with chiral porphyrin catalysts based on P-450 limit their potential applicability in organic synthesis. In addition to this the enantioselectivities that have been obtained to date in the epoxidation of alkenes are generally low.

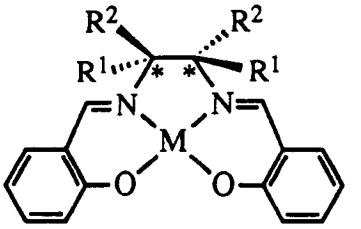
1.5.2.2 Salen-Based Oxo Transfer Catalysts

A breakthrough for asymmetric epoxidation of unfunctionalized alkenes was reported by Zhang and Jacobsen in 1991 using chiral Mn(III) salen [analogues of *N,N'*-ethylenebis(salicylidene aminato)] complexes. Unlike porphyrin systems, salen complexes bear tetravalent and thus potentially stereogenic carbon centres in the vicinity of the metal binding site. Stereochemical communication in epoxidation is thus enhanced, at least in principle, as a result the proximity of the reaction site to the ligand dissymmetry.[95]

Systematic variation of the steric and electronic environment of the chiral manganese salen complexes by Jacobsen's group has led to the discovery of effective and practical catalysts for the epoxidation of various important classes of olefins.



(100)



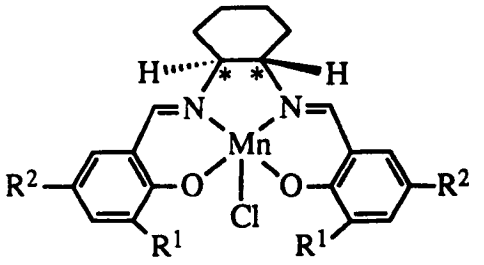
(101)

Generalized structures for chiral porphyrin and chiral salen complexes.

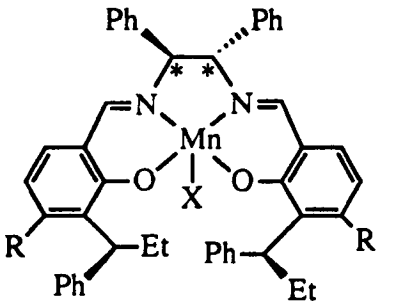
Figure 1.5

Chiral salen complexes with the general structure (**101**) shown in Figure 1.5 possess several structural and chemical features in common with porphyrins that render them appealing templates for chiral catalyst design. Both classes of coordination compound are sterically well defined and kinetically nonlabile, and thus they provide a sensible matrix for rational ligand design. The synthesis of salen complexes from chiral diamines is generally efficient and extremely straightforward. Some important chiral manganese (III) complexes are illustrated in Figure 1.6.

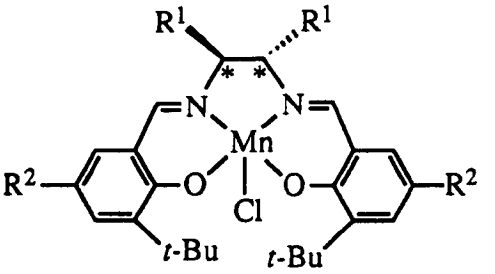
The side-on approach mechanism for olefin epoxidation which is proposed in Scheme 1.30 [104] has provide a useful model for making rational modifications and improvements to the catalyst system. The simplest possible mechanism would involve concerted, although not necessarily synchronous, formation of both oxygen carbon-bonds (Scheme 1.24a). Alternatively, stepwise bond formation may take place, through either polar or nonpolar intermediates (Scheme 1.24b). Evidence for rate-limiting electron transfer (Scheme



(**102**) $R^1 = R^2 = t$-Bu
Zhang,and Jacobsen,[21]
(**103**) $R^1 = t$-Bu, $R^2 = OSiMe_3$
Jacobsen and coworkers,[96]
(**104**) $R^1 = t$-Bu, $R^2 = OSi i$-Pr_3
Jacobsen and coworkers,[97]
(**105**) $R^1 = t$-Bu, $R^2 = Ot$-Bu
Jacobsen and coworkers,[98]
up to 98% e.e.

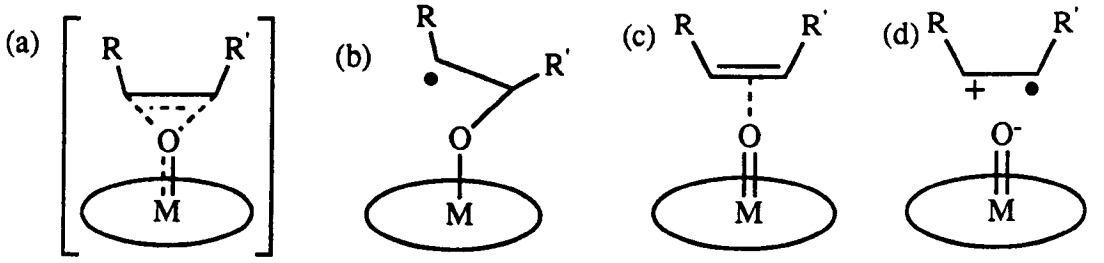


(**108**) R = H, X = OAc
(**109**) R = Me, X = PF_3
Katsuki and coworkers,[99-103]
up to 89% e.e.



(**106**) R^1 = Ph, R^2 = Me
(**107**) R^1 = Ph, $R^2 = Ot$-Bu
Jacobsen and coworkers,[98]
up to 93% e.e.

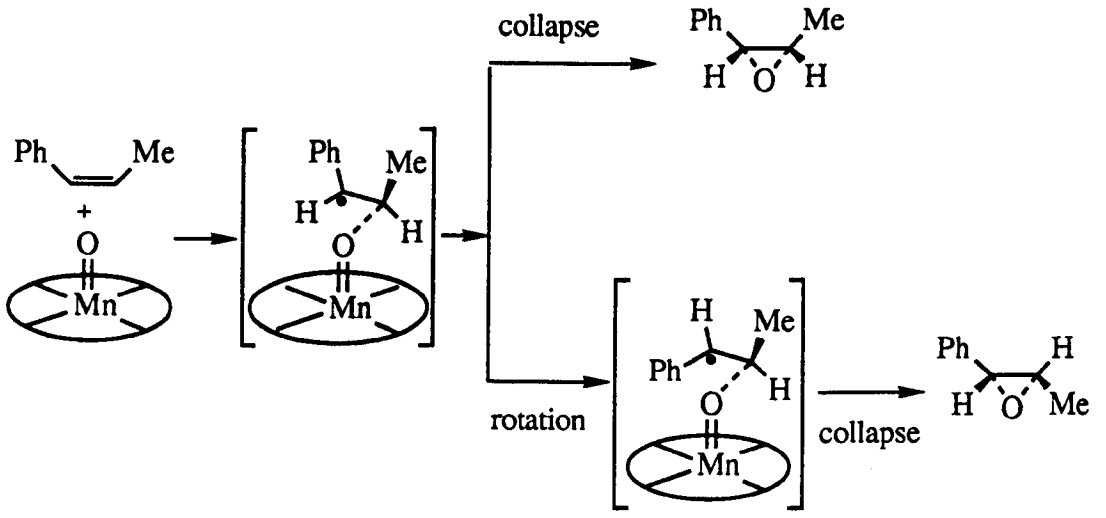
Figure 1.6 These chiral salen complexes are the most effective, and practical catalysts for epoxidation of unfuctionalized alkenes.



Scheme 1.24: Proposed mechanisms for oxygen atom transfer: (a) transition state for concerted mechenism, (b) nonpolar intermediate in stepwise mechanism, (c) charge transfer complex formation, and (d) electron transfer.

1.24c)[105] or charge transfer complex formation (Scheme 1.24d) has been presented in the porphyrin system.[106]

The mechanism favoured by Jacobsen and coworkers is the stepwise mechanism shown in Scheme 1.25[107] . However, as yet, the absolute configuration of the product epoxides can not be predicted.



Scheme 1.25

§ 1.6 Asymmetric Organic Synthesis involving Silicon

1.6.1 Silicon in Asymmetric Organic Synthesis

Silicon compounds have been used in asymmetric synthesis, especially in the area of asymmetric hydrosilylation, since "Wilkinson complex", $RhCl(PPh_3)_3$, first appeared.[108] Until the early 1980s, most chiral phosphine-rhodium catalysts afforded only low to moderate enantioselectivities(<58% e.e.). In 1989 the chiral bis(oxazolinyl)pyridine, Pybox, was introduced as a C_2-symmetric nitrogen ligand for the asymmetric hydrosilylation of ketones.[109] Improvements were obtained in the enantioselectivity of up to 95% *(S)*. Some examples of asymmetric hydrosilylations are:

1.) The asymmetric hydrosilylation of ketones shown as Scheme 1.26 [110];

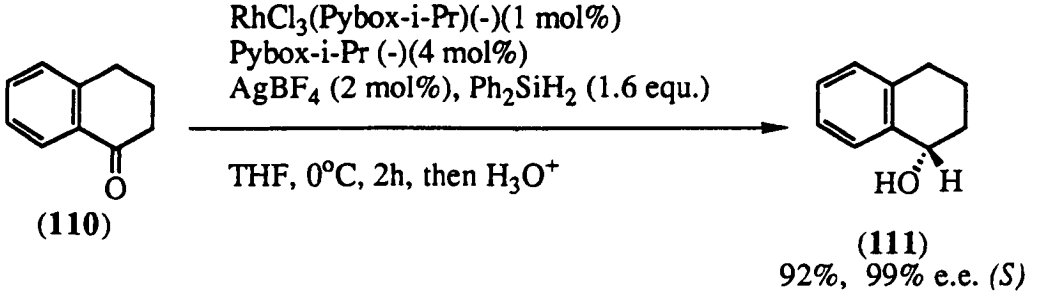
2.) The related reaction shown as Scheme 1.27 using ligands (**115**) and (**114**).

3.) The asymmetric hydrosilylation of keto esters shown in Scheme 1.28 [110].

4.) The asymmetric hydrosilylation of imines shown in Scheme 1.29 [111], using the chiral ligands (**120**), (**121**) and (**122**).

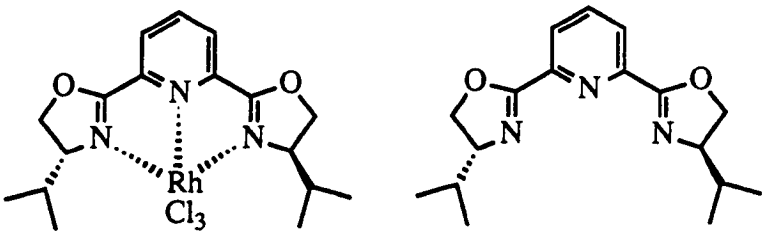
5.) The asymmetric hydrosilylation of alkenes shown in Scheme 1.30,[112] using the chiral ligands (**120**), (**121**) and (**122**).

6.) The asymmetric synthesis of chiral silicon compounds as shown in Scheme 1.31 [113] using the chiral ligands (**120**), (**121**) and (**122**).



(**110**)

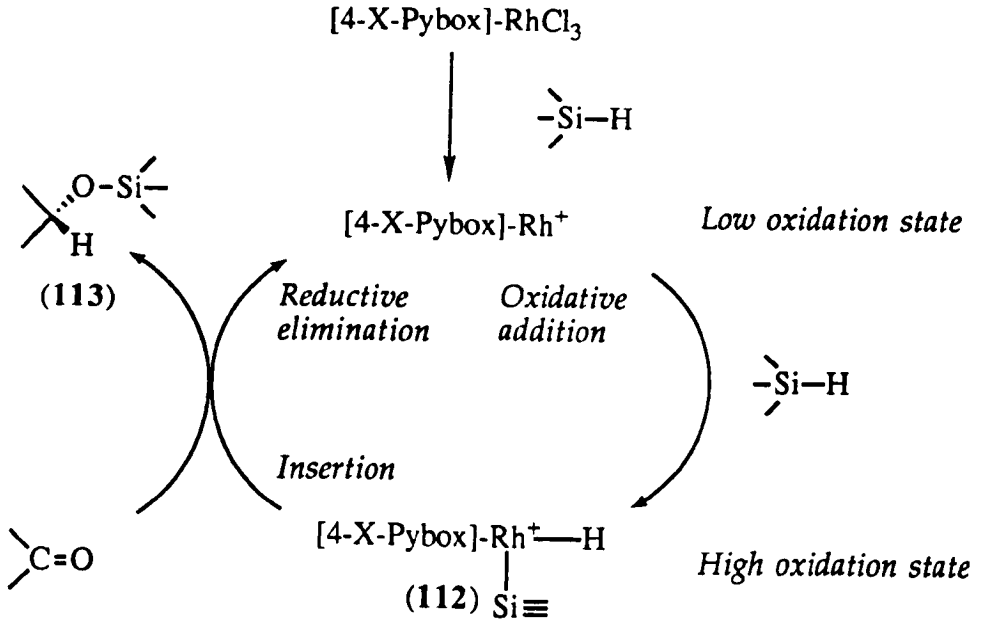
(**111**)
92%, 99% e.e. *(S)*



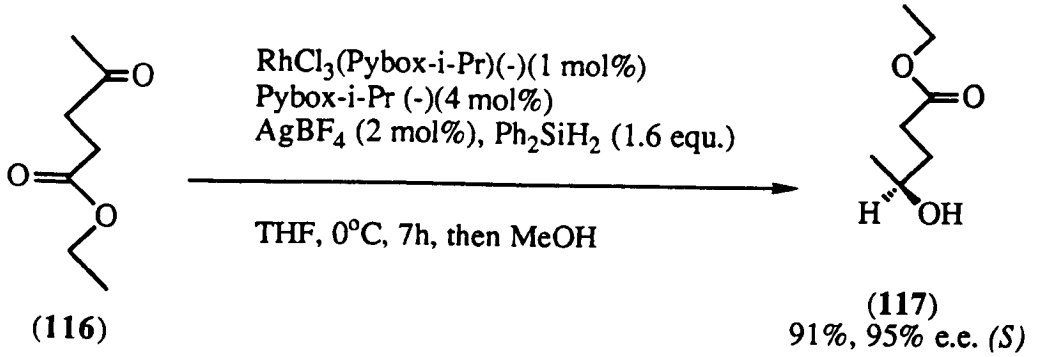
(**115**)

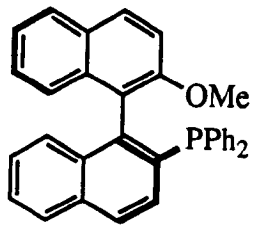
(**114**)
(R,R)-Pybox

Scheme 1.26

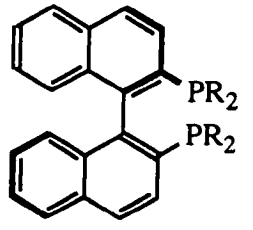


Scheme 1.27

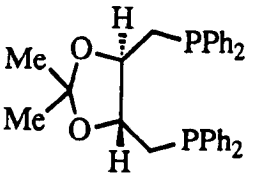




(S)-(-)-MOP
(120)

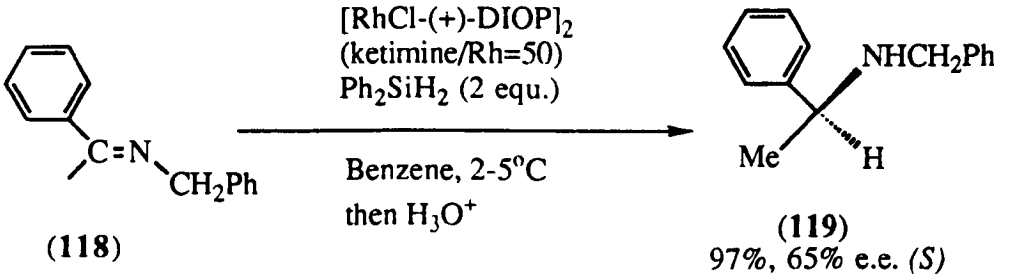


(R)-(+)-Cy-BINAP
R = cyclohexyl
(121)



(R,R)-(-)-DIOP
(122)

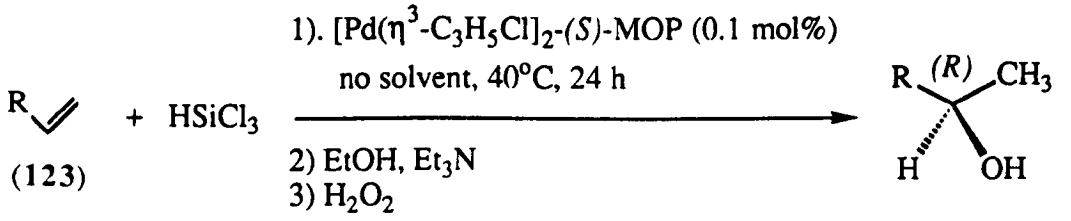
Scheme 1.28



(118)

(119)
97%, 65% e.e. *(S)*

Scheme 1.29

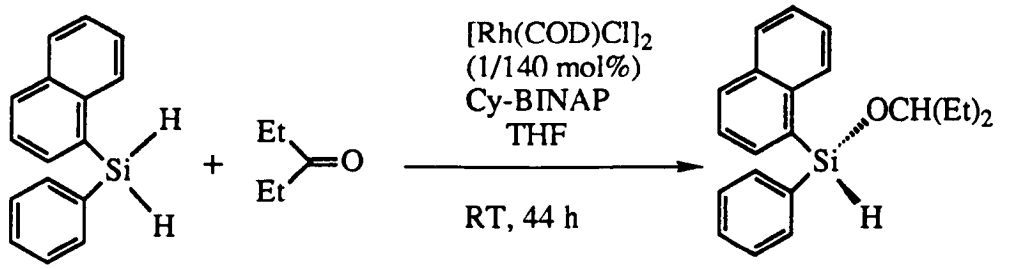


(123)

(124)

R=n-C_6H_{13}-	71%, 95% e.e. *(R)*
R=$PhCH_2CH_2$-	68%, 97% e.e. *(S)*

Scheme 1.30



(125)

(126)
64%, 85% e.e. *(R)*

Scheme 1.31

1.6.2 Objectives of the Present Work

Homogeneous chiral catalysis has been very successful in producing chiral compounds from achiral compounds containing double bond. This includes: ruthenium(II) asymmetric hydrogenation, rhodium (II) asymmetric isomerisation, titanium(d^0) asymmetric

epoxidation rhodium (III) asymmetric hydrosilylation. Most of these processes require a functionality containing a strong donor atom (oxygen or nitrogen) coordinated to the central metal. The most important silicon containing alkenes, allyl- and vinylsilanes do not contain such groups.

Allylsilanes [114,115] and vinylsilanes [114, 116,117] and their derivatives are versatile reagents in organic synthesis, owing to the powerful activating and directing effect of the silyl groups and ease of removal of the silicon fragment through such reaction as the Peterson reaction [118] β-eliminations [114] and fluorodesilylations [114,115,119]. Asymmetric reactions of the double bond of unfunctionalized allylsilanes and vinylsilanes would no doubt be of great synthetic utility.

The main aim of this work is the asymmetric oxidation of unfunctionalized allyl- and vinylsilanes. The traditional route based on the osmium tetroxide catalysed dihydroxylation of alkenes has already established a sound foundation on which to build. The present work involves an investigation of the asymmetric dihydroxylation of allyl- and vinylsilanes using the Sharpless asymmetric dihydroxylation. The results of such a study using allyl- and vinylsilanes are given in Chapter 2. The elaboration of these novel chiral silyldiols will be discussed in Chapter 3 and 4. This includes converting them into synthetically more valuable optically active silyl cyclic sulphites, cyclic sulphates, epoxides, azidoalcohols, aminoalcohols, and aziridines.

Another of our aims was the asymmetric epoxidation of allyl- and vinylsilanes. Jacobsen's manganese (III) salen complexes provides a convenient method for our purpose. During this study, a variety of axial ligands and substrates were investigated and this will be presented in Chapter 5.

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Chapter 2

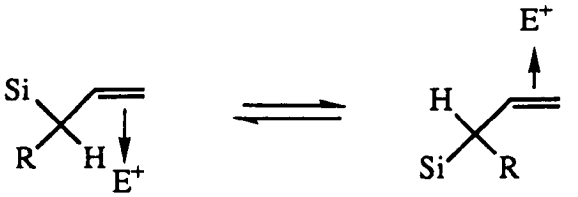
Asymmetric Dihydroxylation of Allyl- and Vinylsilanes

Contents

§ 2.1 Introduction

The synthesis of α,β–dihydroxysilanes by acid-catalyzed hydrolysis of α,β-epoxysilanes and subsequently by osmium tetroxide-catalyzed oxidation of vinylsilanes was first reported by Hudrlik.[1-3] He also reported[3] that α,β-dihydroxysilanes undergo elimination reactions with metalhydrides. With potassium hydride there was competition between the Brook[4] rearrangement and the Peterson reaction.[5] However, when sodium hydride was used as the base, the Brook rearrangement was the exclusive route and the silylenol ether was obtained with a high degree of stereoselectivity.

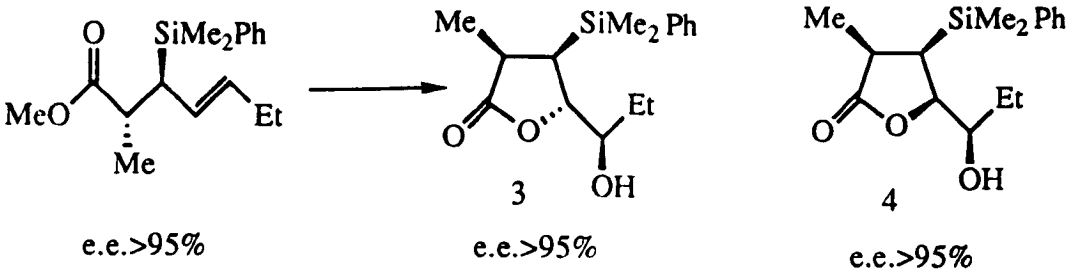
Fleming[6-8] examined the selective dihydroxylation of racemic E- and Z-allylsilanes, R(PhMe$_2$Si)CHCH=CHR and found some diastereoselectivity, especially when R=Ph. However, the selectivity was not as good as that obtained by epoxidation or the Yamamoto version of the Simmon-Smith methylation. In general increasing the size of R increased the likehood that the reaction took place in the Sense 1.



1 2

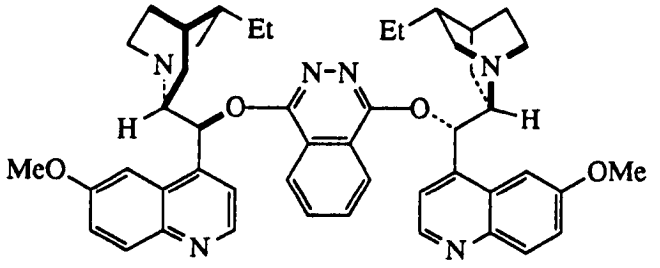
Fleming[7,8] also showed that the diols could undergo the Peterson elimination with sodium hydride, or a related fluoride-ion induced elimination, to give the allyl alcohols in stereoprecise reactions. Other diastereoselective osmylations of chiral allylsilanes using OsO_4, followed by the Peterson elimination, have been reported.[9,10]

Procter[11] carried out a double asymmetric induction of two chiral allylsilanes and, by using dihydroquinidine 4-chlorobenzoate as the catalyst[12], obtained e.e. values as high as 95% with a diastereoselectivity of **3:4**, of 91:9.

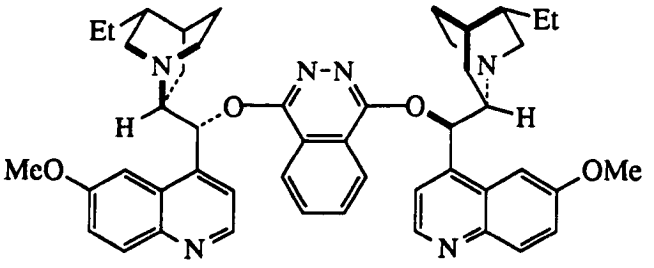


e.e.>95% e.e.>95% e.e.>95%

Silylated diols and their derivatives are versatile reagents in organic synthesis owing to the powerful activating and directing effect[13] of the silyl groups and ease of removal of the silicon fragment through such reaction as the Peterson reaction [5] β–eliminations[2] and fluorodesilylations. [14,15,16] However, no optically active silylated diols had been prepared before we began our study. Most of the approaches available to us were third-generation methods with the associated disadvantages of high cost and lower product e.e..



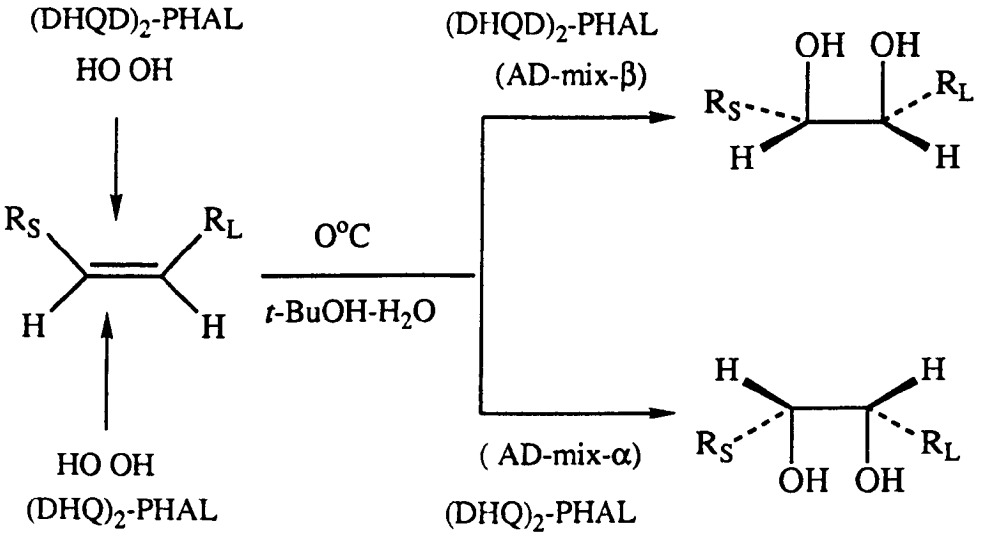
Bisdihydroquinidine- 9-*O*-phthalazine ether,
$(DHQD)_2$-PHAL



Bisdihydroquinine-9-*O*-phthalazine ether.
$(DHQ)_2$-PHAL

Figure 2.1

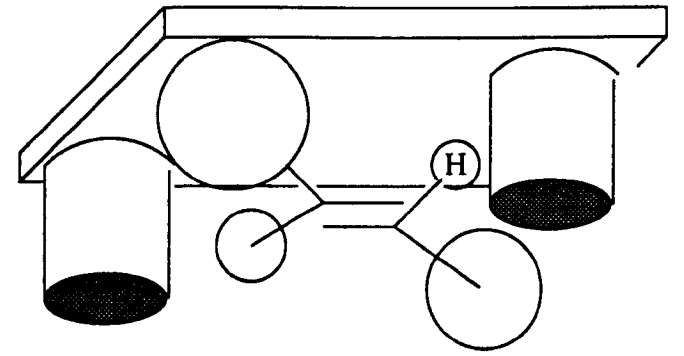
Sharpless's with osmium complex catalysts dihydroquinidine 4-chlorobenzoate (DHQD-CLB) ligands employing *N*-methylmorpholine *N*-oxide (NMO) as the oxidant provided a unique fourth-generation method for asymmetric dihydroxylation. With allyl-trimethylsilane the corresponding diol was obtained with an e.e. of 21%. This was obviously not satisfactory. Sharpless and coworkers subsequently published a process using osmium complex catalysts with phthalazine derivatives (Figure 2.1) of dihydroquinidine and dihydroquinine combined with $K_3Fe(CN)_6$-K_2CO_3 as the co-oxidant (Sharpless AD-mix) [17]. This process is illustrated in Scheme 1.19 and Scheme 2.1.

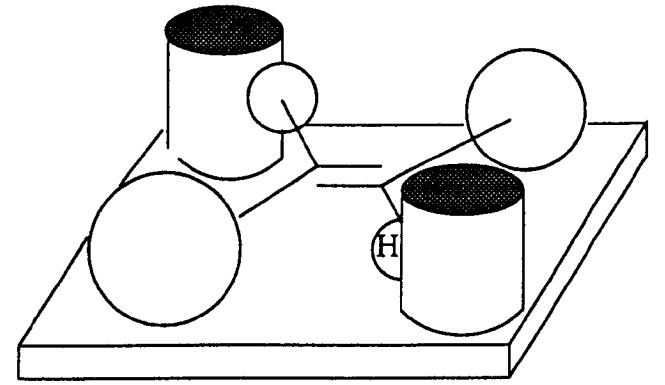


Scheme 2.1

The absolute configuration of the enantiomer enriched diol prepared using the dihydroquinidine derivative (AD-mix-β) is a mirror image of that prepared using the dihydroquinine derivative (AD-mix-α). The products can tentatively be predicted by the Sharpless mnemonic [17, 22] shown in Figure 2.2.

$(DHQD)_2$-based catalyst attack from above





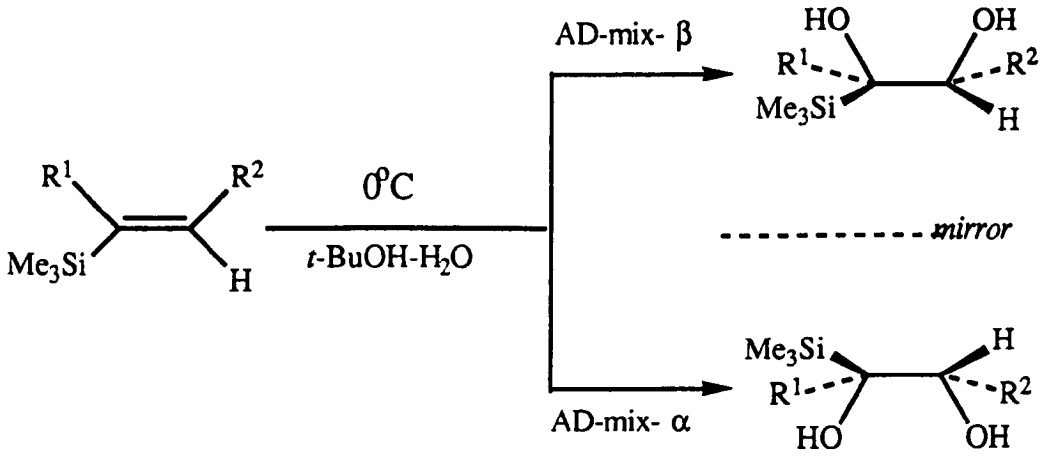
$(DHQ)_2$-based catalyst attack from below

Figure 2.2

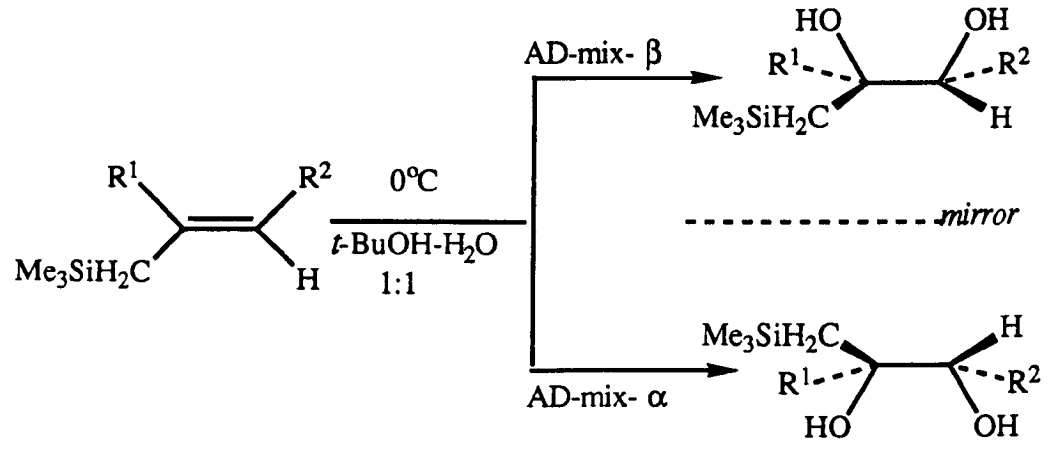
The enantiomeric excess of the diols formed from the *trans* alkenes, is normally greater than 94%, up to 99%; from trisubstituted alkenes, it is greater than 95% e.e.; and from terminal alkenes, it is greater than 70% e.e. However, the selectivity of this route for asymmetric dihydroxylation of allyl- and vinylsilanes was still unknown.

§ 2.2 Investigation of the asymmetric dihydroxylation of allyl- and vinylsilanes

Based on the atomic priority of the substituent groups on the alkenes, the asymmetric dihydroxylation of terminal, *trans*, and trisubstituted allyl- and vinylsilanes are illustrated in Scheme 2.2. The products from *cis* allyl-, and vinylsilanes is shown in Scheme 2.3.

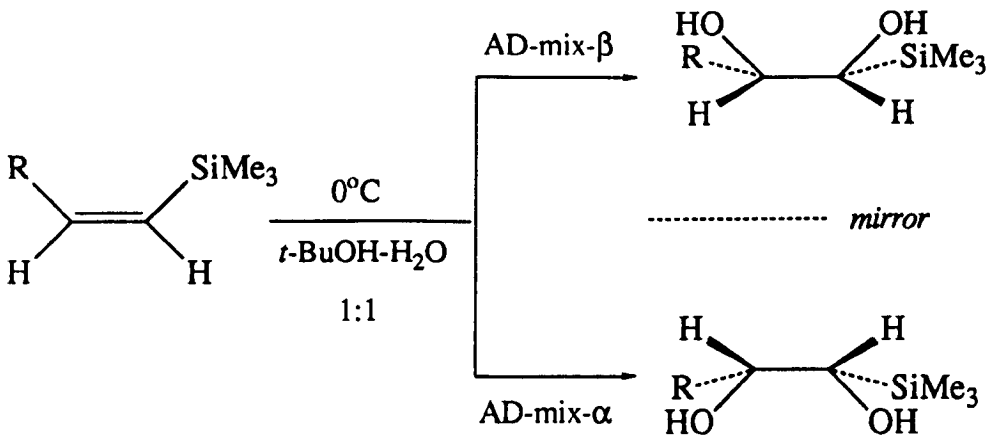


AD of terminal, trans, trisubstituted vinylsilanes

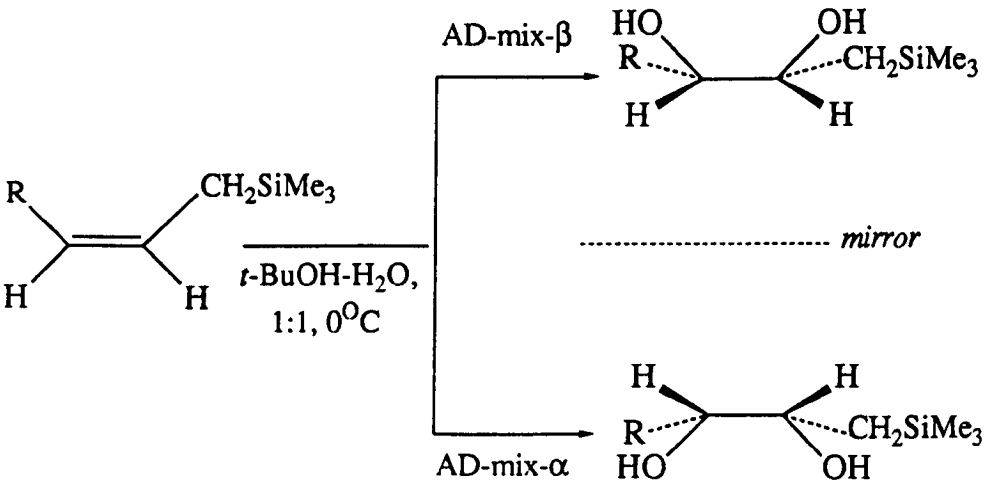


AD of terminal, trans, trisubstituted allylsilanes

Scheme 2.2



Asymmetric Dihydroxylation of *cis*-Vinylsilanes



Asymmetric Dihydroxylation of *cis*-Allylsilanes

Scheme 2.3

A variety of allyl- and vinyl-silanes were subjected to the Sharpless asymmetric dihydroxylation reaction using AD-mix-α and AD-mix-β catalysts. The aim was to

examine the effect of the silyl group on the enantioselectivity of the reaction and to use the resulting diols in synthesis. The effect of substitution at silicon was also examined.[18] We wished to investigate the effect of successively replacing the methyl groups in $SiMe_3$ by phenyl groups in the hope that there may be specific interactions with the aromatic ligands that would enhance the enantioselectivity. In the light of the strong directive and activating effect of the R_3Si group and its high steric bulk we were interested as to whether Z-vinyl- and allyl-silanes were dihydroxylated with any greater selectivity than their organic counterparts.

In this initial investigation we chose to limit the asymmetric dihydroxylation conditions to the use of the commercially available AD-mix-α and -β (Aldrich Chemical Co. Inc.). We prepared seventeen different vinyl- and allyl-silanes and dihydroxylated each using both AD-mix-α and -β. The enantiomeric excess of each reaction was measured by the use of the chiral shift reagent $Eu(hfc)_3$. This method involved the direct addition of $Eu(hfc)_3$ to the diol and integrating selected ^1H NMR resonances from each enantiomer.

2.2.1 Investigation of Asymmetric Dihydroxylation of Terminal Vinylsilanes

The isolated yields, conditions and e.e. for asymmetric dihydroxylation of terminal vinylsilanes are given in Table 2.1.

We were surprised to discover that the e.e. for dihydroxylation of $Me_3SiCH{=}CH_2$ with either of the two AD-mixes was as low as 34%, since Sharpless had obtained e.e. values between 74 and 93% for monosubstituted alkenes.[17] We repeated the experiment several times and each time obtained a similar result. Subsequently we discovered[18, 19] that Sharpless[20] and Soderquist[21] found e.e. values of about 44% for dihydroxylation of vinyltrimethylsilane. It is not clear why the trimethylsilyl group should lower the e.e. so significantly, but it is now well-established that large substituents on the silicon lower the enantioselectivity even more. We found that as methyl was replaced by

Table 2.1, Asymmetric Dihydroxylation of Terminal Vinylsilane

Vinyl silane	AD-mix- β				AD-mix- α			
	%e.e.†	°C	h	yield%	%e.e.†	°C	h	yield%
Me_3Si	34	0	14	80	34	0	14	81
$PhMe_2Si$	27	0	48	83	25	0	48	84
Ph_2MeSi	0	0	62	30	0	0	62	31
Ph_3Si	0	0	96	25	0	0	96	0
n-C_8H_{17} *	84				80			

† The enantiomeric excess was determined by ^1H NMR in the presence of europium chiral shift reagent [Eu(hfc)$_3$]: tris[3-(heptafluoropropylhydroxymethylene)-(+)-camphorato], europium(III) derivative.

* From reference 17.

phenyl, two effects were observed. First, the time for reaction increased and isolated yields decreased considerably. As n in $Me_{3-n}Ph_nSiCH=CH_2$ increased from 0 to 3 the time for reaction with AD-mix-β at 0°C increased from 14 to 96 h while the yield dropped from 80 to 25% (there were no observed by-product. The remainder of the mass balance was accounted for by unchanged vinylsilane). With AD-mix-α there was no reaction with $Ph_3SiCH=CH_2$ after 96 h and the silane was recovered unchanged. Concomitantly, as the number of phenyl groups and the reaction time increased the e.e. decreased dramatically from 34% with vinyltrimethylsilane to 0% with vinyl methyldiphenylsilane and vinyltriphenylsilane. A similar effect has been noted previously[20, 21] as isopropyl groups replaced methyl groups, but the effect on the e.e. and the yield was not as marked. In both reports the increased steric effect of the isopropyl group was cited as the most likely cause of the effect. The phenyl group is roughly equivalent to an isopropyl group in size, so it is possible that with a phenyl group both steric and electronic effects militate against efficient asymmetric induction.

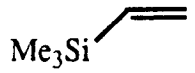
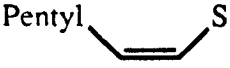
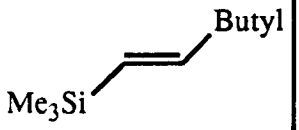
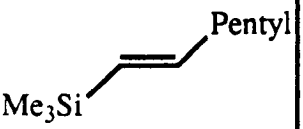
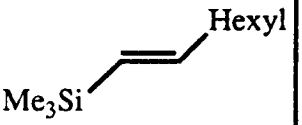
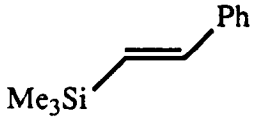
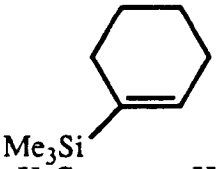
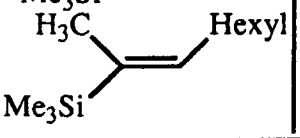
2.2.2 Investigation of asymmetric dihydroxylation of vinylsilanes

Of the nine vinyltrimethylsilanes used there is at least one example of each of the five types of alkene: monosubstituted vinylsilanes; *E*- and *Z*-disubstituted vinylsilanes; a trisubstituted vinylsilane; and a cyclic vinylsilane. The results of dihydroxylation are shown in Table 2.2.

The large trimethylsilyl group was not a universally ineffective substituent in asymmetric dihydroxylations. The *E*-vinylsilanes(entries 4-7 in Table 2.2) gave extremely high e.e. values, >95%, with both AD-mixes.

The one example of a disubstituted vinylsilane (entry 9) was interesting in that it did not react with either AD-mix at the usual 0°C even after more than one week. However, after

Table 2.2, Asymmetric dihydroxylation of vinylsilane

	Vinyl silane	AD-mix- β				AD-mix- α			
		%e.e.*	°C	h	yield%	%e.e.*	°C	h	yield%
1		34	0	14	80	34	0	14	81
2		61	0	26	81	61	0	26	78
3		61	0	24	84	61	0	24	83
4		96	0	24	76	95	0	24	79
5		96	0	24	86	97	0	24	65
6		96	0	24	87	97	0	24	85
7		97	0	28	83	97	0	28	82
8		82	0	24	82	81	0	24	84
9		85	20	168	53	80	20	168	47

* The enantiomeric excess was determined by ^1H NMR in the presence of europium chiral shift reagent [Eu(hfc)$_3$]: tris[3-(heptafluoropropylhydroxymethylene)-(+)-camphorato], europium(III) derivative.

a week at 20°C an isolated yield of about 50% was obtained with e.e. values of 80 and 85% with AD-mix-α and AD-mix-β, respectively.

2.2.3 Investigation of asymmetric dihydroxylation(AD) of allylsilanes

The asymmetric dihydroxylation of five of allylsilanes was tested with both AD-mixes, and the conditions, chemical yields, and enantiomeric excess are illustrated in Table 2.3.

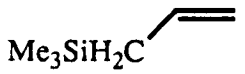
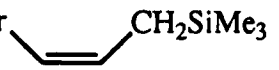
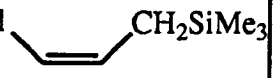
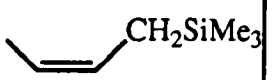
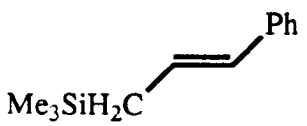
As with dihydroxylation of non-silylated alkenes [12, 22] the *Z*-alkenes gave diols with a lower e.e. than their *E*-counterparts. *Z*-1-trimethylsilyloct-2-ene (entry 4, Table 2.3) was readily dihydroxylated but the e.e. was relatively modest 53%. Sharpless commented on the 'meso' problem, as modelled by catalyst-substrate interactions [23], as a factor in the lower e.e. values obtained for *Z*-alkenes. The pentyl and the methyl trimethylsilyl groups should have rather different steric demands and it is not easy to rationalise the low e.e. value in this case simply by a meso effect. Similarly low e.e. values were obtained for the *Z*-allylsilanes shown in entries 2 and 3, in Table 2.3. In these examples we varied the length of the carbon chain attached to the double bond but found it to have no measurable effect on reaction times. Once again the difference between vinyl- and allyl-silanes in asymmetric dihydroxylation is insignificant.

§ 2.3 Determination of Enantiomeric Excess of Silyldiols

Although rapid progress has been made in the last ten years in developing sensitive and accurate GC [24] and HPLC [25] methods of analysis to determine the enantiomeric excess of chiral compounds, many practising organic chemists prefer NMR methods. Gas chromatographic methods in particular are preferred for quality control in pharmaceutical and fine chemical applications, being more precise than the NMR-based methods. The HPLC methods of chiral analysis are also used to an increased extent as a result of improvements in column lifetime and performance.

Although enantiomers cannot be distinguished by NMR in an achiral medium, since the resonances of enantiotopic nuclei are isochronous, diastereomers may be distinguished because the resonances (of certain diastereotopic nuclei) are anisochronous. The chemical shift

Table 2.3, Asymmetric dihydroxylation of allylsilane

	Allylsilanes	AD-mix- β				AD-mix- α			
		%e.e.*	℃	h	yield%	%e.e.*	℃	h	yield%
1		34	0	14	82	34	0	14	81
2		54	0	24	83	50	0	24	81
3		43	0	24	81	50	0	24	79
4		53	0	24	82	53	0	24	84
5		95	0	28	86	95	0	28	86

* The enantiomeric excess was determined by ^1H NMR in the presence of an europium chiral shift reagent [Eu(hfc)$_3$].

nonequivalence of diastereotopic nuclei in diastereoisomers in which the stereogenic centres are covalently linked in a single molecule was first noted by Cram.[26]

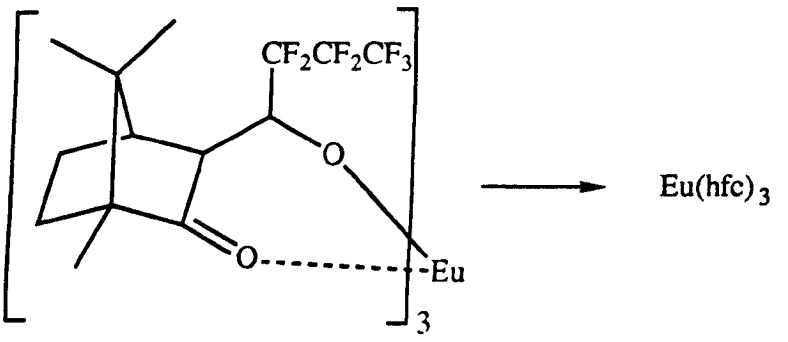
The determination of the enantiomeric purity using NMR requires the use of a chiral auxiliary that converts the mixture of enantiomers into a diastereomeric mixture. As long as there is a large enough chemical shift nonequivalence to give baseline resolution of the appropriate signals, then integration gives a direct measure of diastereoisomeric composition which can be related directly to the enantiomeric composition of the original mixture.

There are three types of chiral auxiliary that can be used. [27] They are Chiral lanthanide shift reagents (CLSRs), [28,29] chiral solvating agents (CSAs), [30,31] and chiral derivatizing agents (CDAs). [32]

A highly convenient method of chiral analysis of alcohols is to use a ^{31}P NMR method through formation of diastereoisomeric phosphate ester derivatives using chiral phosphorus derivatizing agent(CDAs).[33-38] Chiral alcohols are analyzed commonly via conversion to their α-methoxy-α-(trifluoromethyl)phenyl acetate (CDAs) [39-45] via reaction of α-methoxy-α-(trifluoromethyl)phenyl acetic acid (MTPA) with the chiral alcohol in the presence of base. The CDAs *O*-methylmandelic [46,47] and *O*-acetylmandelic acid [48] (both available commercially) often give improved shift nonequivalence in ^{1}H NMR analysis (particularly the latter) and the esters may be formed under nonracemizing conditions by the use of dicyclohexylcarbodiimide as a coupling agent, in the presence of the acyl-transfer catalyst dimethylaminopyridine. Alcohols are amenable to analysis using CSA but generally only small Δδ values are obtained.

In the case of chiral silyldiols, the most convenient method of chiral analysis is CLSR analysis with $Eu(hfc)_3$. The advantages of this approach over other methods are cheapness, directness, big Δδ values (the HO chemical shift, δ, up to 50 ppm), reliability and speed. The disadvantage is the line broadening of ^{1}H NMR of HO resonances, but this does not necessarily affect chiral analysis.

$Eu(hfc)_3$ is tris [3 -(heptafluoropropylhydroxymethylene) - (+) - camphorato], europium (III):



The magnetic interaction between the $Eu(hfc)_3$ chiral shift reagent and the protons of the silyldiol coordinated to the Eu(III) ion is shown in Figure 2.3. [49,50]

The resonances of the OH are broadened by interaction with the paramagnetic Eu(III) ion.

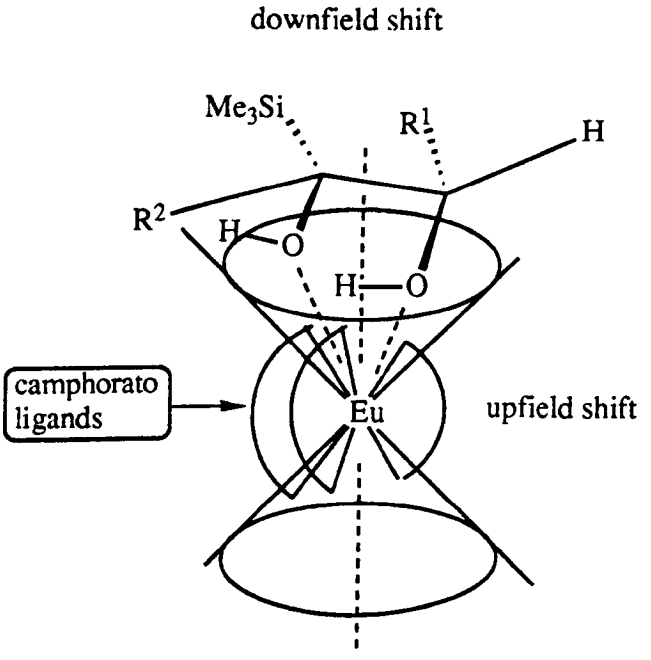


Figure 2.3. Deshielding occurs along the effective pseudosymmetry axis of $Eu(hfc)_3$ complexes, and shielding perpendicular to this axis.

The diols derived from allyltrimethylsilane with both AD-mixes are presented as an example. The protons in these two enantiomers are designated as shown as Figure 2.4.

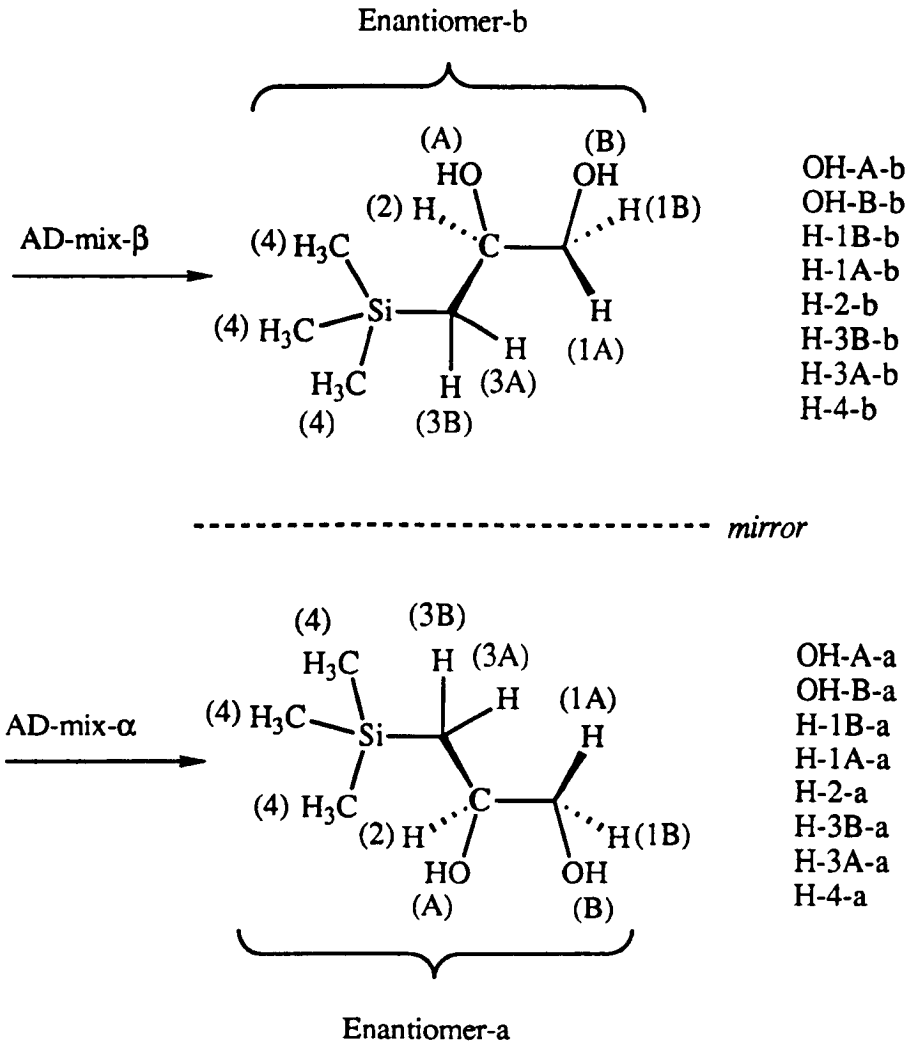


Figure 2.4

When the $Eu(hfc)_3$ is gradually added to the racemic diol, the molar ratio of the chiral shift reagent to diol increases from 0 to 1 and all of the protons in the two enantiomers were gradually shifted down field. Figures 2.5, 2.6, 2.7, 2.8, and 2.9 show the changes in 1-H chemical shift (ppm) against the ratio of the shift reagent to diol.

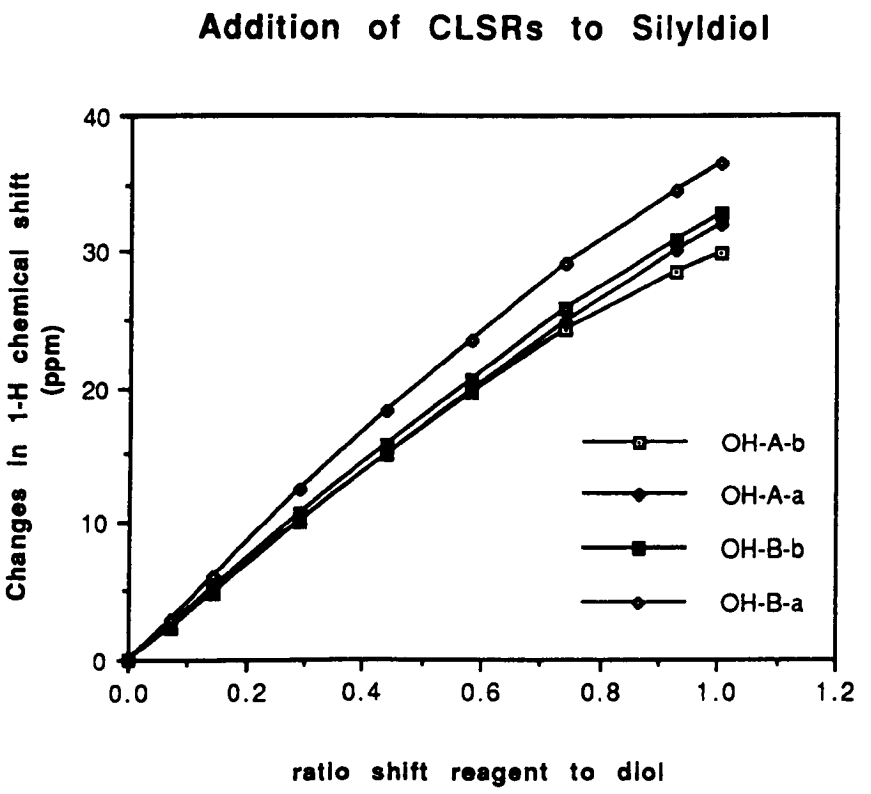


Figure 2.5

The changes in 1-H chemical shift of the protons of the OH groups (OH-A-b, OH-A-a, OH-B-b, OH-B-a) are greater than 30 ppm (Figure 2.5), but the peaks are broadened (Figure 2.10). The changes in the two CH (H-1A-b, H-1A-a, H-1B-b, H-1b-a) resonances on the terminal hydroxy-bearing carbon atom are greater than 17 ppm (Figure. 2.6, Figure. 2.9, and Figure 2.10). The changes in the CH (H-2-b, H-2-a) resonances on the other hydroxy-bearing carbon atom are only about 9.5 ppm (Figure 2.8, Figure 2.10). Very remarkable results were obtained (Figure 2.7, Figure 2.10) for the separation of the resonances for the protons (H-3A-b, H-3A-a, H-3B-b, H-3B-a) on the carbon next to the hydroxy-bearing carbon. The changes of the chemical shifts of these protons is greater than 7 ppm (Figure 2.7). Good separations were obtained for the resonances of the CH_3 protons (H-4-b, H-4-a) in the silyl groups as shown in Figure 2.8, but these resonances overlapped with shift reagents.

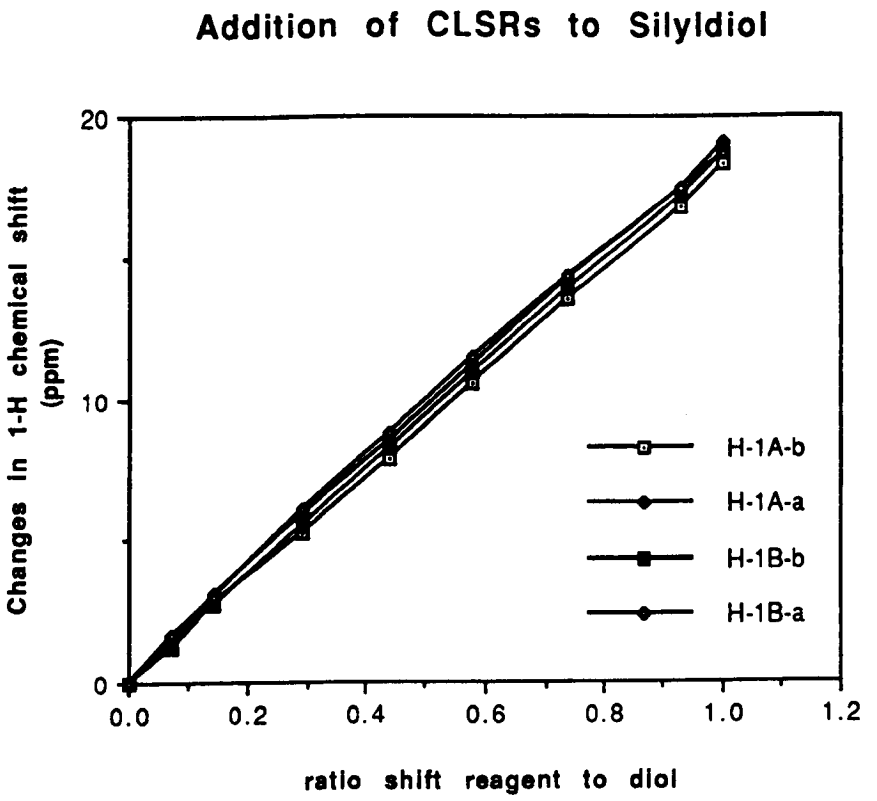


Figure 2.6

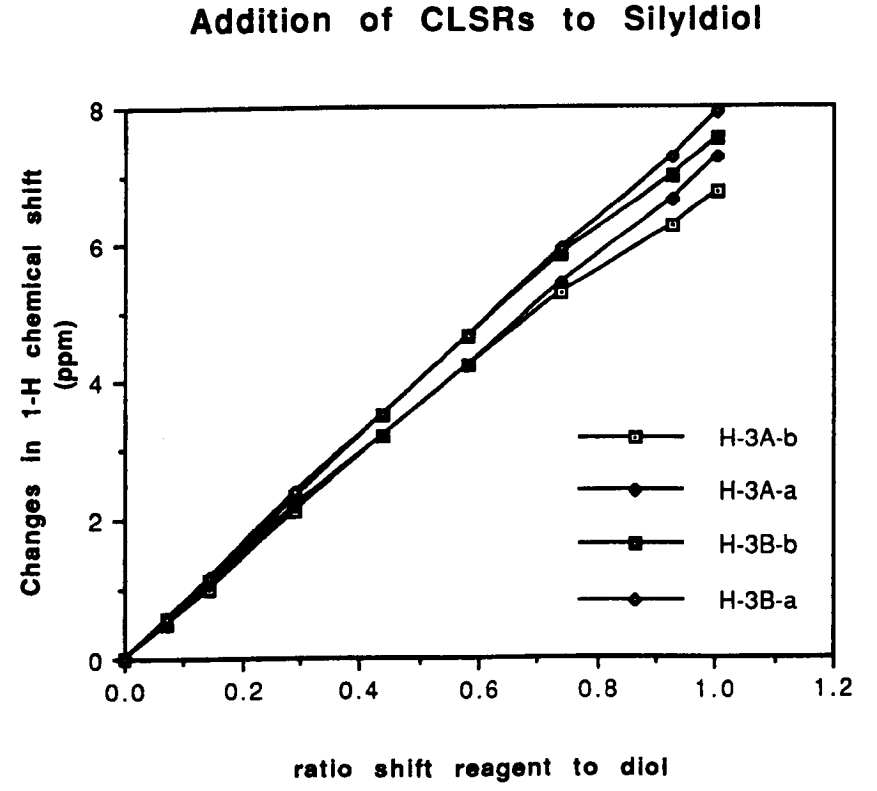


Figure 2.7

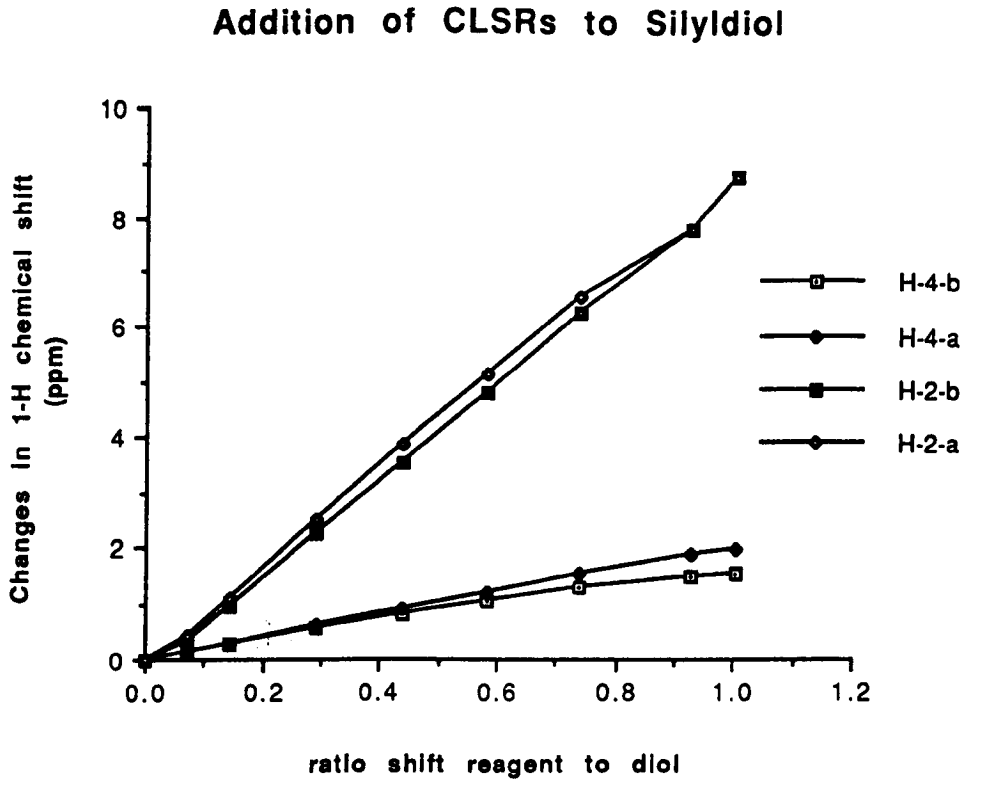


Figure 2.8

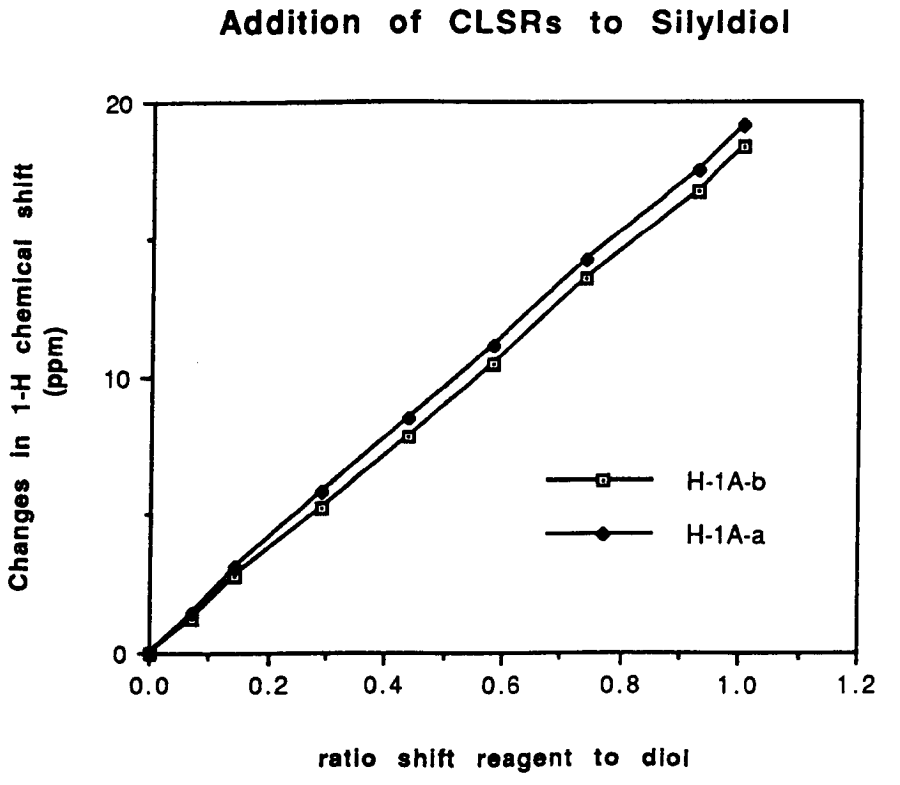


Figure 2.9

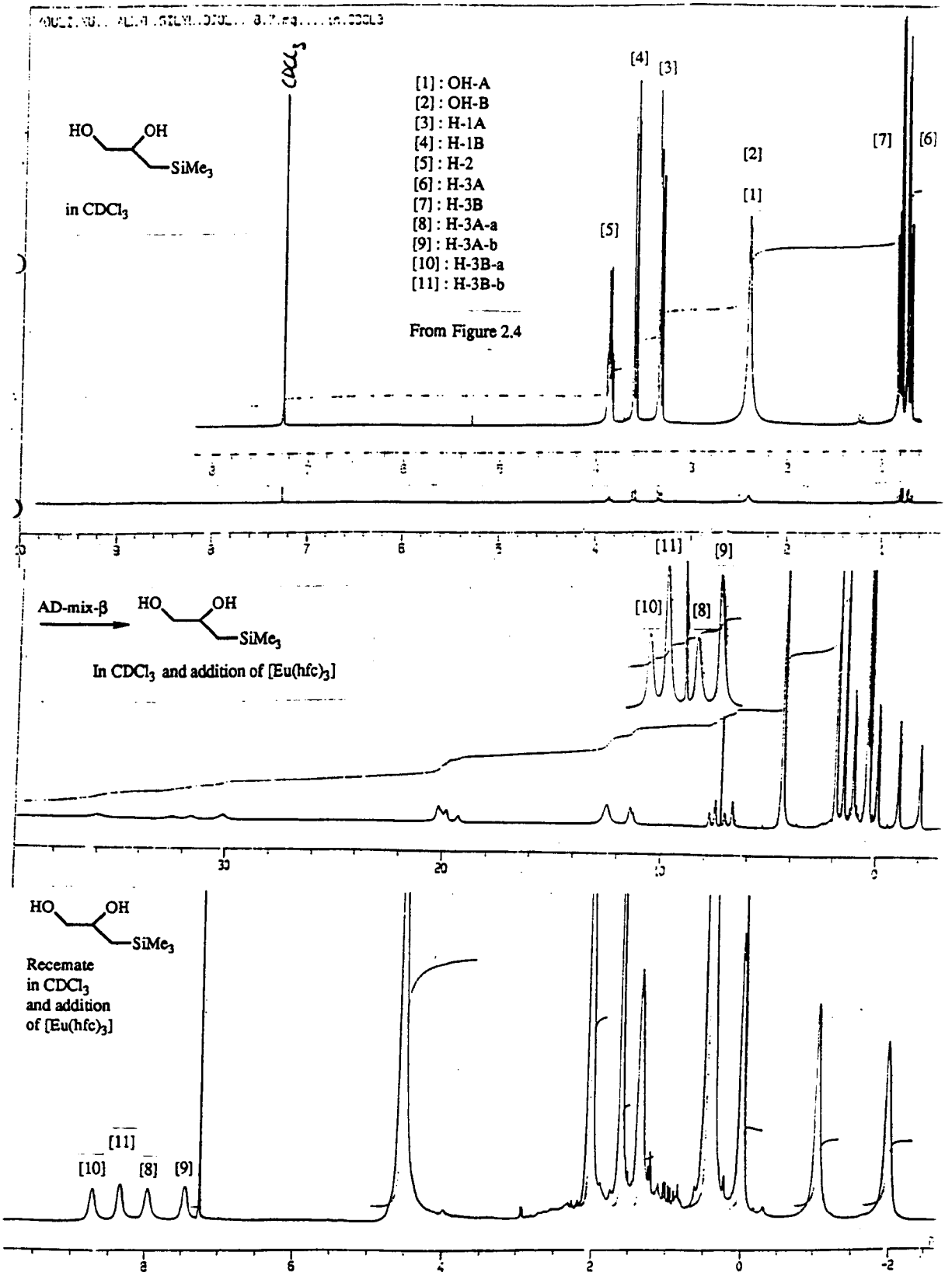

HO
OH
SiMe3
in CDCl3
[1] : OH-A
[2] : OH-B
[3] : H-1A
[4] : H-1B
[5] : H-2
[6] : H-3A
[7] : H-3B
[8] : H-3A-a
[9] : H-3A-b
[10] : H-3B-a
[11] : H-3B-b
From Figure 2.4
AD-mix-β
In CDCl3 and addition of [Eu(hfc)3]
Recemate
in CDCl3
and addition
of [Eu(hfc)3]

Figure 2.10

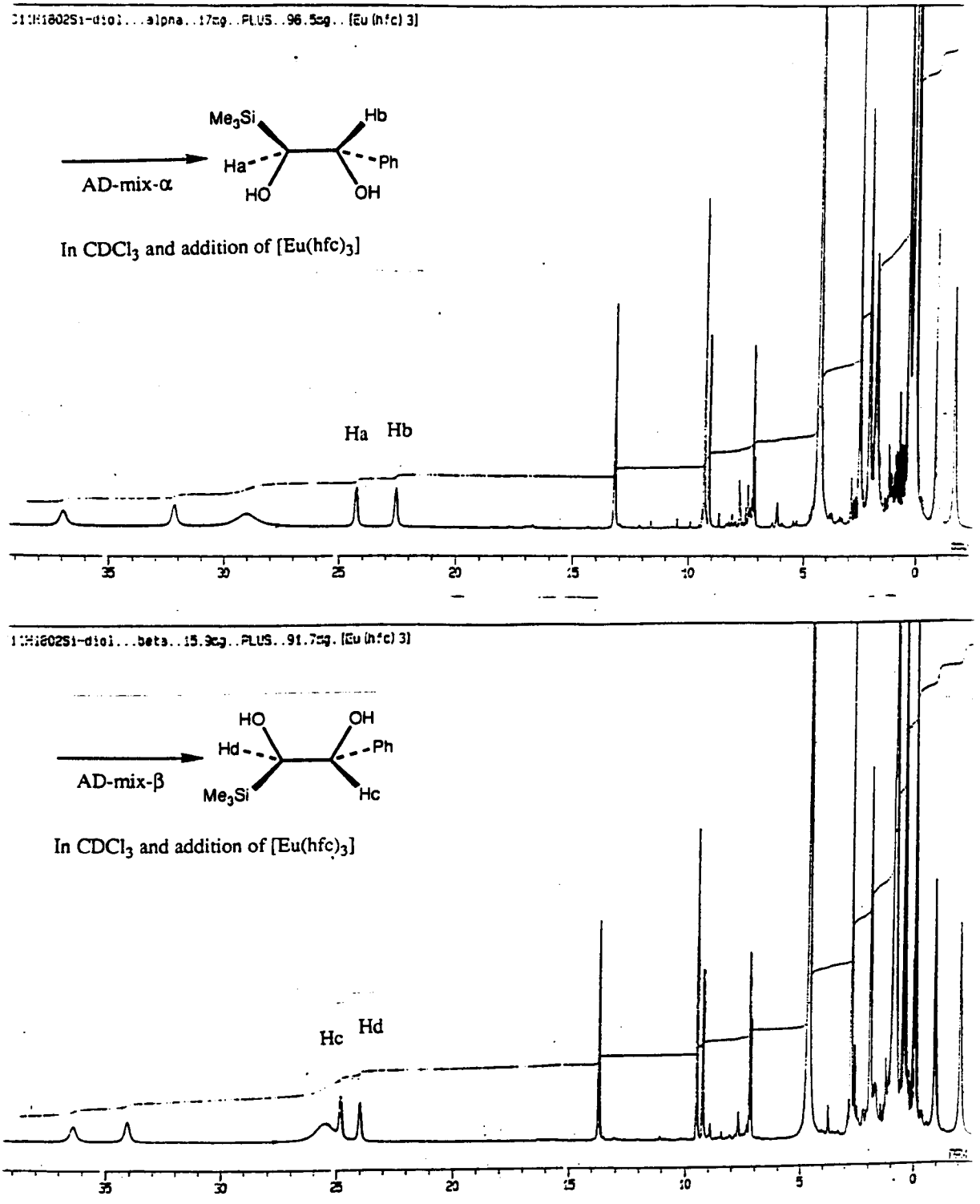
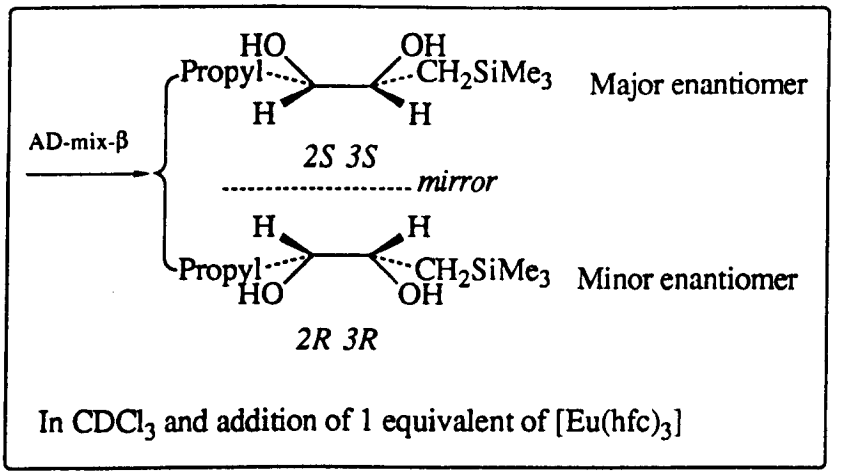
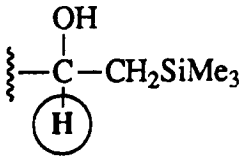

Me3Si
Hb
Ha
Ph
HO
OH
AD-mix-α
In CDCl3 and addition of [Eu(hfc)3]
Ha Hb
35 30 25 20 15 10 5 0
HO
OH
Hd
Ph
AD-mix-β
Me3Si
Hc
In CDCl3 and addition of [Eu(hfc)3]
Hc Hd
35 30 25 20 15 10 5 0

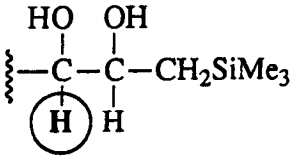
Figure 2.11

Sample:

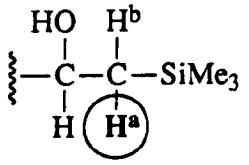




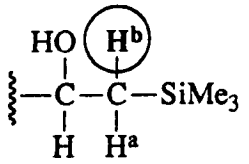
[1] *2S 3S* [2] *2R 3R*



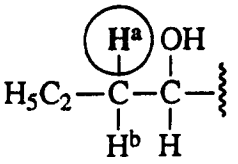
[3] *2S 3S* [4] *2R 3R*



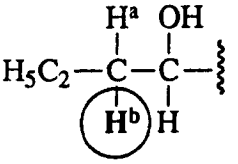
[5] *2S 3S* [6] *2R 3R*



[7] *2S 3S* [8] *2R 3R*



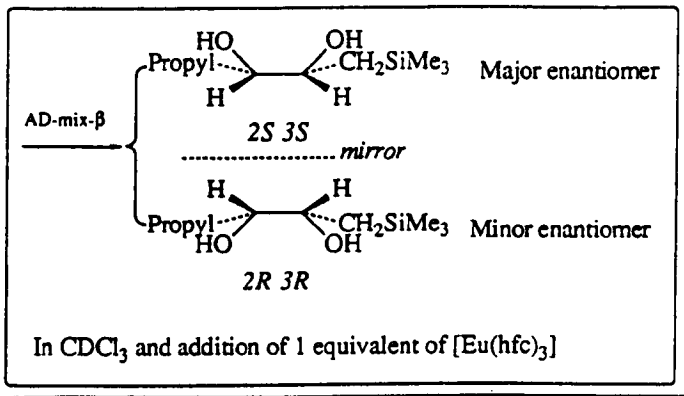
[9] *2S 3S* [10] *2R 3R*



[11] *2S 3S* [12] *2R 3R*

Figure 2.12.1

Sample:



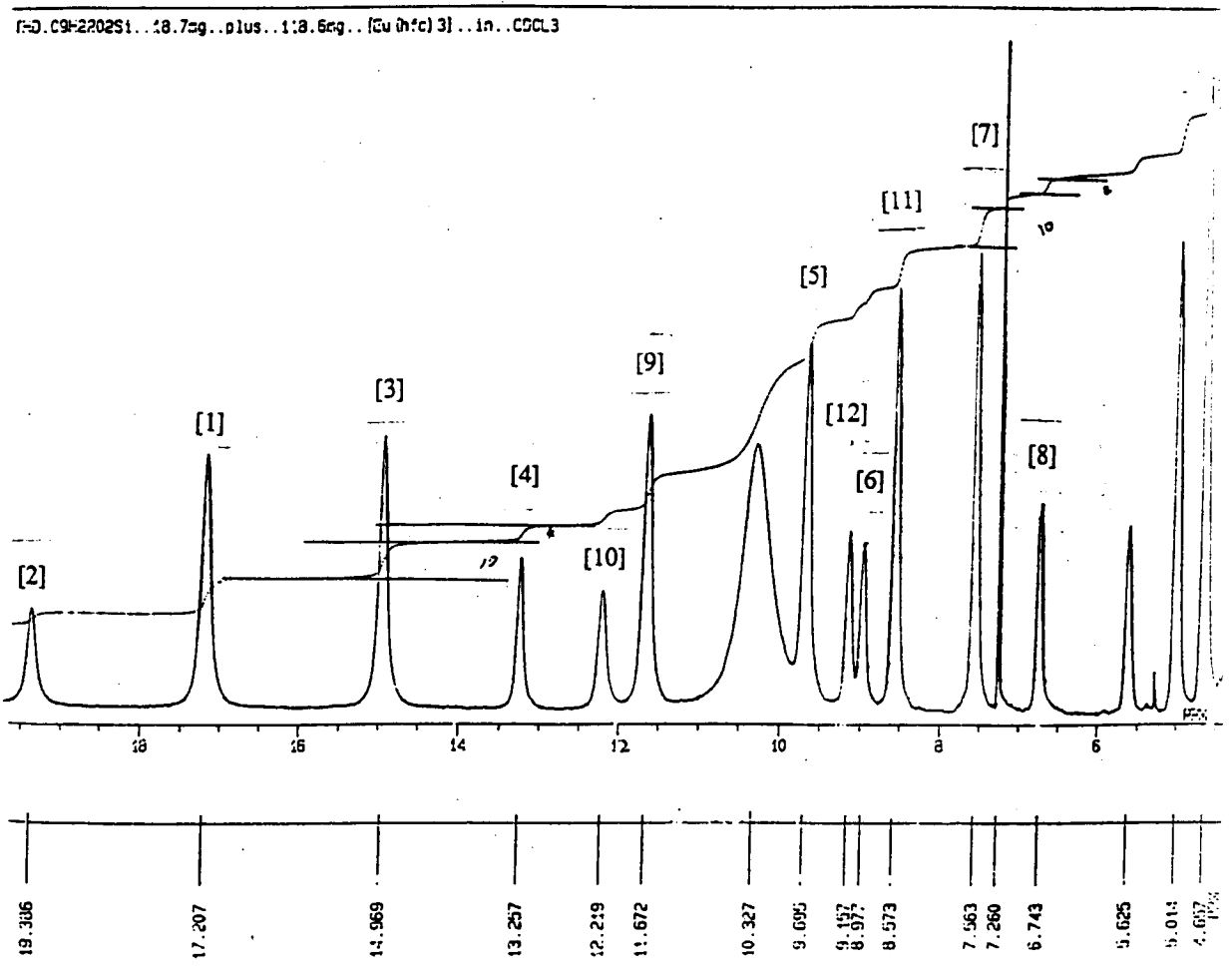


Figure 2.12.2

In general, in the presence of $Eu(hfc)_3$, the CH resonances on the hydroxy-bearing carbon atoms gave isolated, readily recognisable signals and integrations that were reproducible (Figure 2.11). Occasionally, especially in the cases of allylsilanes or allyl- and vinyl-silanes with carbon chain substituents, the best proton resonances for chiral analysis were those from protons bonded to the carbon adjacent to, or next but one to, the hydroxy-bearing carbon (Figure 2.12.1 and 2.12.2). The results obtained compare very favourably with those obtained by derivatisation to form Mosher's diesters. [21,40,52] The shift reagent mixtures reached equilibrium within 30 minutes and provided a quick and reliable measure of the enantiomeric excess. To confirm our interpretation, racemic diols were prepared in a number of examples and in each case the relative position and integration of the CHO or others resonances of the two enantiomers matched those of the enriched samples.

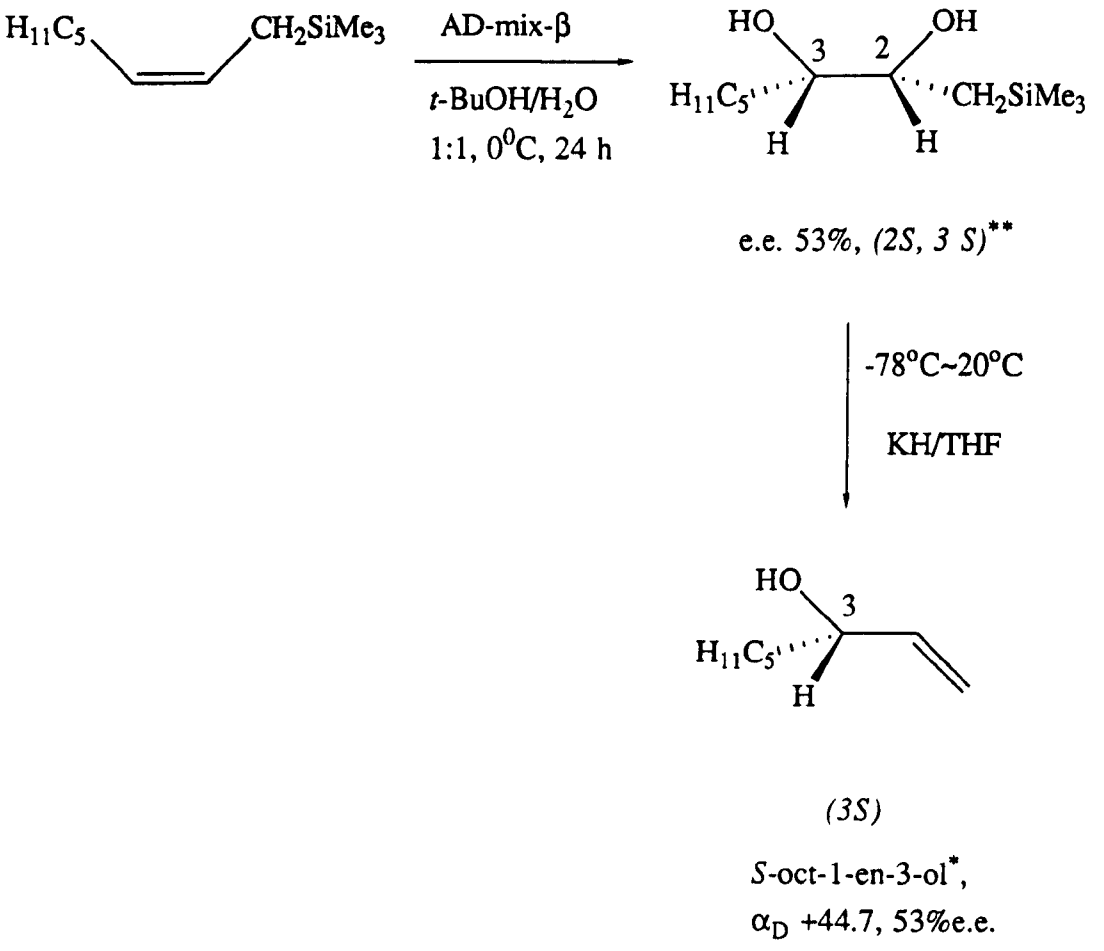
§ 2.4 Absolute Configuration of Silyldiols

The configuration of a particular enantiomer can be determined by X-ray diffraction, and was first applied in 1951 by Bijvoet to (+)-tartaric acid. The procedure is difficult and time consuming and can be applied only to certain compounds. In spite of this limitation, the configurations of thousands of other compounds are now know, since their structure can be related by chemical methods to (+)-tartaric acid Most of these relationships were established by application of the axiom that the configurational relationship between two optically active compounds can be determined by converting one into the other using reactions that do not involve breaking of a bond to a chiral centre.

All of the optically active silylated diols prepared by asymmetric dihydroxylation of allyl- and vinyl-silanes with AD-mixes are new compounds. Employing the Sharpless mnemonic, [22,17] and with the changes in the group priorities taken into account, the configuration of diols can be predicted using Scheme 2.2, and Scheme 2.3. For example, the configuration of the diol obtained from *Z*-trimethylsilyloct-1-ene with AD-mix-β is *1R*,

2S (see Scheme 2.3), and diol from *E*-trimethylsilyloct-1-ene is *1R, 2R* (see Scheme 2.2). Nevertheless, these structures need to be confirmed.

Scheme 2.4



* Reference 51. ** Reference 22 and 17.

Table 2.4, Asymmetric dihydroxylation of allyl & vinylsilane (to be continued)

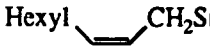
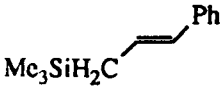
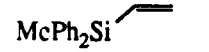
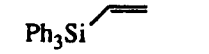
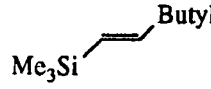
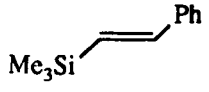
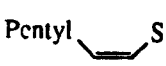
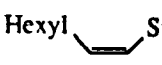
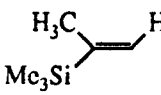
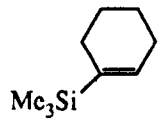
Entry, Allyl & vinyl silane	AD-mix-β / $(DHQD)_2$-PHAL					AD-mix-α / $(DHQD)_2$-PHAL				
	e.e.%†	config*.	°C	h	yield%	e.e.%†	config*.	°C	h	yield%
1 	34	*2S*	0	14	82	34	*2R*	0	14	81
2 	54	*2S,3S*	0	24	83	50	*2R,3R*	0	24	81
3 	43	*2S,3S*	0	24	81	50	*2R, 3R*	0	24	79
4 	95	*2S,3R*	0	28	86	95	*2R,3S*	0	28	86
5 	53	*2S,3S*	0	24	82	53	*2R,3R*	0	24	84
6 	34	*1R*	0	14	80	34	*1S*	0	14	81
7 	27	*1R*	0	48	83	25	*1S*	0	48	84
8 	0	----	0	62	30	0	----	0	62	31
9 	0	----	0	96	25	0	----	0	96	0
10 	96	*1R,2R*	0	24	76	95	*1S,2S*	0	24	79
11 	96	*1R,2R*	0	24	86	96	*1S,2S*	0	24	85
12 	96	*1R,2R*	0	24	87	96	*1S,2S*	0	24	85
13 	97	*1R,2R*	0	28	83	97	*1S,2S*	0	28	82

Table 2.4, Asymmetric dihydroxylation of allyl & vinylsilane (continued)

	Entry, Allyl & vinyl silane	AD-mix-β / $(DHQD)_2$-PHAL					AD-mix-α / $(DHQD)_2$-PHAL				
		e.e.%†	config*.	°C	h	yield%	e.e.%†	config*.	°C	h	yield%
14		61	*1R,2S*	0	26	83	61	*1S,2R*	0	26	85
15		61	*1R,2S*	0	26	81	61	*1S,2R*	0	26	78
16		85	*1R,2R*	20	168	53	80	*1S,2S*	20	168	47
17		82	*1R,2R*	0	24	86	81	*1S,2S*	0	24	87

† The enantiomeric excess was determined by 1H NMR in the presence of europium chiral shift reagent [Eu(hfc)3]: tris[3-(heptafluoropropylhydroxymethylene)-(+)-camphorato], europium(III) derivative.

* The absolute configuration are tentatively predict by Sharpless mnemonic. [17, 22] Some of them have been confirmed by a chemical degradation method.

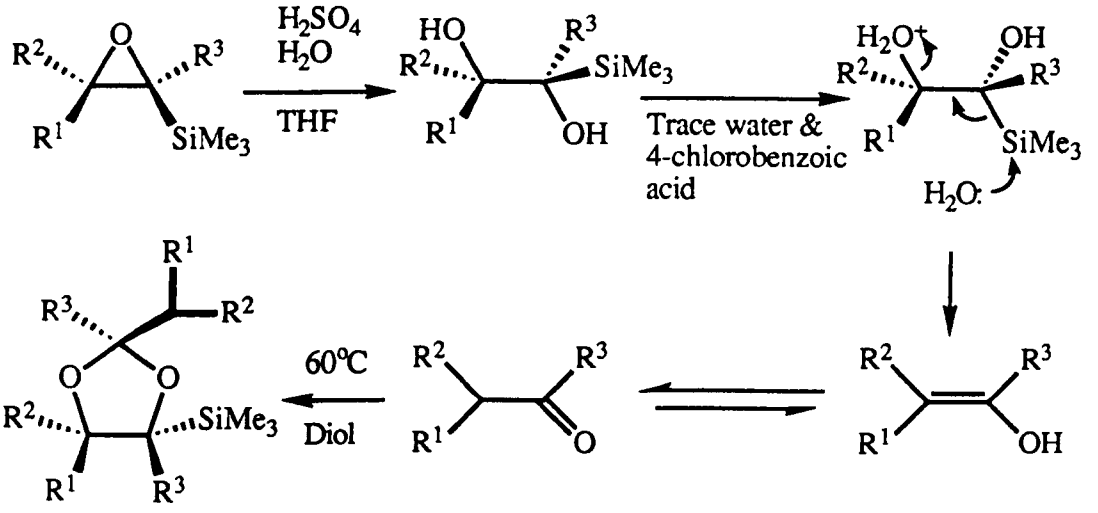
We successfully prepared chiral secondary alcohols of known configurations in high yield by the KH-induced Peterson elimination reaction of the diols obtained from asymmetric dihydroxylation of *E*- and *Z*-allylsilanes. For example, the configuration of the diol derived from *Z*-allylsilane with AD-mix-β entry 5 in Table 2.4 was predicted to be *2S,3S*. This was converted to the *S*-oct-1-en-3-ol using KH as shown in Scheme 2.4. The *3S*-configuration of the secondary alcohol was confirmed by comparison of its positive rotation of +44.7 with that of an authentic sample of *S*-oct-1-en-3-ol.

So far, we have been unable to confirm the absolute configuration of the diols derived from vinylsilanes because we have been unable to find a reaction that can be used

unambiguously to convert these diols into compounds of know configuration. However, we have no reason to believe that the Sharpless mnemonic will not be followed.

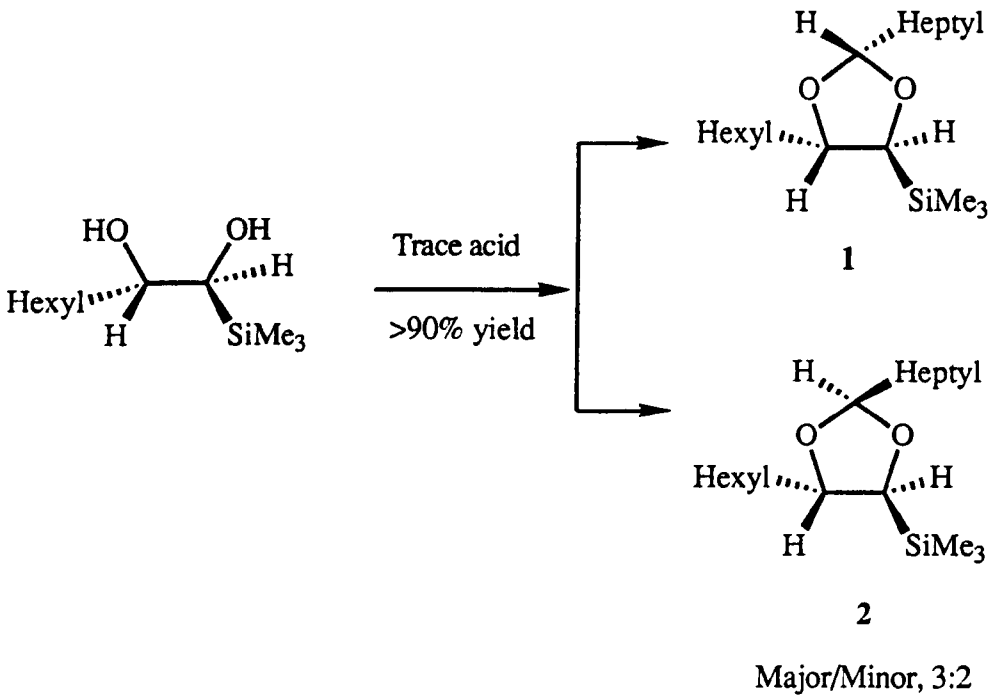
§ 2.5 Formation of silyl cyclic acetal compounds

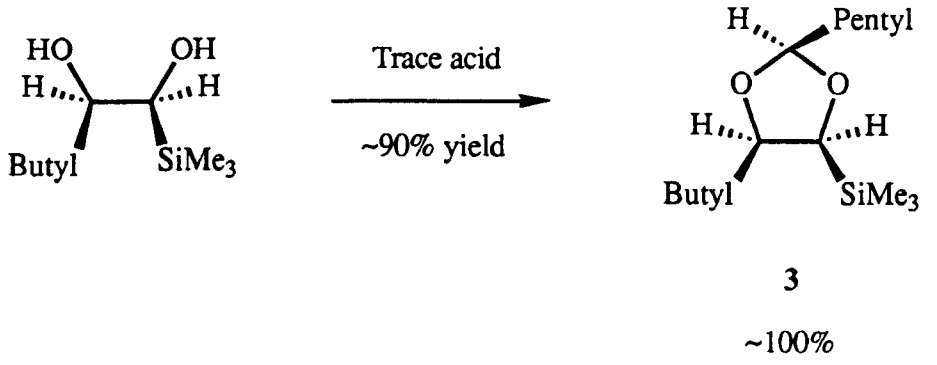
All of the diols that were prepared are stable under normal conditions and show no tendency to decompose spontaneously in the absence of acid or base. Hudrlik has described the reaction of 1-trimethylsilyl-1,2-diols with base but there is no information about their reactions with acid. We heated *threo*-1-trimethylsilyloctane-1,2-diol under reduced pressure with a trace of acid and obtained an almost quantitative yield of the diastereoisomeric acetal **1** and **2**. Presumably the acid catalyses the elimination of Me_3SiOH to give octanal which, again with acid catalysis, reacts rapidly with the diol to form the cyclic acetals (Scheme 2.5). NMR spectroscopy clearly shows the presence of two diastereoisomers in a ratio of about 60:40. No attempt was made to separate the diastereoisomers or identify which was formed in excess.



Scheme 2.5

A similar reaction with *erythro*-1-trimethylsilylhexane-1,2-diol gave a single acetal, **3**, stereoselectively (Scheme 2.6). This was shown unambiguously by NOE measurements to be the *cis*-isomer (Figure 2.13). The all-*cis* configuration of **3** initially seemed surprising, but examination of molecular models showed that in this configuration the substituent groups can all adopt pseudo-equatorial conformations. Such a relief of strain is not possible in the superficially less crowded *cis, trans, -trans* configuration.





Scheme 2.6

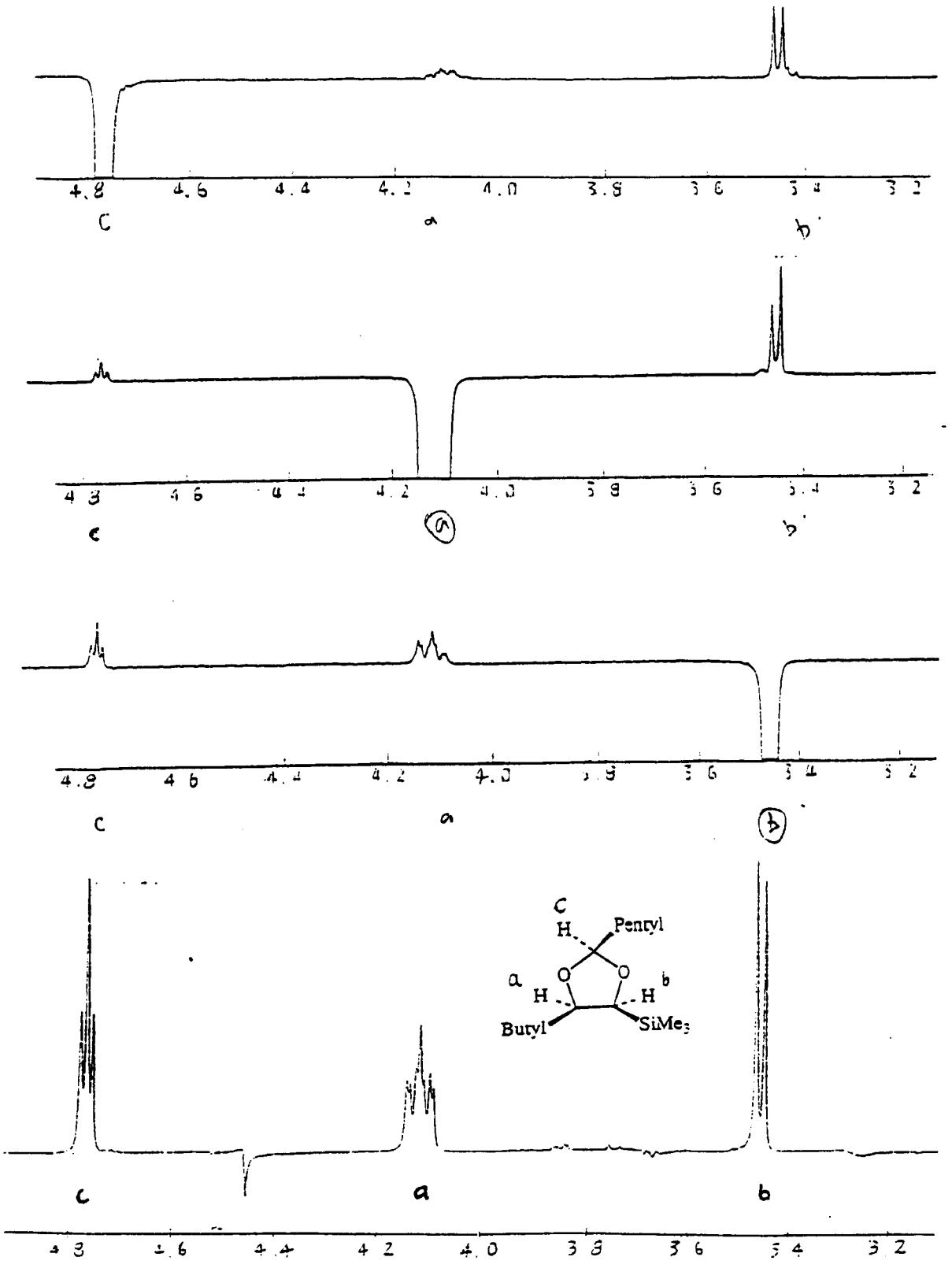


Figure 2.13 NOE experiment of silyl cyclic acetal

§ 2.6 Conclusion

1. AD-mix-α and AD-mix-β are successful catalysts for asymmetric dihydroxylation of *trans*-vinyl and allyl-silanes. An enantiomeric excess of silyldiol of greater than 95% can be achieved.

2. With terminal vinylsilanes, as the size of the silyl group is increased the e.e. drops from 34% to 0%, the yields drop from 80% to 25% (or 0% for AD-mix-α), but the reaction time increase from 14 to 96 hours.

3. The absolute configuration of optically active silyl-2,3-diols can be tentatively predict by the Sharpless mnemonic, and can be confirmed by chemical degradation.

4. The enantiomeric excess of silyldiols can be determined using ^{1}H NMR in the presence of europium chiral shift reagent Eu(hfc)$_3$

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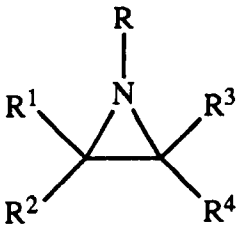
Chapter 3

Synthesis of Optically Active Trimethylsilyl Amino Alcohols and Aziridines

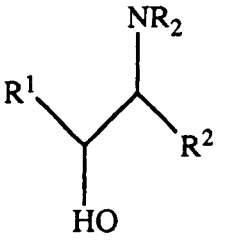
Contents

§ 3.1 Making Use of The New Source of Chiral Trimethylsilyl Vicinal Diols

The previous chapter described the preparation of a variety of optically active trimethylsilyl diols. One of our aims was to convert these diols into synthetically useful trimethylsilyl amino alcohols and aziridines. Aziridines (**1**) are saturated three-membered heterocycles containing one nitrogen atom.

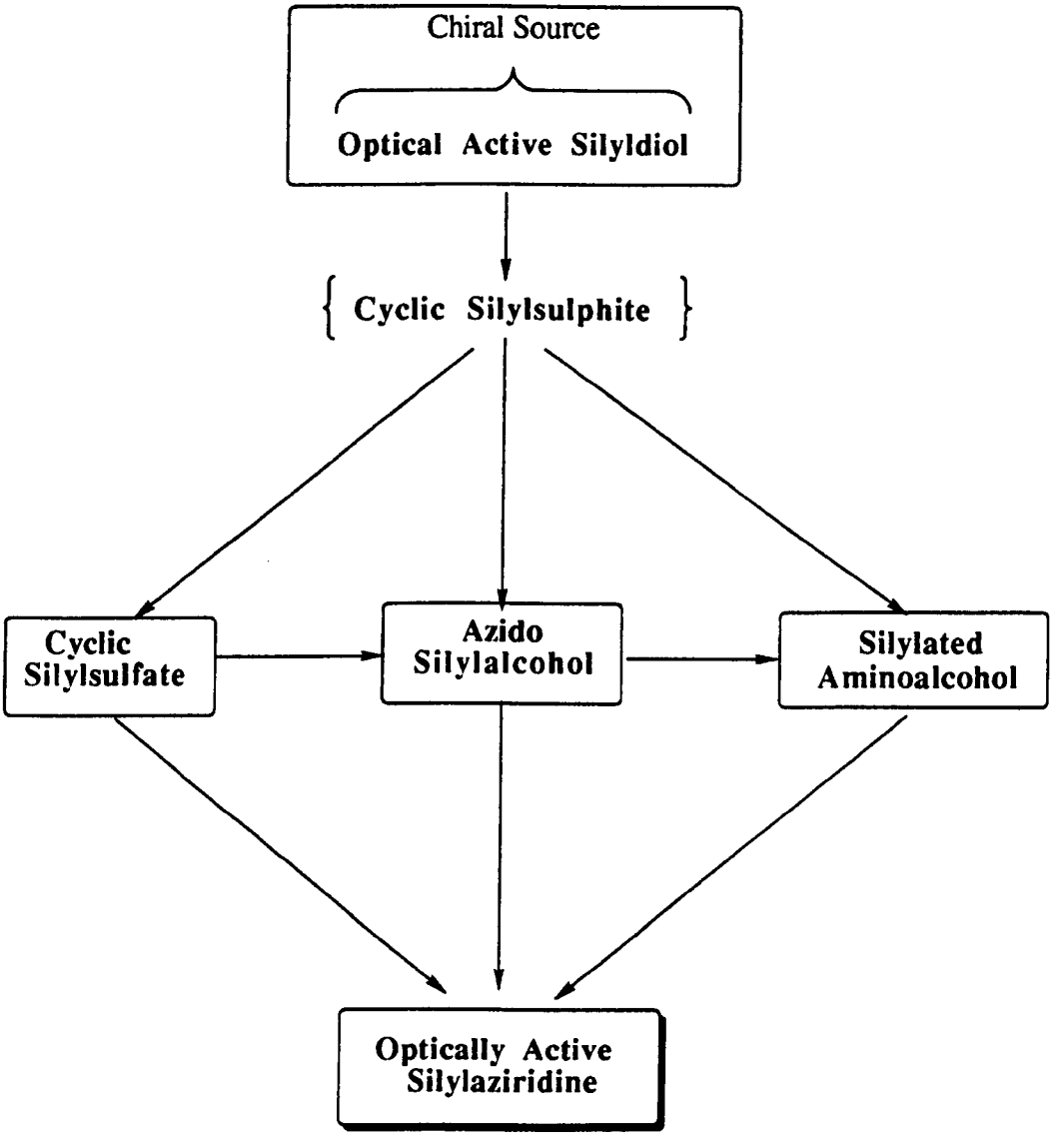


(**1**)



(**2**)

This class of compound dates back to 1888, when Gabriel (unwittingly) synthesized the parent member.[1] Like other three membered rings such as cyclopropanes and epoxides, aziridines are highly strained.[2] Ring strain renders aziridines susceptible to ring opening reactions and this dominates their chemistry, making them useful synthetic intermediates that fully deserve a prominent place in the arsenal of the organic chemist. With such a long history of aziridine chemistry, it is not surprising that the literature on the subject is very extensive. Several excellent reviews are available.[3] The growing importance of functionalized aziridines in organic synthesis, [4 3c)] and their presence in biologically active molecules [5-10], has created a need for synthesizing optically active aziridines. 1,2-Aminoalcohols (**2**), like amino acids are widely used[4-6] as chiral starting materials in organic synthesis, bioorganic synthesis and the pharmaceutical industry.



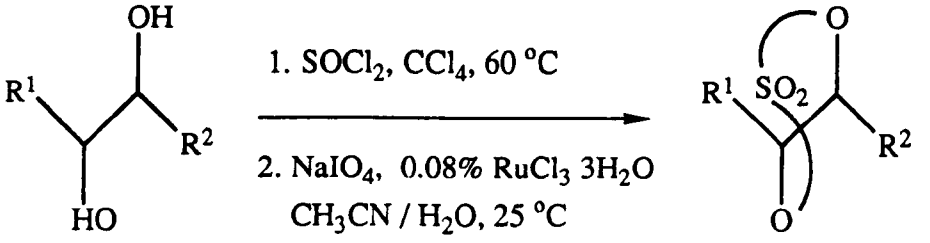
Scheme 3.1

However, optically active trimethylsilyl amino alcohols and aziridines are not known. To prepare such compounds , we need a chirality transformation from the diols to the target products. Routes, via cyclic sulphites, and cyclic sulphates to amino alcohols and aziridines have been reported for the organic counterparts.[11,12] We thus applied a similar strategy starting with the silyldiols as shown in Scheme 3.1.

§ 3.2 Synthesis of Silyl Aziridines via Cyclic Sulphate Intermediates

3.2.1 Synthesis of Silyl Cyclic Sulphates

In contemporary organic synthesis, epoxides have played a significant role, presumably due to their high reactivity, together with the simultaneous protection of the adjacent functionalized carbon atom from nucleophilic attack. They are usually superior to their acyclic counterparts because of their cyclic nature, which renders the competing elimination process stereoelectronically unfavourable.[13] Similar properties are also shared by a hitherto neglected class of compounds - the cyclic sulphates. Although the chemistry of cyclic sulphates has been known for a long time, the synthetic utilization of this class of compounds was not found main steam application unlike the epoxides. Recently, a novel high yielding, ruthenium tetroxide catalysed, one-pot procedure for the preparation of vicinal diol cyclic sulphates has been reported (Scheme 3.2).[11]



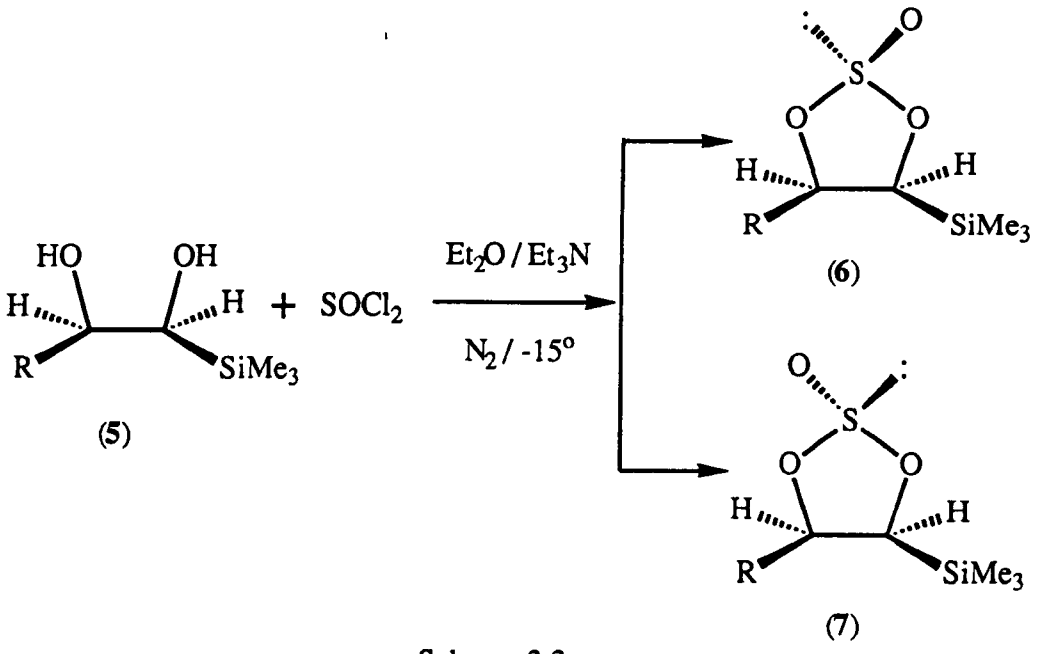
(3) (4)

Scheme 3.2

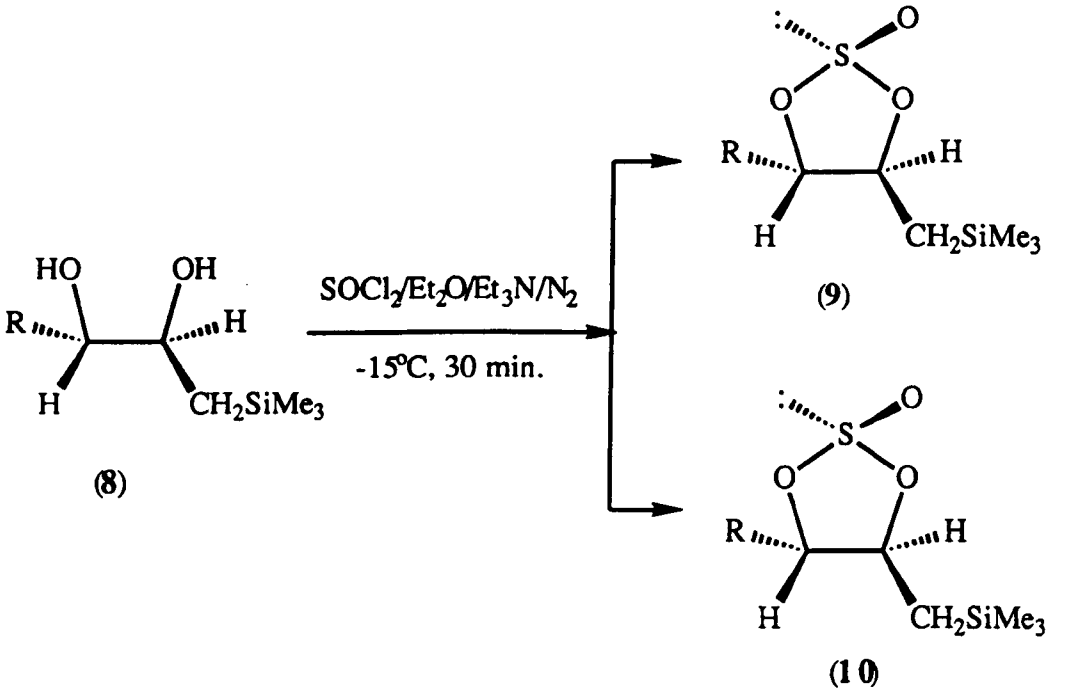
We used this procedure to try to make silylated cyclic sulphates from their corresponding diols. The results showed that the starting material was consumed but the compounds isolated were desilylated. During this process, although most of the HCl formed in the first step was expelled by refluxing, or scavenged by Et_3N at 0°C, the silylated 1, 2– and 2, 3- cyclic sulphates, which were formed from the cyclic sulphites, most likely, hydrolyzed and or underwent a Peterson-elimination.

After a number of failed attempt using this procedure, we decided to concentrate on an alternative, two-pot procedure which allowed us to isolate and purify the intermediates and thus reduce the likehood of hydrolysis. In the first step, the cyclic sulphite was prepared. The solvent was carefully dried, and the HCl formed in the reaction was scavenged by Et_3N at -15°C (Scheme 3.3 and Scheme 3.4). In the second step, the silylated cyclic sulphite was oxidized using $RuCl_3$-$NaIO_4$ in CCl_4 / CH_3CN / H_2O at 0°C (Scheme 3.5). 1-trimethylsilylethane-1,2-diol cyclic sulphate and 1-dimethylphenylsilylethane-1,2-diol cyclic sulphate could be isolated by this procedure.

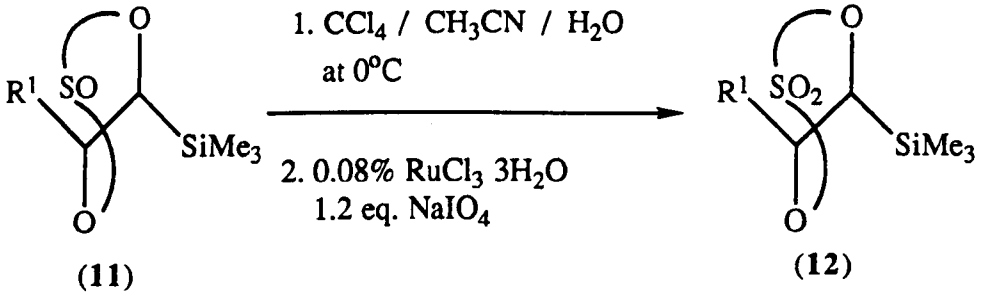
A series of silylated 1,2-diol cyclic sulphites were prepared as described (Scheme 3.3). Where R=H, the cyclic sulphite is stable and exists as two diastereoisomers in a ratio about (**6:7**). However, when R=Alkyl or Aryl, the cyclic sulphites are unstable and decomposed gradually in the atmosphere.



Scheme 3.3



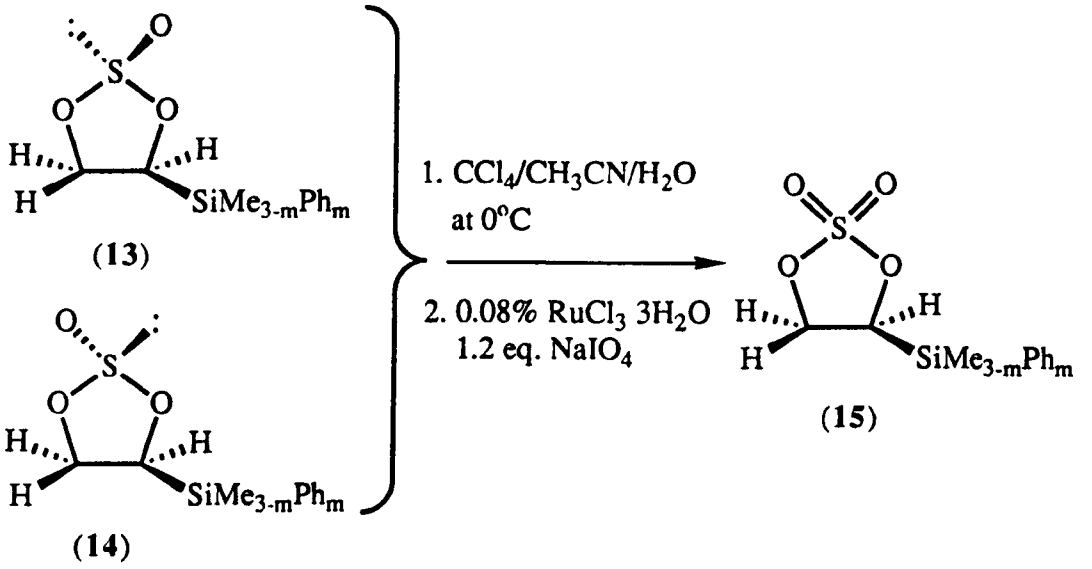
Scheme 3.4



Scheme 3.5

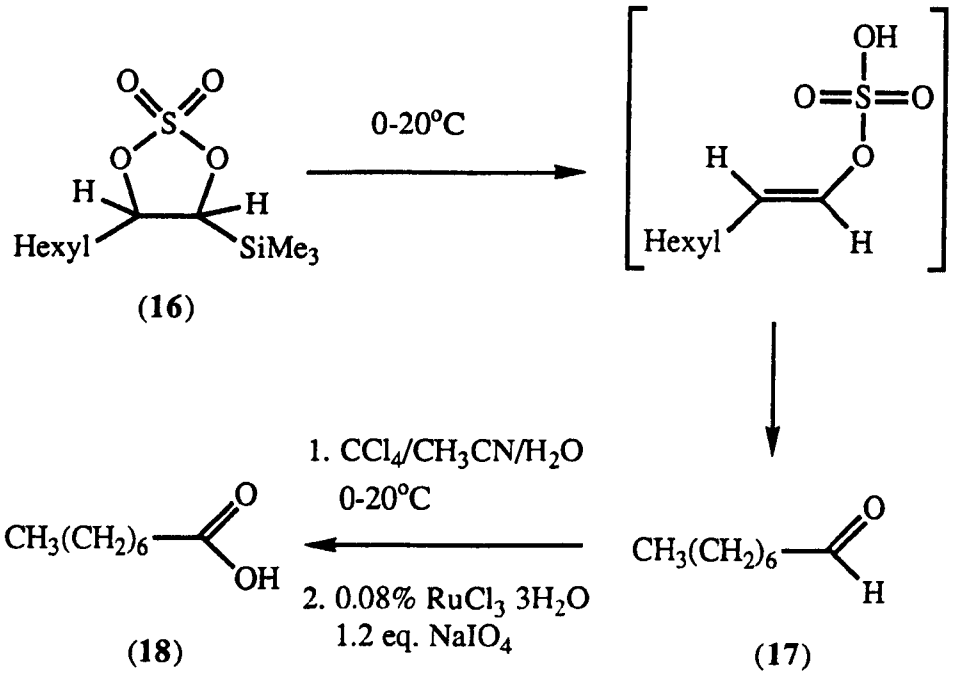
Silylated 2,3-diol cyclic sulphites, were also prepared in this way (Scheme 3.4). They were generally more stable compounds which exist as two diastereoisomers, when R=H, Alkyl or Aryl. However, the sulphites (**9**) and (**10**) do not undergo oxidation with $RuCl_3$-$NaIO_4$ under the conditions of the reaction shown in Scheme 3.5.

1-Trimethylsilylethane-1,2-diol cyclic sulphite and 1-dimethyphenylsilylethane-1,2-diol cyclic sulphite were oxidized to the corresponding sulphates using Scheme 3.5's condition shown in Scheme 3.6. These sulphates decompose at room temperature, but can be stored in the fridge for several weeks without decomposition.



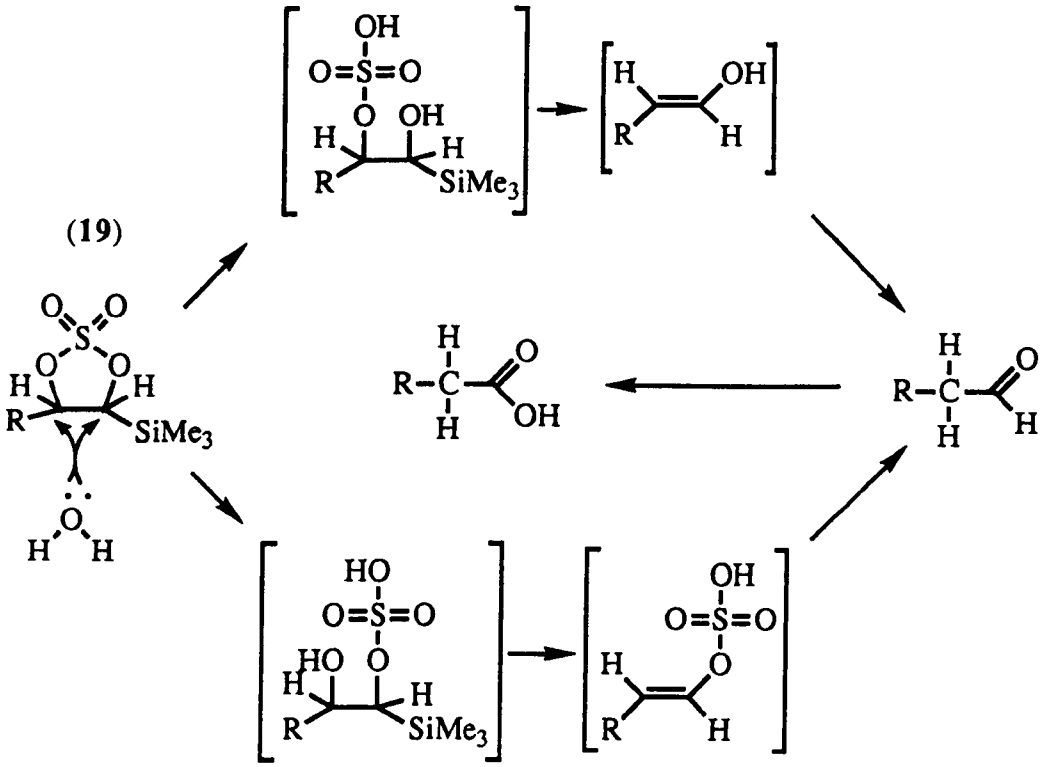
Scheme 3.6

When R was alkyl, or aryl, the oxidation did not proceed as expected. The final products were shown by NMR and IR spectroscopy to be the corresponding aldehyde and carboxylic acid. Scheme 3.7 (R=hexyl) shows one possible way in which these products were formed.



Scheme 3.7

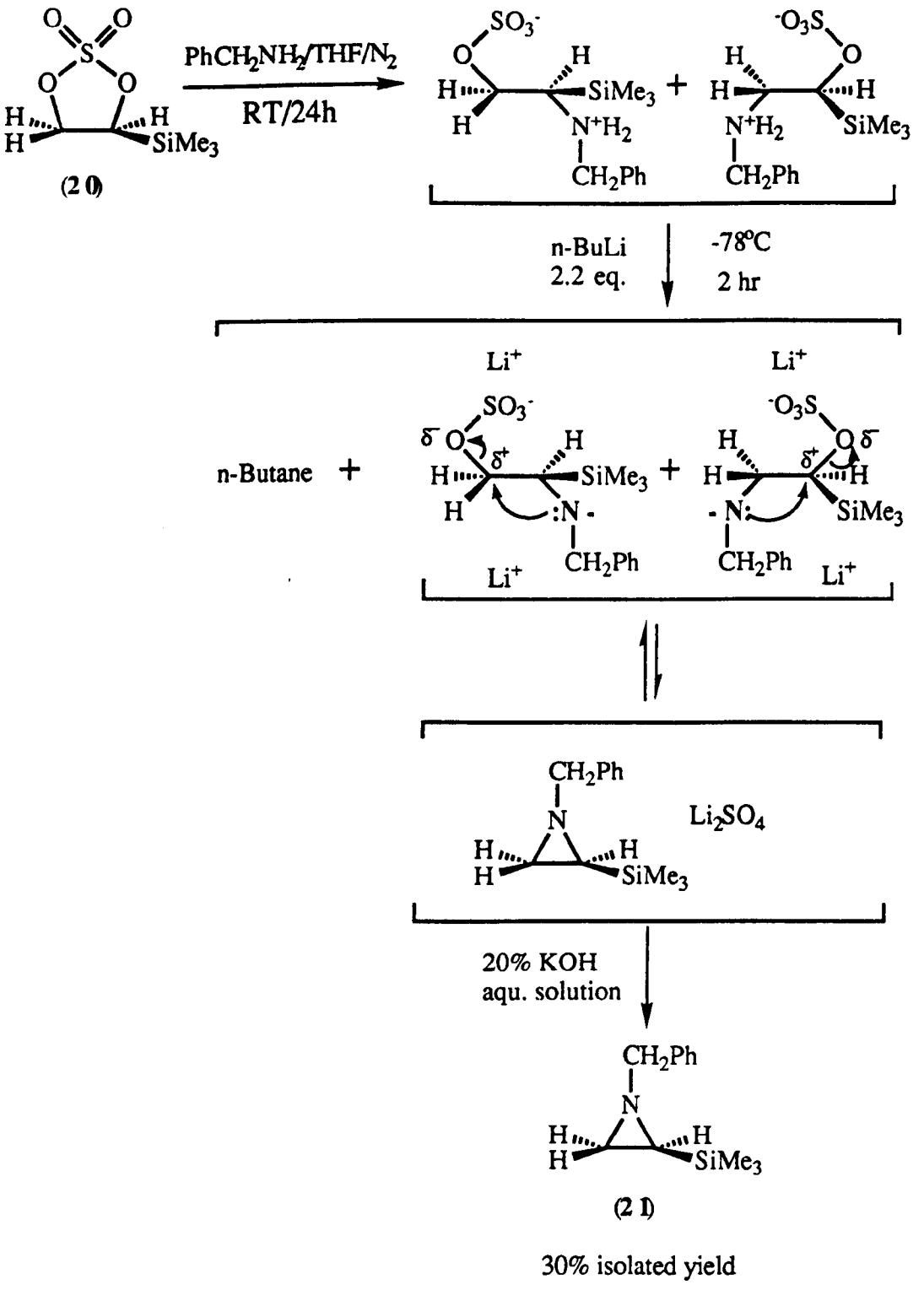
Hydrolysis of the silylated cyclic sulphate was followed by a Peterson elimination. A proposed mechanism is illustrated in Scheme 3.8. Subsequent hydrolysis gave the aldehyde which could be oxidized further to the carboxylic acid.



Scheme 3.8

3.2.2 Aziridines from The Silylated Cyclic Sulphates

The silylated 1,2-cyclic sulphate (**20**) is readily attacked by many nucleophiles at the α, or β carbons leading to ring opening and development of a second



Scheme 3.9

good leaving group, SO_3^-. If the nucleophile is a primary amines[12] a ring opened zwitterionic species is formed. These zwitterions react with strong bases such as n-butyllithium to form a nucleophilic amide ion which attacks the SO_3^--bearing carbon

intramolecularly to give the silylated aziridine (**21**) in about 30% yield (Scheme 3.9). This procedure was employed to give the aziridine in the two cases that a silylated cyclic sulphate could be isolated.

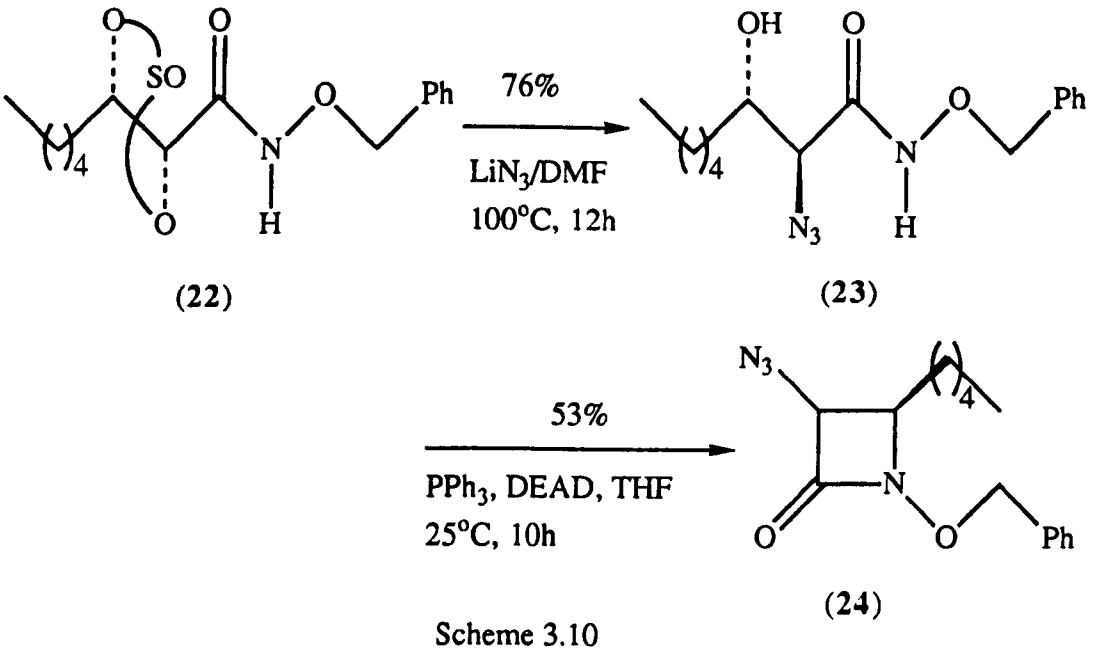
§ 3.3 Synthesis of Trimethylsilyl Amino Alcohols and Aziridines via their Cyclic Sulphites

3.3.1 Investigation of Silylated Cyclic Sulphites

Although the silylated cyclic sulphites could be obtained quite easily the cyclic sulphates proved to be more elusive. We therefore decided to prepare the aziridine and amino alcohols derictly from the cyclic sulphites.

Like cyclic sulphates, the cyclic sulphites also react with nucleophiles, but they are less reactive. The reaction of cyclic sulphites with oxygen nucleophiles has been reported in 1966 and 1989.[17,18] Recently, Rebiere and Kagan [19] have reported the reaction of several carbon nucleophiles with cyclic sulphites. [19] One of the earliest reactions of carbon nucleophiles with cyclic sulphites was reported by Szmant and Emerson. [20] The reaction of nitrogen nucleophiles with cyclic sulphites is the most extensively studied of the nucleophiles. [17,18] The reaction of isopropylamine with various substituted cyclic sulphites has been used for the synthesis of several drugs and drug intermediates such as the atenolol derivatives. [21-27] Recently, Kim and Sharpless [28] have reported a short synthesis of a β-lactam derivative (**24**) via stereoselective ring opening of cyclic sulphite (**22**) with lithium azide in dimethylformamide at 100°C (Scheme 3.10). The azido alcohol (**23**) was cyclized to the β-lactam (**24**) under Mitsunobu conditions. Lohray and Ahuja [29] have reported the synthesis of several homochiral amino alcohols, aziridines and diamines via stereoselective nucleophilic ring opening of cyclic sulphites.

The reactions of nucleophiles with silylated cyclic sulphites has not yet been reported.

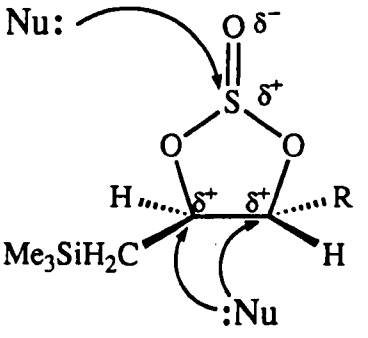


(22) (23) (24)

Scheme 3.10

3.3.1.1 The Reactions of Hard Nucleophiles with Silylated Cyclic Sulphites

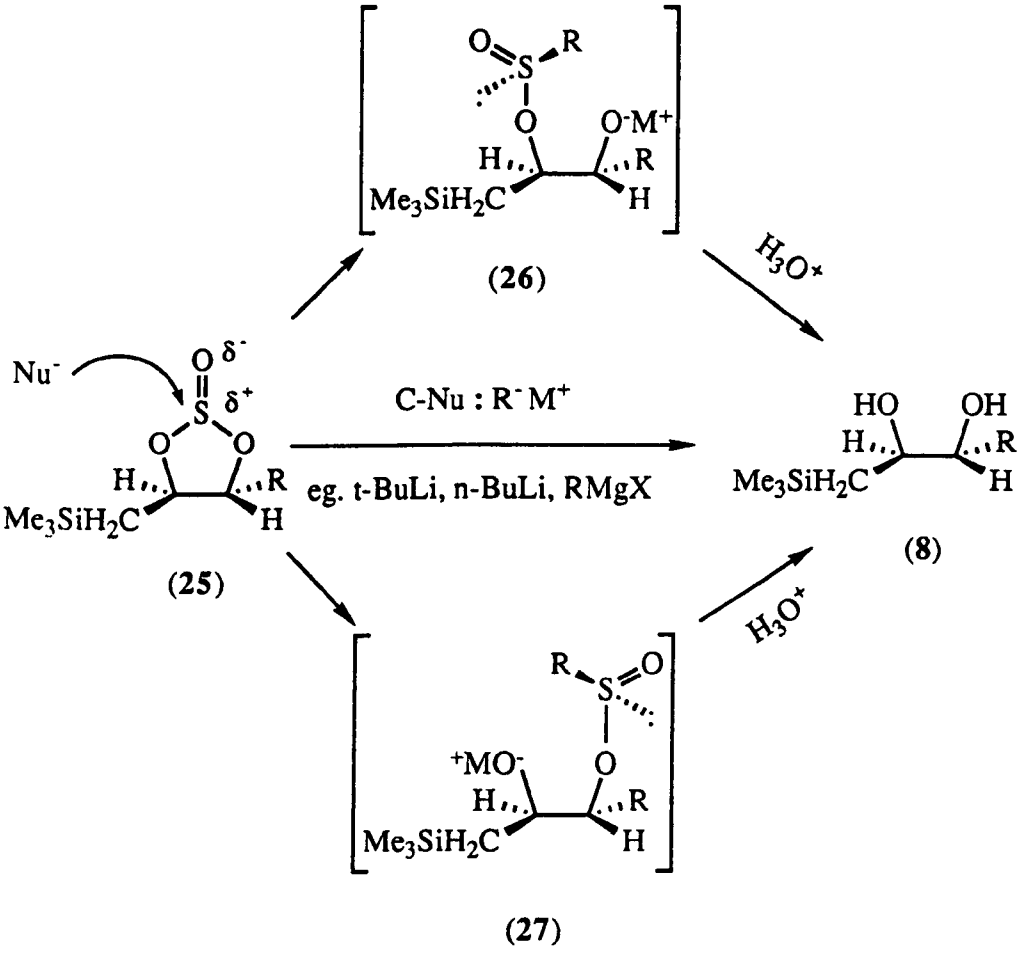
Silylated cyclic sulphites (**25**) have three electrophilic atoms which can be attacked by nucleophiles. They are shown below:



(25)

To begin our study, several organometallic reagents including *t*-BuLi, n-BuLi, and RMgX were selected as carbon nucleophiles. We predicted that this type of nucleophile could attack the partially positively charged sulphur atom rather than the other two carbon

positions. The nucleophilic substitution on the sulphur atom would be expected to follow the S_N2 mechanism rather than the S_N1 route, so dried polar aprotic solvents were used to favour this mechanism. The reactions of silylated cyclic sulphites (**25**) with hard carbon nucleophiles were performed at 0°C under inert gas. In all cases they gave the metal alkoxides(**26**), (**27**), which on hydroxylic work gave the silylated diol (**8**), as shown in Scheme 3.11.

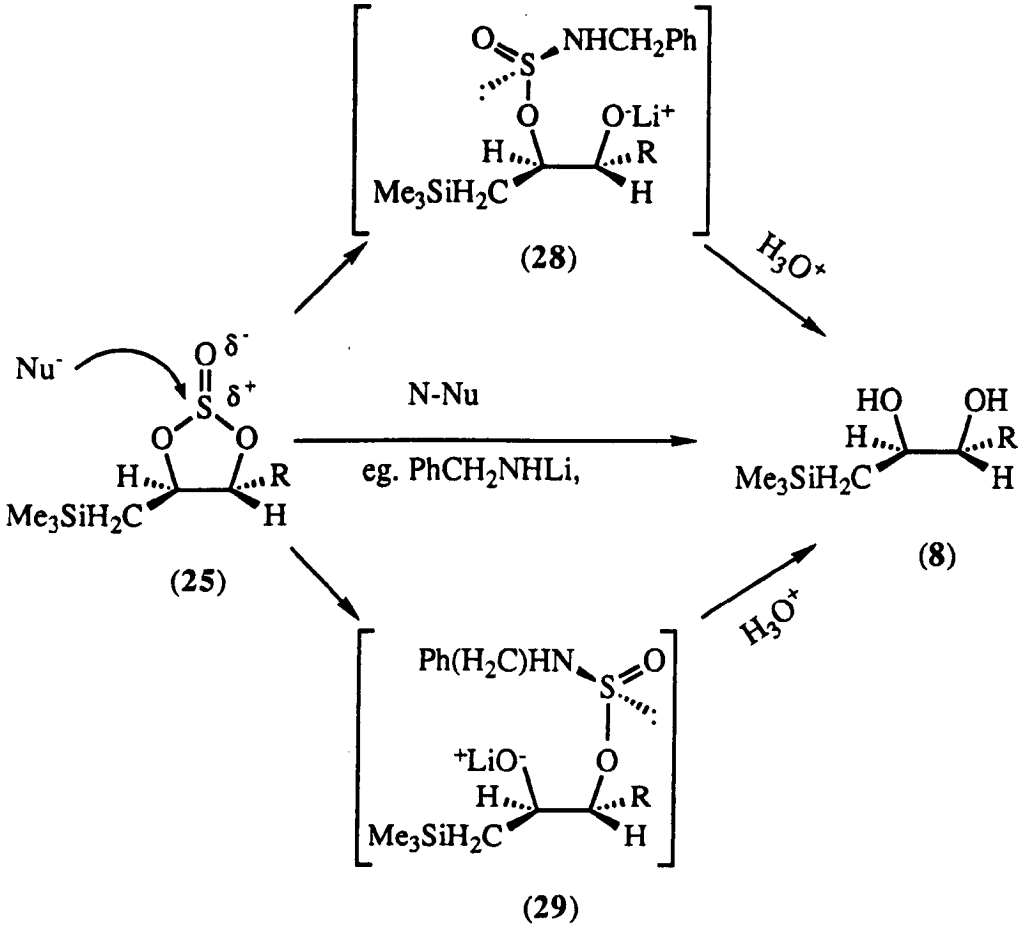


Scheme 3.11

Surprisingly, the nitrogen nucleophile lithium benzylamide attacked the sulphur atoms unlike other soft nucleophiles which attack the partially positively charged carbon positions.

The lithium benzylamide was prepared from benzylamine by reaction with 1 equivalent of n-BuLi, in dried THF, under nitrogen. To this red solution 1 equivalent of 1-

trimethylsilyl-3-phenyl-2,3-cyclic sulphite (**25**) was added at 0°C against a stream of nitrogen. This reaction mixture was kept at room temperature with stirring for 3 h. On hydrolytic work up, 1-trimethylsilyl-3-phenylpropane-2,3-diol (**8**) was obtained (Scheme 3.12).



Scheme 3.12

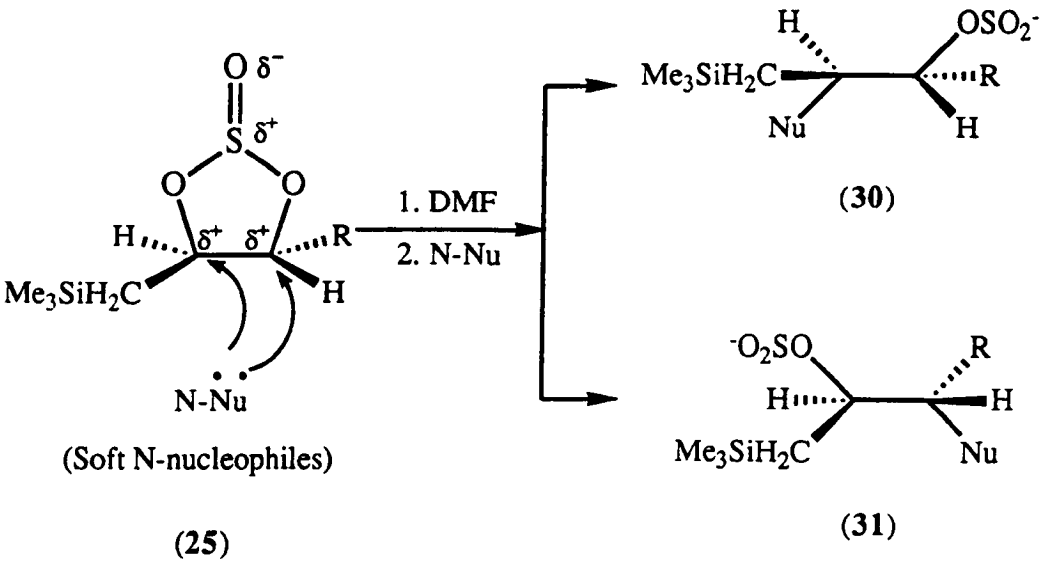
The mechanism shown in Scheme 3.12 involves the benzylamide attacking the sulphur atom to give two possible metal alkoxides(**28**) and (**29**), followed by hydrolysis to yield the diol (**8**).

3.3.1.2 The Reaction of Soft Nucleophiles with Silylated Cyclic Sulphites

Nitrogen containing species such as LiN_3, NaN_3, primary and secondary amines are another important type of nucleophile for the synthesis of silylated amino alcohols and aziridines. In contrast to their organic counterparts, silylated cyclic sulphites react with soft nitrogen nucleophiles via an S_N2 mechanism. Since the cyclic sulphites are less reactive, forcing reaction conditions, are required such as high temperature and polar aprotic solvents which stabilize the metal cations and increase the reactivity of the nucleophilic azide ions, as shown below.

As expected the soft nitrogen nucleophiles attack the two electrophilic carbon atoms rather than the sulphur atom, as shown in Scheme 3.13.

The regioselectivity C_2 versus C_3 of the ring opening of (**25**) with soft nitrogen nucleophiles depends on the R group. When R=Ph, the ratio of regioisomers of the ring opened products (**30**) / (**31**) was 1 / 99, when R=H, the ratio (**30**) / (**31**) was 1 / 1.

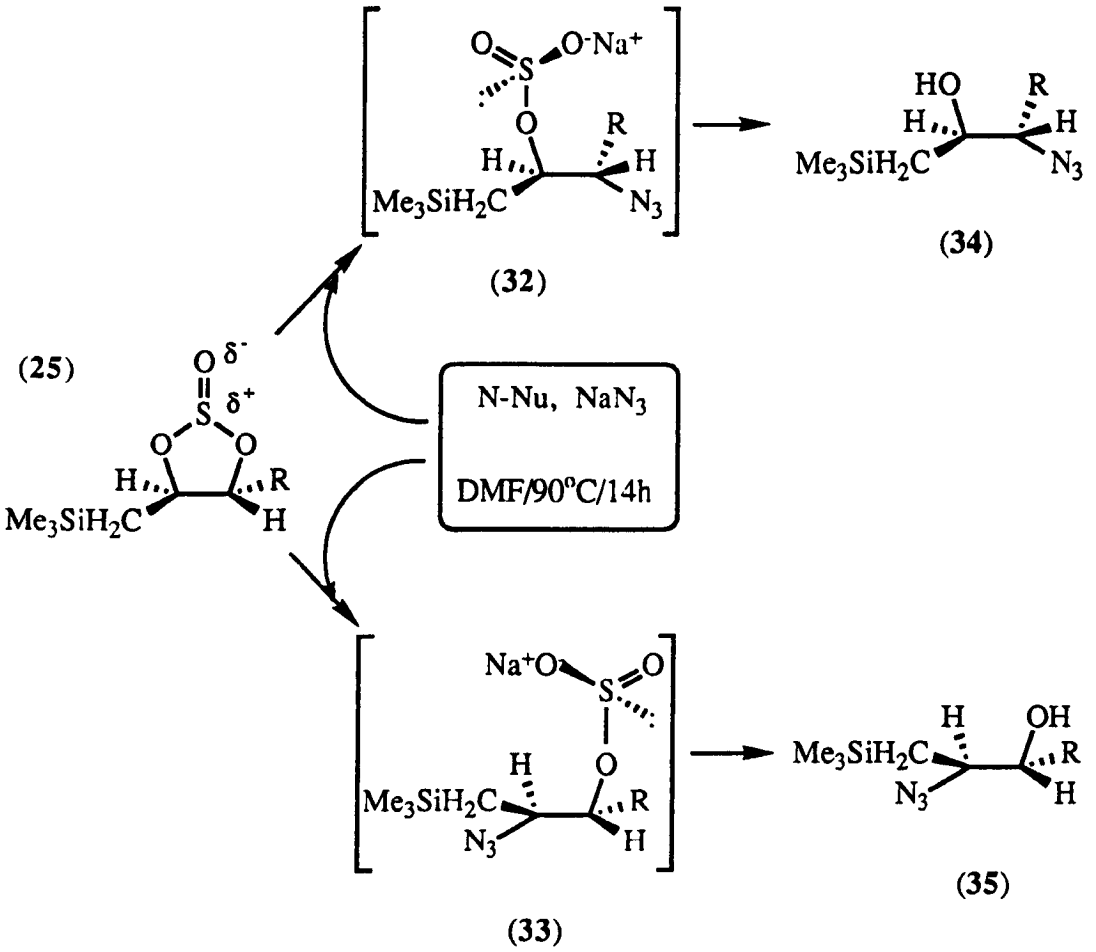


Scheme 3.13

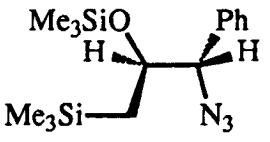
The reaction of 1-trimethylsilyl-3-phenylpropane-2,3-cyclic sulphite (**25**) (R = Ph) with sodium azide (Scheme 3.14) was carried out in DMF at 90°C under nitrogen for 14 hours. After removal of the DMF under vacuum, the solid sodium sulphites (**32**), and (**33**) were obtained. Hydrolysis of (**32**), and (**33**) afforded 1-trimethylsilyl-3-phenyl-3-azido-

propan-2-ol (**34**), and 1-trimethylsilyl-3-phenyl-2-azido-propan-3-ol (**35**) in 80% yield and with high regioselectivity: (**34**) / (**35**) = 99 / 1. The silylated aminoalcohol (**34**) was easily purified by flash chromatography on silica gel (hexane/EtOAc=75/25).

Occasionally, a byproduct (**36**), 1-trimethylsilyl-2-trimethylsiloxy-3-azido-3-phenyl propane, was isolated in less than 10% yield.

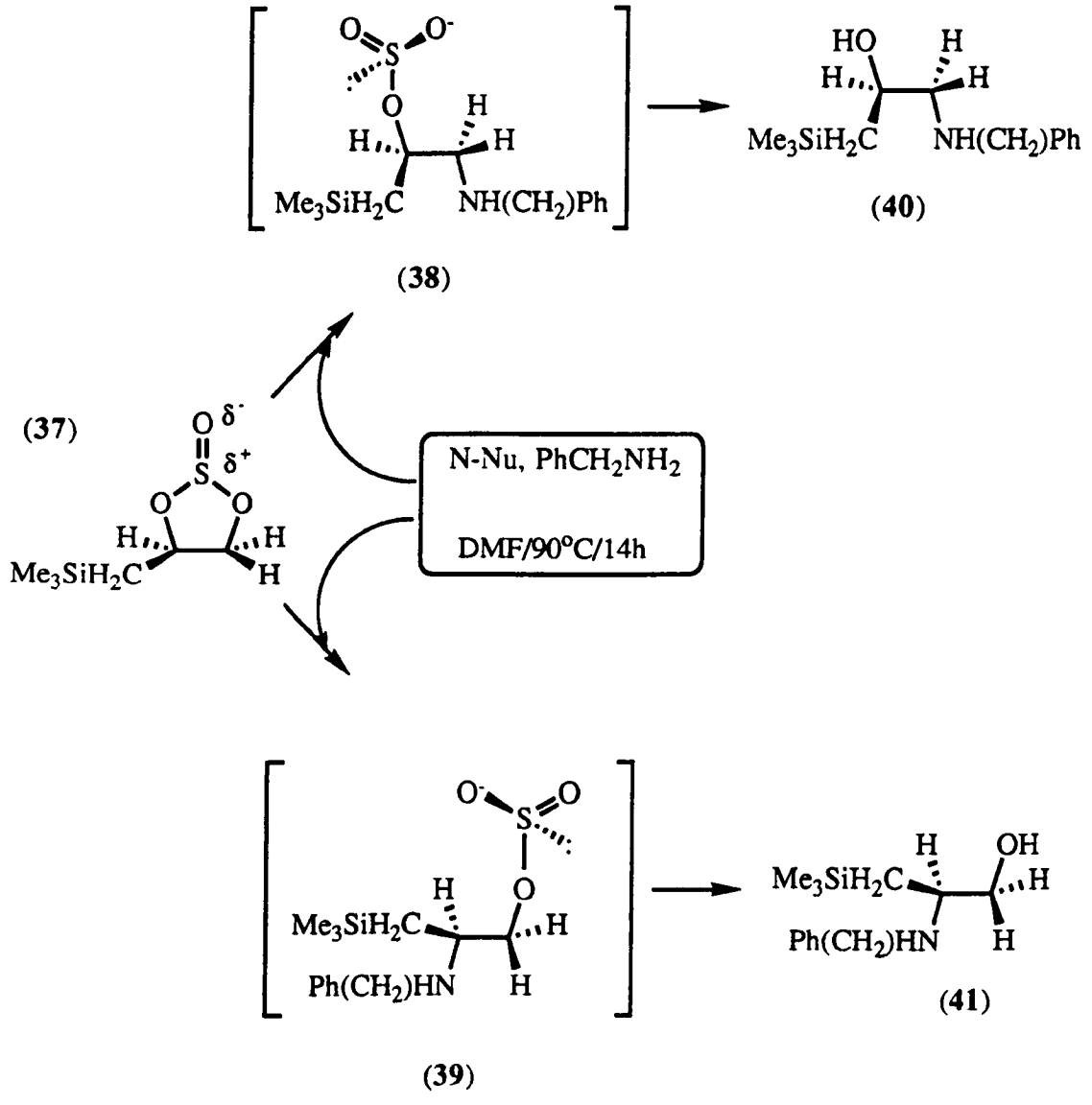


Scheme 3.14



(**36**)

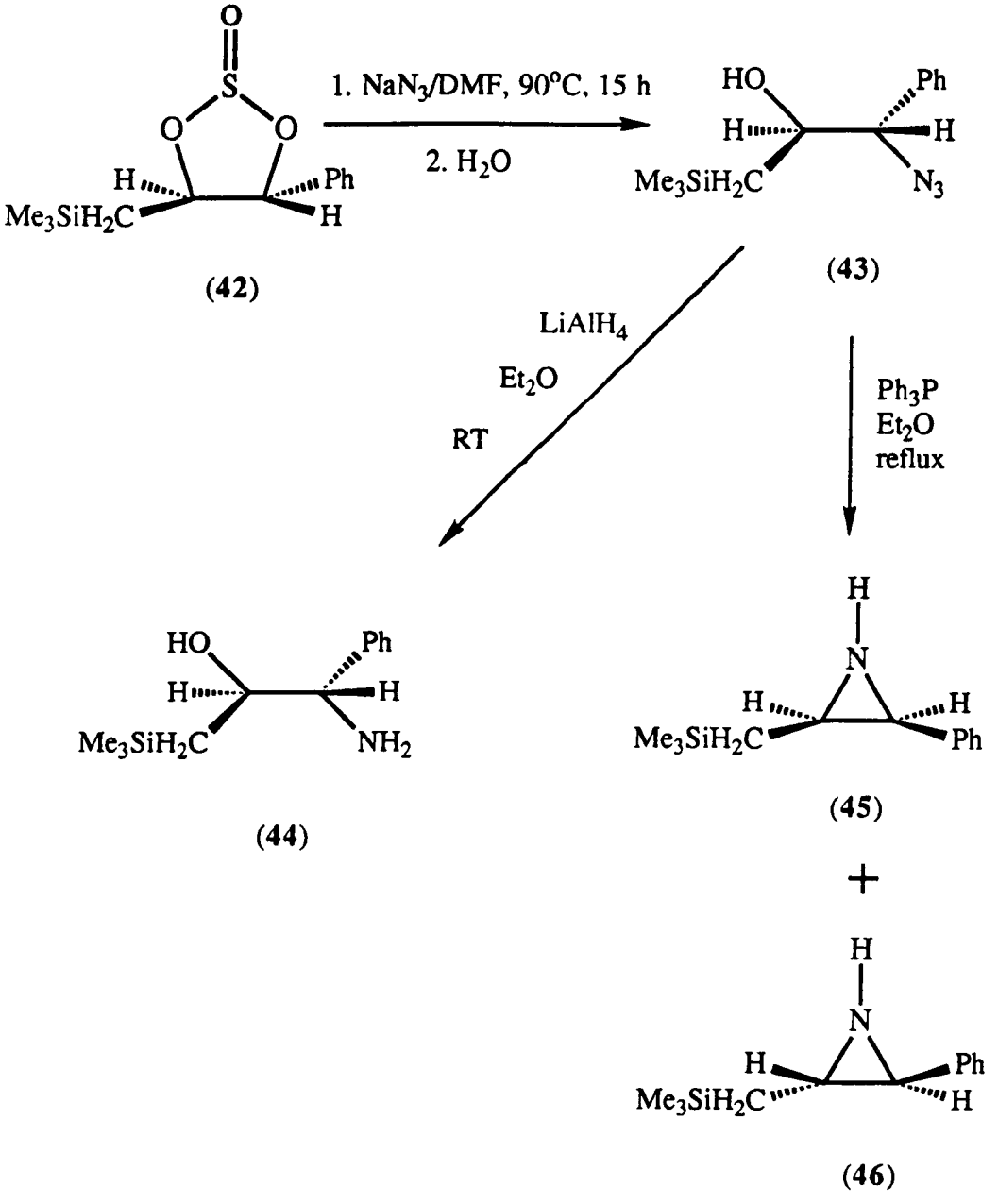
No reaction was observed between the silylated cyclic sulphite (**25**), (R=Ph), and benzylamine in DMF at 90°C for 14 hours. However, under the same conditions, the silylated cyclic sulphite (**37**), (R=H), underwent ring opening with amine nucleophiles such as benzylamine (Scheme 3.15). Two regioisomers (**40**) and (**41**) were isolated from this reaction in a ratio, (**40**) / (**41**), of 1 / 1. In this reaction, a large excess (e.g. 5equ.) of amine was required to avoid complications from the reaction of the primary amine with DMF.



Scheme 3.15

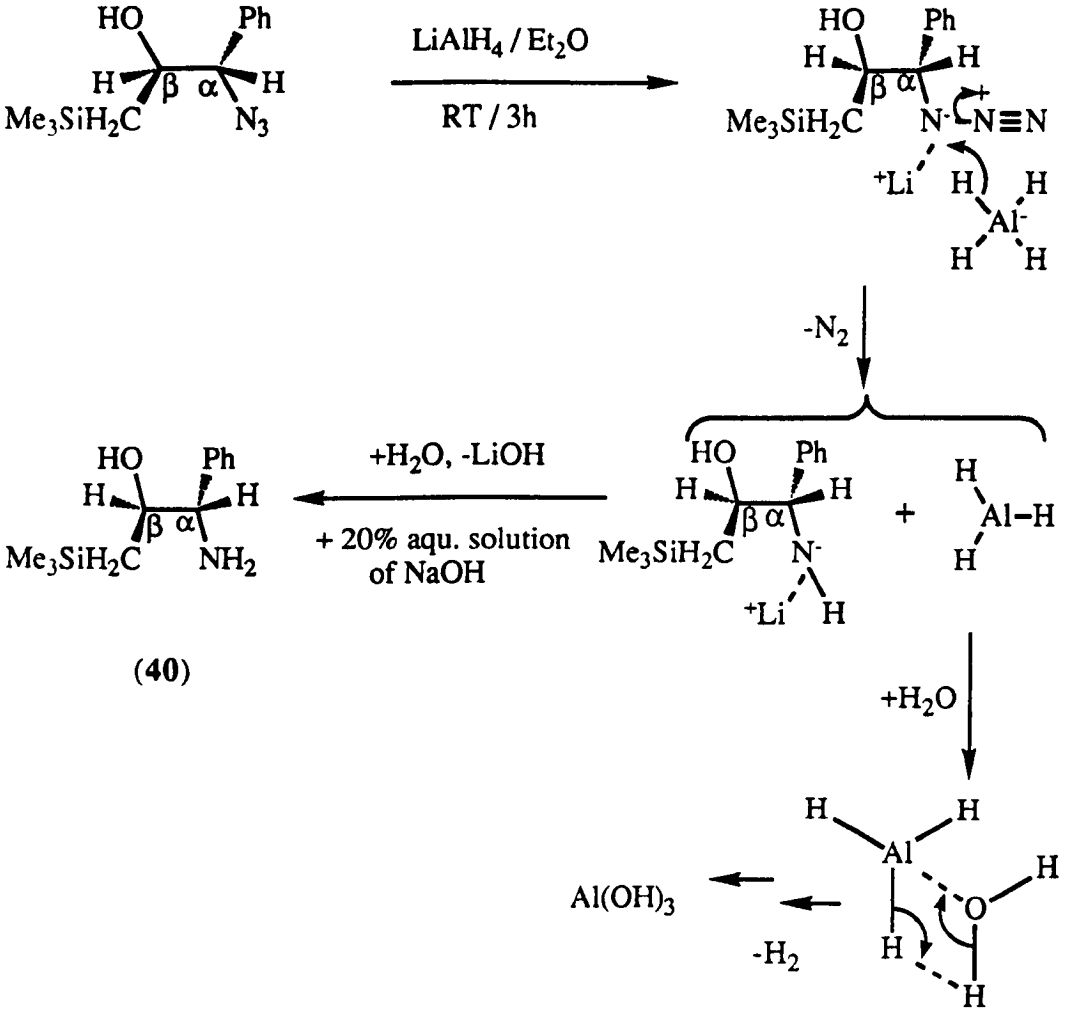
3.3.2 Synthesis of Trimethylsilyl Amino Alcohols and Aziridines

The relatively straightforward preparation of trimethylsilyl azido alcohols means that they could be used as precursors to trimethylsilyl amino alcohols and aziridines, as illustrated in Scheme 3.16.



Scheme 3.16

In the presence of lithium aluminium hydride, the azido group, loses a molecule of nitrogen to form a lithium β-amino alkoxide. Aqueous work up of the reaction mixture gives the related amino alcohol in almost quantitative yield. The mechanism involved is shown in Scheme 3.17.



Scheme 3.17

The trimethylsilyl aziridines could be formed from their azido alcohols using triphenyl phosphine. [31-33]

The simple procedure involves the addition of 1 equivalent of triphenyl phosphine dissolved in dry diethyl ether to 1 equivalent of the azido alcohol under nitrogen at room

temperature. The reaction mixture was then refluxed for three hours. A pure sample of both the *cis* and *trans* aziridines, (**45**) and (**46**) could be obtained using column chromatography on silica gel (ether). The ratio of *cis* (**45**) / *trans* (**46**) is 70 / 30.

The products of aziridine formation, showed that the reaction proceeded with both *syn* and *anti* stereochemistry. The silylated azido alcohol is assumed to add to the triphenyl phosphine via its terminal nitrogen atom [30] (**47**). Loss of nitrogen from (**47**) gives the nitrogen phosphorus ylid (**48**).

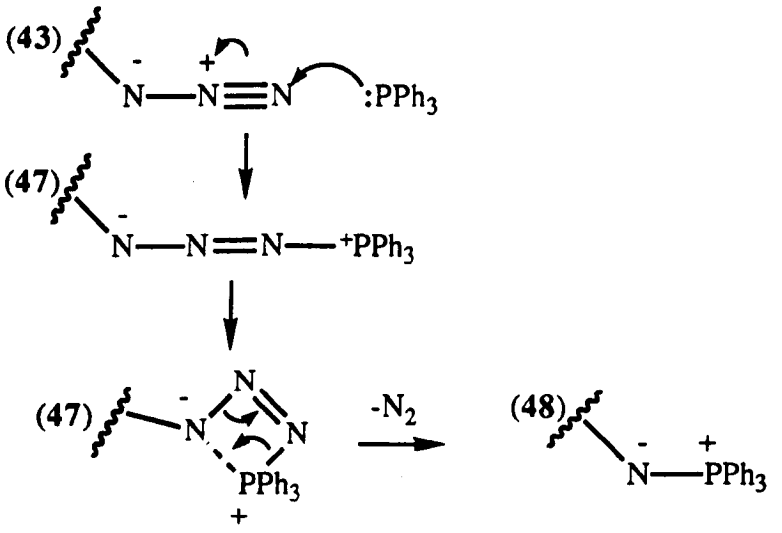
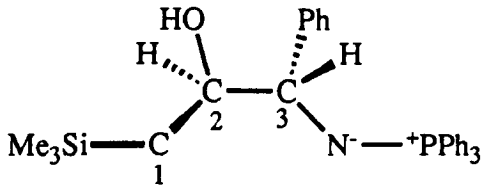
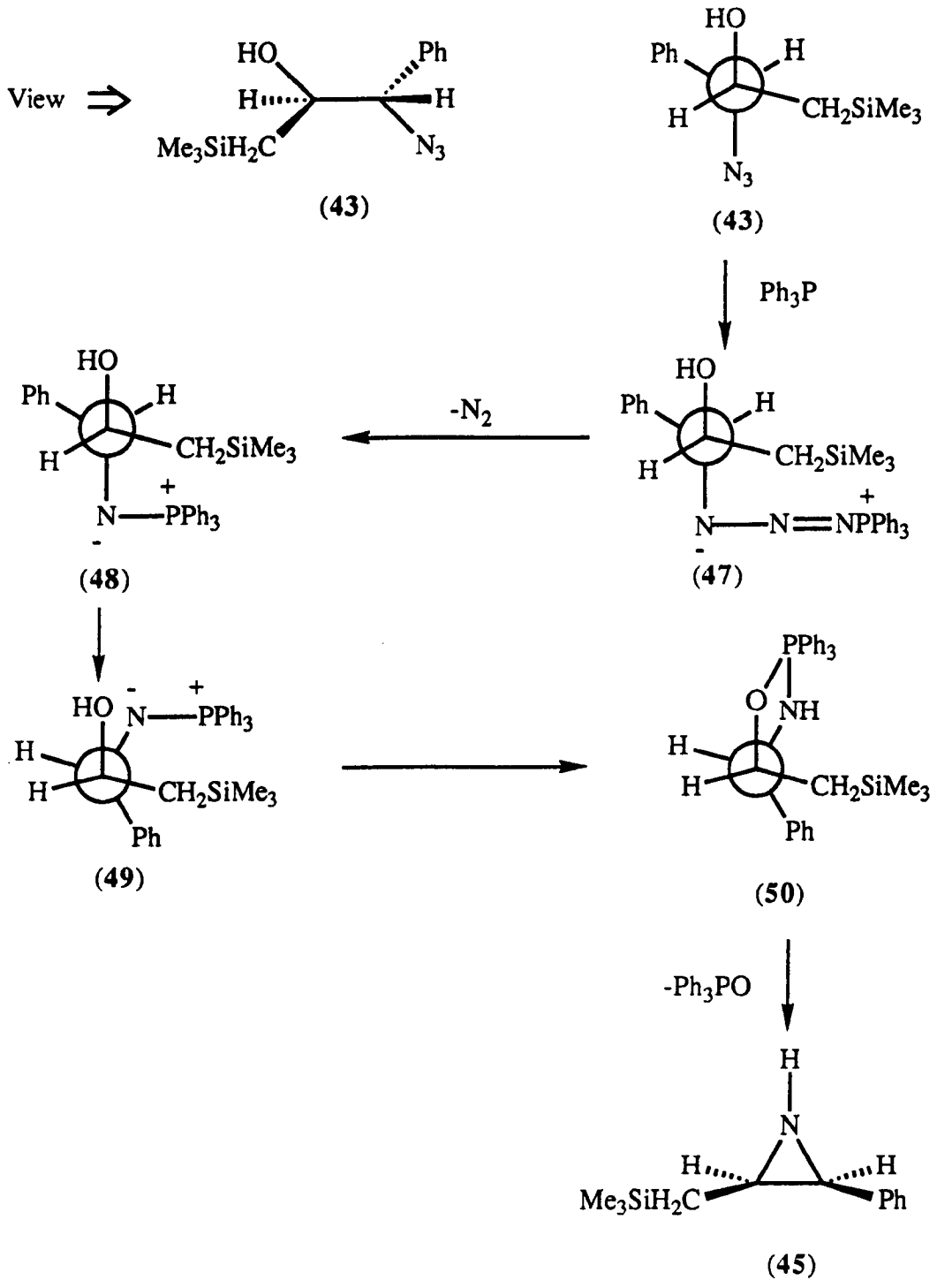


Figure 3.1



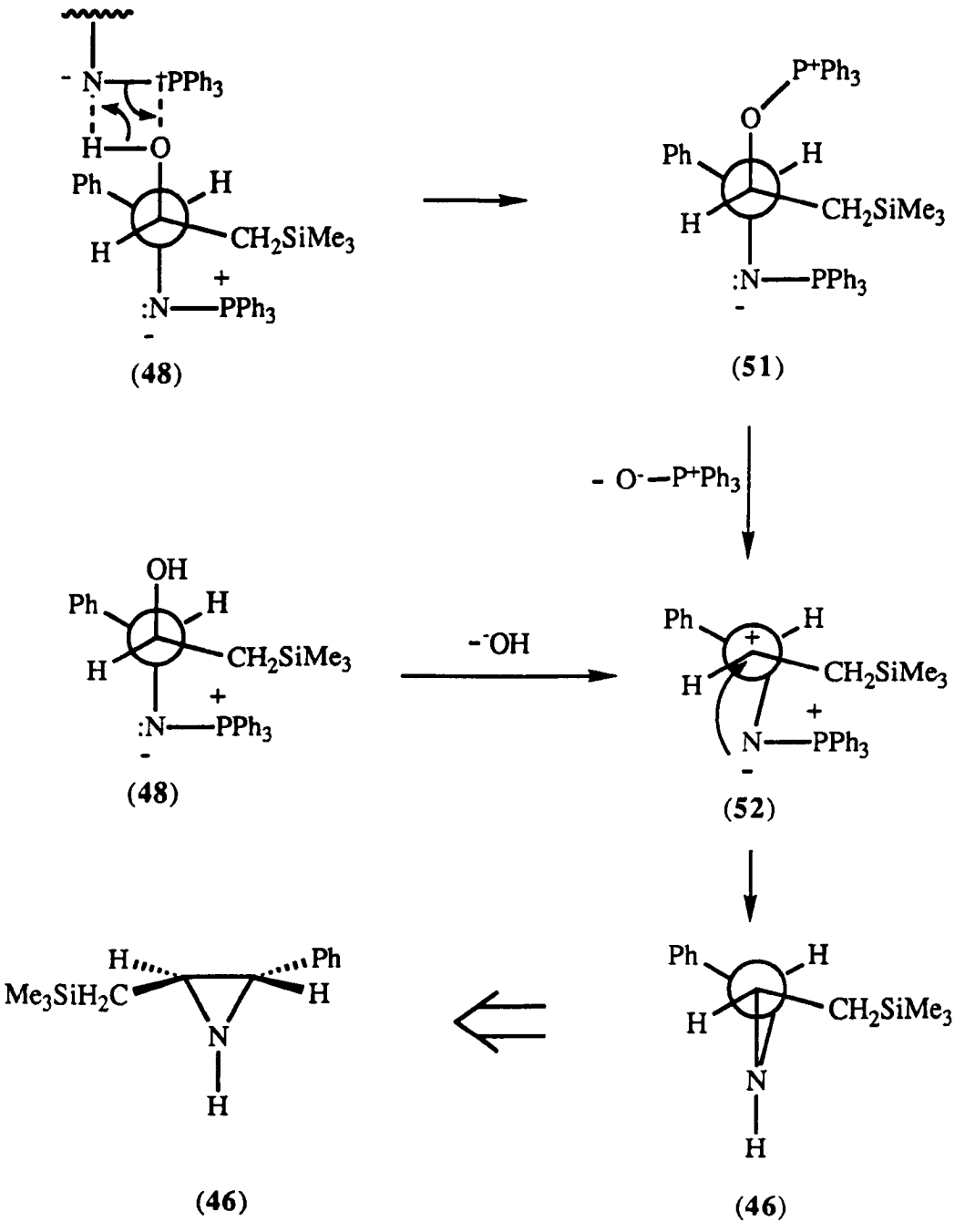
(**48**)

The syn products are thought to arise from (**48**) by reaction of the oxygen with the phosphorus to give (**50**), followed by concerted loss of triphenylphosphine oxide.



Scheme 3.18 *syn*-Mechanism of aziridine formation

If the loss of triphphenylphosphine oxide occurs in *anti* periplanar fashion, the alternate products may obtained.

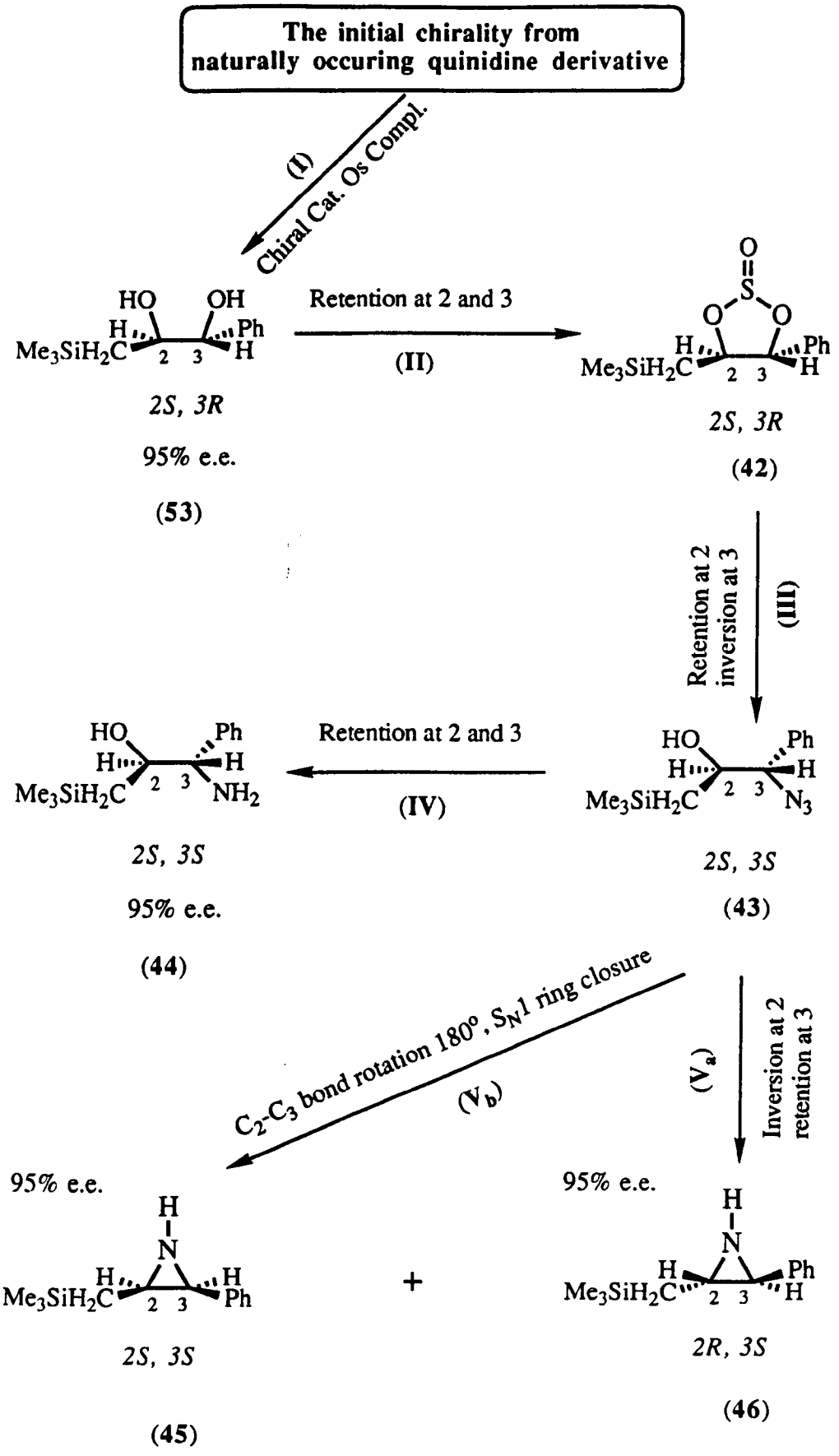


Scheme 3.19 *anti*-Mechanism of aziridine's formation

An anti-mechenism [31] involving intramolecular reaction in a stepwise fashion has been reported by Ittah in 1978. Thus an alternative mechanism is proposed in Scheme 3.19.

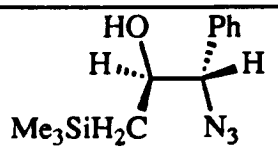
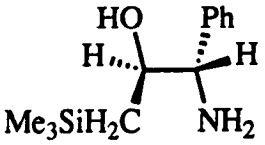
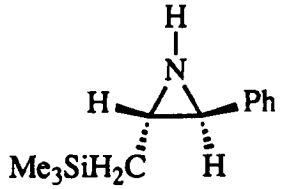
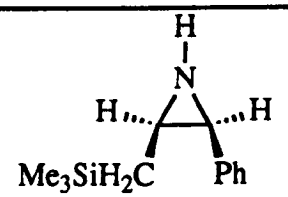
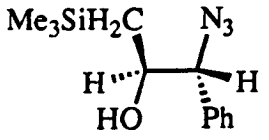
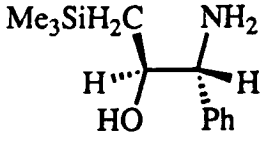
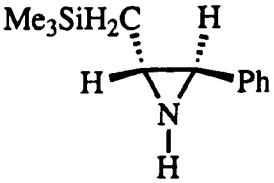
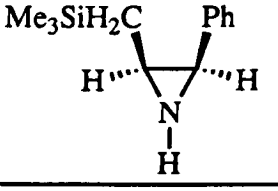
From a chirality transfer point of view (Scheme 3.20), the amino alcohols (**44**), aziridines (**45**),(**46**) and their precursor (**53**), all have the same stereogenic units: C_2, and C_3. The initial chirality come from natural occurring quinidine. Its chirality was transferred to the allylsilane to form the optically active diol (**53**) (step I). The chirality of the cyclic sulphite retained the stereochemistry of the diol (**53**) because no bonds were broken (to C_2, or C_3) in the cyclization reaction of the thionyl chloride with the diol (**53**)(step II). The stereochemistry of the of azido alcohol (**43**) was generated from the cyclic sulphite (**42**) by S_N2 nucleophilic substitution of azide ion at the C_3 position. Thus the C_2 position has retained its configuration whilst that at C_3 has inverted its configuration (step III). The chirality of the amino alcohol (**44**) reflected that in the azido alcohol (**43**) because no bonds have been broken at C_2 and C_3 (step IV). The chirality of the *cis*-aziridine (**45**) was obtained by a cyclization reaction involving a *syn* mechanism with retention of configuration at C_2 and C_3 (step V_b). The chirality of the *trans*-aziridine (**46**) was determined by an *anti* cyclization with inversion of configuration at C_2 and with the retention of configuration at C_3 (step V_a).

The absolute configuration of silyldiols has been shown to follow the Sharpless mnemonic as discussed in Scheme 2.4 in Chapter 2. The absolute configuration of all of the azido, and amino alcohols and aziridines are deduced from their precursor diols and are shown in Table 3.1. Unfortunately, it has not been possible to confirm this stereochemistry by specific experiments.


The initial chirality from naturally occuring quinidine derivative
(I)
Chiral Cat. Os Compl.
HO OH
H Ph
Me3SiH2C 2 3 H
2S, 3R
95% e.e.
(53)
Retention at 2 and 3
(II)
O
S
O O
H Ph
Me3SiH2C 2 3 H
2S, 3R
(42)
Retention at 2 inversion at 3
(III)
HO Ph
H H
Me3SiH2C 2 3 N3
2S, 3S
(43)
Retention at 2 and 3
(IV)
HO Ph
H H
Me3SiH2C 2 3 NH2
2S, 3S
95% e.e.
(44)
C2-C3 bond rotation 180°, SN1 ring closure
(Vb)
(Va)
Inversion at 2 retention at 3
95% e.e.
H
N
H H
Me3SiH2C 2 3 Ph
2S, 3S
(45)
+
95% e.e.
H
N
H Ph
Me3SiH2C 2 3 H
2R, 3S
(46)

Scheme 3.20

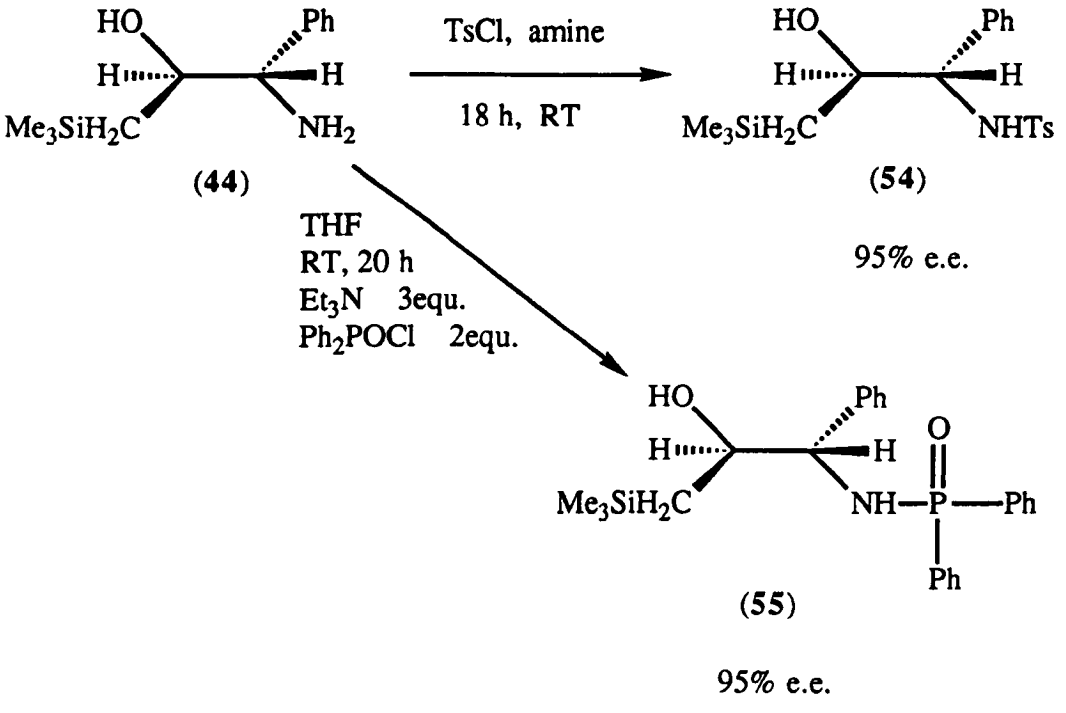
Table 3.1

No.	Silylated Azido, Amino, Alcohols and Aziridines		regiosel. C_2 / C_3	config.	e.e. %	yield %
a			1/99	*2S,3S*	(95)	80
b			1/99	*2S,3S*	95	95
c		c : d = 30 / 70		*2R,3S*	95	75(c+d)
d				*2S,3S*	95	
e			1/99	*2R,3R*	(95)	80
f			1/99	*2R,3R*	95	95
g		g : h = 30 / 70		*2S,3R*	95	75(g+h)
h				*2R,3R*	95	

However, the stereochemistry of chirality transfer proposed above supported by the observation that enantiomer excess does not change from the precursor silyldiols (**53**) with 95% e.e. to the silyl amino alcohols and aziridines both with 95% e.e.. These results are shown in Table 3.1.

We tried to convert the silylated amino alcohol (**44**) into the corresponding aziridines, but have sofar been unsuccessful.

The silylated amino alcohol (**44**) was easily *N*-tosylated and *N*-phosphinylated at room temperature but we were unable to observe tosylation or phosphinylation of (**44**) of the hydroxy group after 18 hours (Scheme 3.21). Both products, 1-trimethylsilyl-3-phenylpropane-2-hydroxy-3-*p*-toluenesulphonamide (**54**) and 1-trimethylsilyl-3-phenylpropane-2-hydroxy-3-*N*-diphenylphosphinoylamide (**55**) retained the chiralities of their precursors.



Scheme 3.21

§ 3.4 Determination of the e.e. of Trimethylsilyl Amino Alcohols and Aziridines

There are many examples of ^{1}H and ^{19}F NMR being used with α-methoxy-α–(trifluoromethyl) phenyl acetic acid (MTPA) as a chiral phosphorus derivatising agent (CDA) for analyzing amines [34-36], β-amino alcohols and α-amino alcohols. [37-38] The isocyanate analogue of MTPA [42] reacts with chiral amines in the NMR tube leading to larger changes in δ in both ^{1}H and ^{19}F spectra. Camphanoyl chloride is a useful alternative CDA for such substrates. [39-41] Amines and amino alcohols (but not α-amino acids) are particularly amenable to analysis with CSAs. By using either mandelic acid,[43] *O*-acetylmandelic acid [44] or binaphthylphosphonic acid,[45] diastereoisomeric salts are formed on mixing in an equimolar ratio in $CDCl_3$, C_6D_6, or pyridine-d_5. Although the observed shift nonequivalence is less than that with CDA, the method is quicker to use and the sample may be easily recovered. The CDAs based on mandelic acid derivatives are certainly cheaper than (9-anthryl) trifluoroethanol, which, although still used for such analyses[46,47] of chiral amines,[46,47] often gives inferior shift nonequivalence.

Due to the problem of broadening in the ^{1}H NMR, chiral analysis of amines and amino alcohols with CLSR is often ruled out. However we have found that chiral analyses of amines and amino alcohols by ^{13}C NMR with CLSR using $Eu(hfc)_3$ is extremely clear, reliable and direct. Generally speaking, the chemically nonequivalent ^{13}C spectra cannot be integrated because the integration areas of ^{13}C spectra do not proportionally reflect the number of ^{13}C atoms in the molecule. However, the ^{13}C spectra of one pair of corresponding carbons in the enantiomeric mixture are comparable. Some examples are presented below:

The ^{13}C NMR spectrum of the silylmethyl groups of racemic 1-trimethylsilyl-3-phenylpropane-2-hydroxy-3-p-toluenesulphonamide with $Eu(hfc)_3$ in $CDCl_3$ is shown in Figure 3.2a . The enantiomer separation of the carbons is very good. The ^{13}C NMR spectra of the silylmethyl groups of *2R,3R*-1-trimethylsilyl-3-phenylpropane-2-hydroxy-

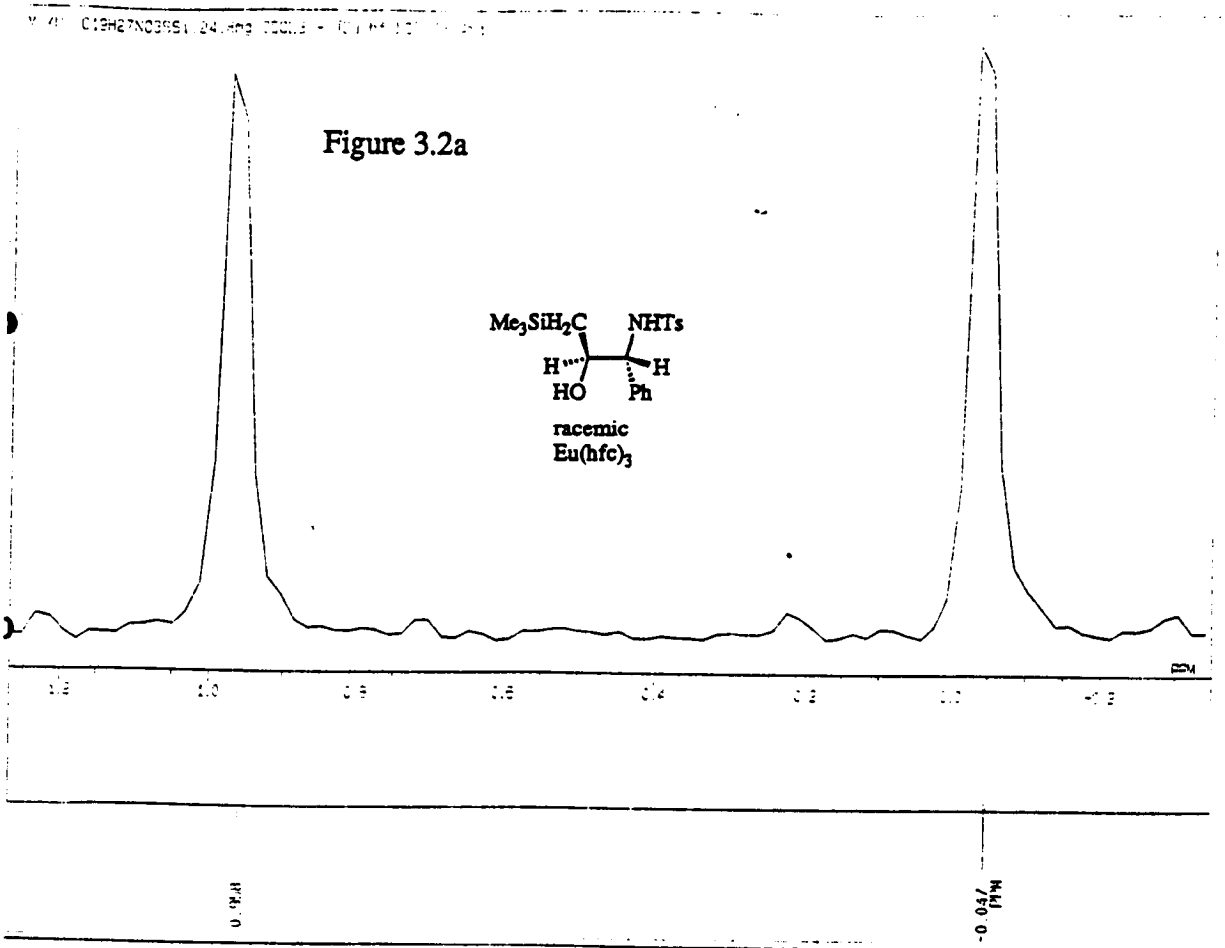


Figure 3.2a
Me3SiH2C
NHTs
H
H
HO
Ph
racemic
Eu(hfc)3

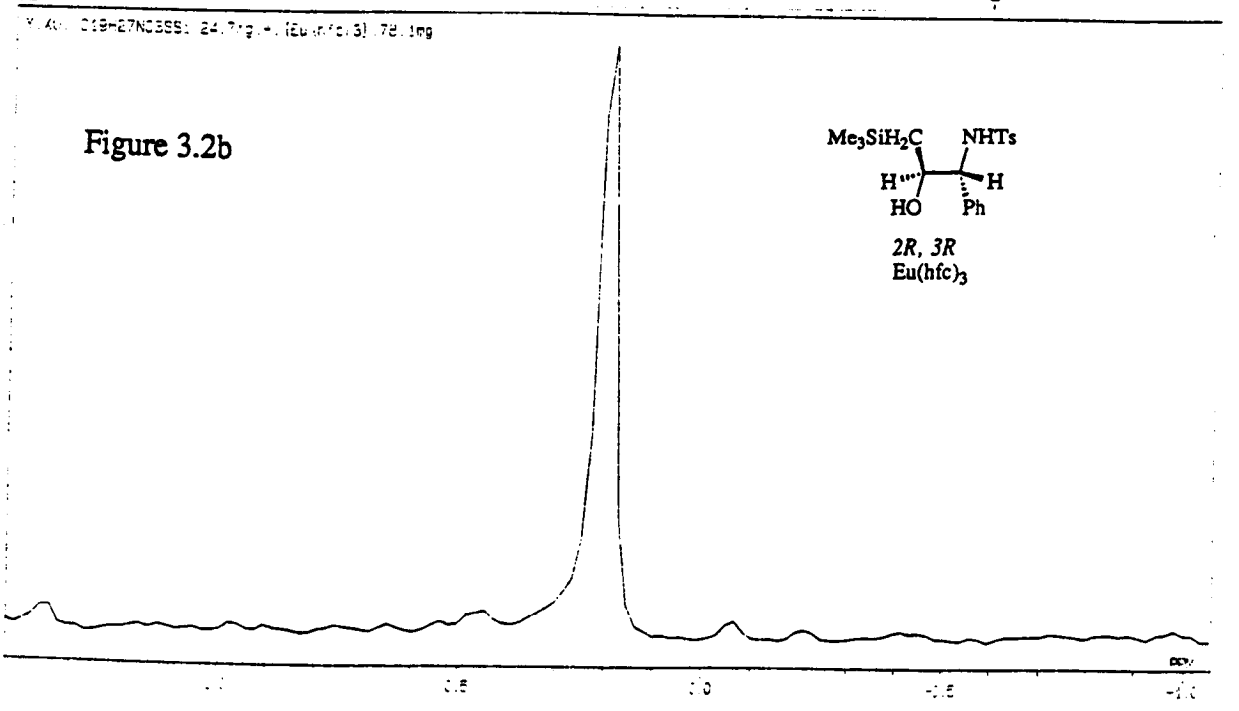
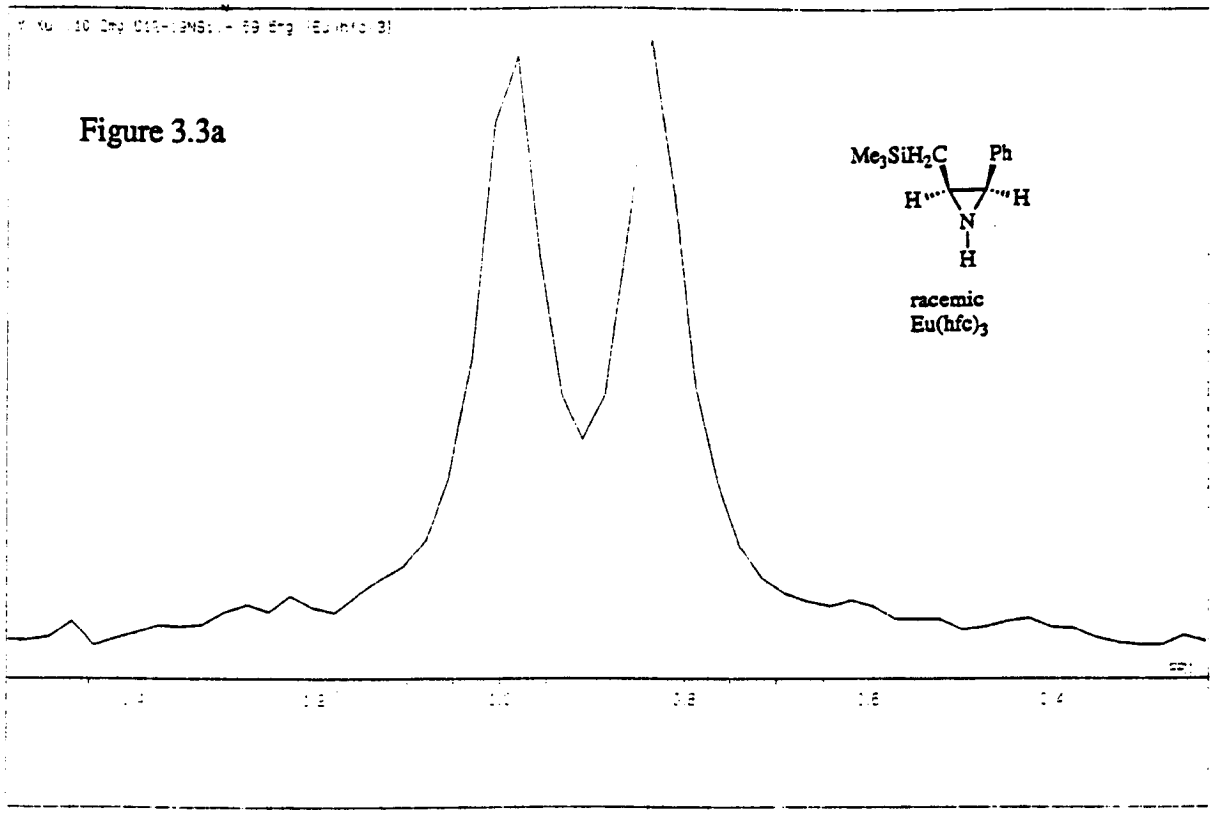


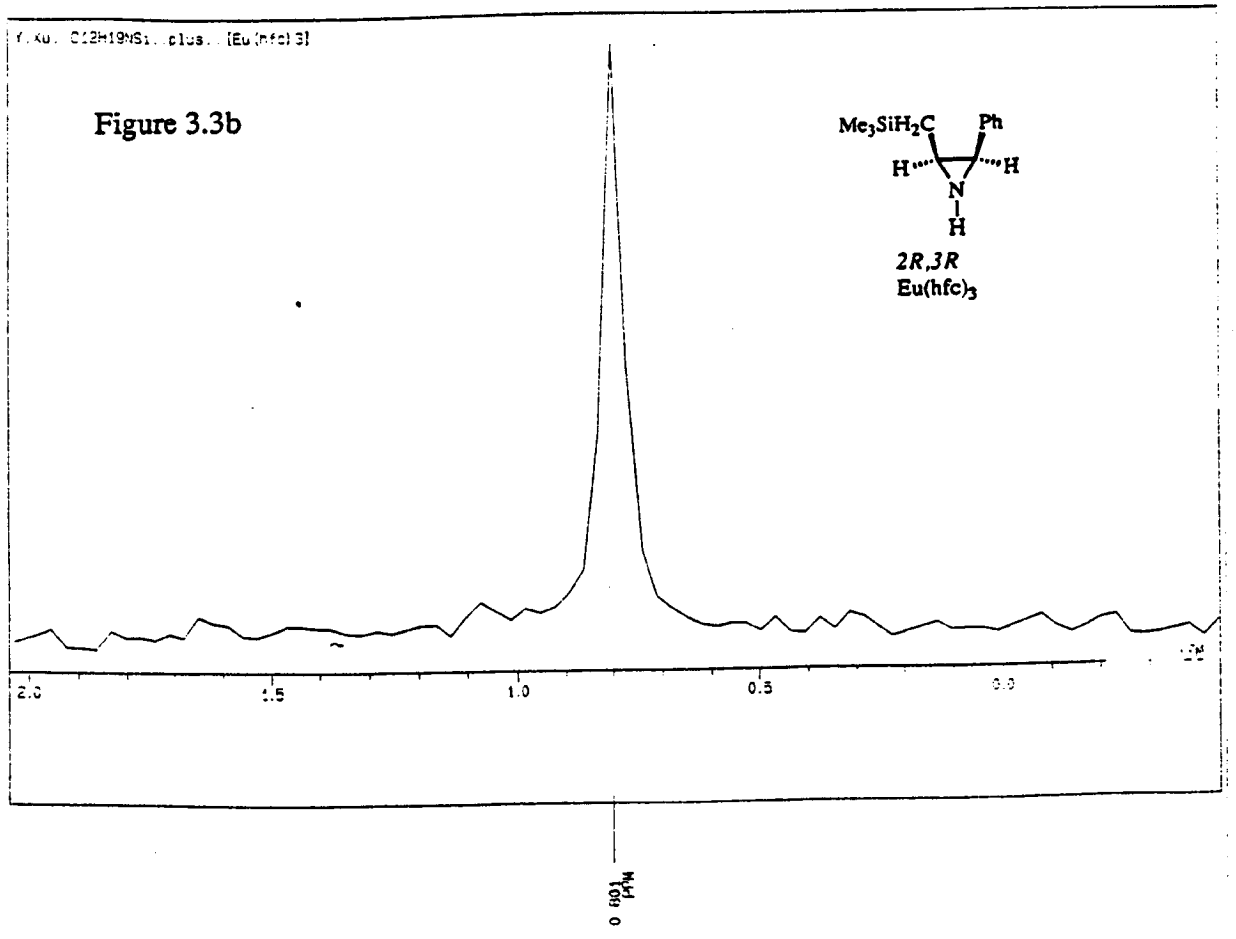
Figure 3.2b
Me3SiH2C
NHTs
H
H
HO
Ph
2R, 3R
Eu(hfc)3

Figure 3.3a



racemic
$Eu(hfc)_3$

Figure 3.3b



2R,3R
$Eu(hfc)_3$

Figure 3.4a

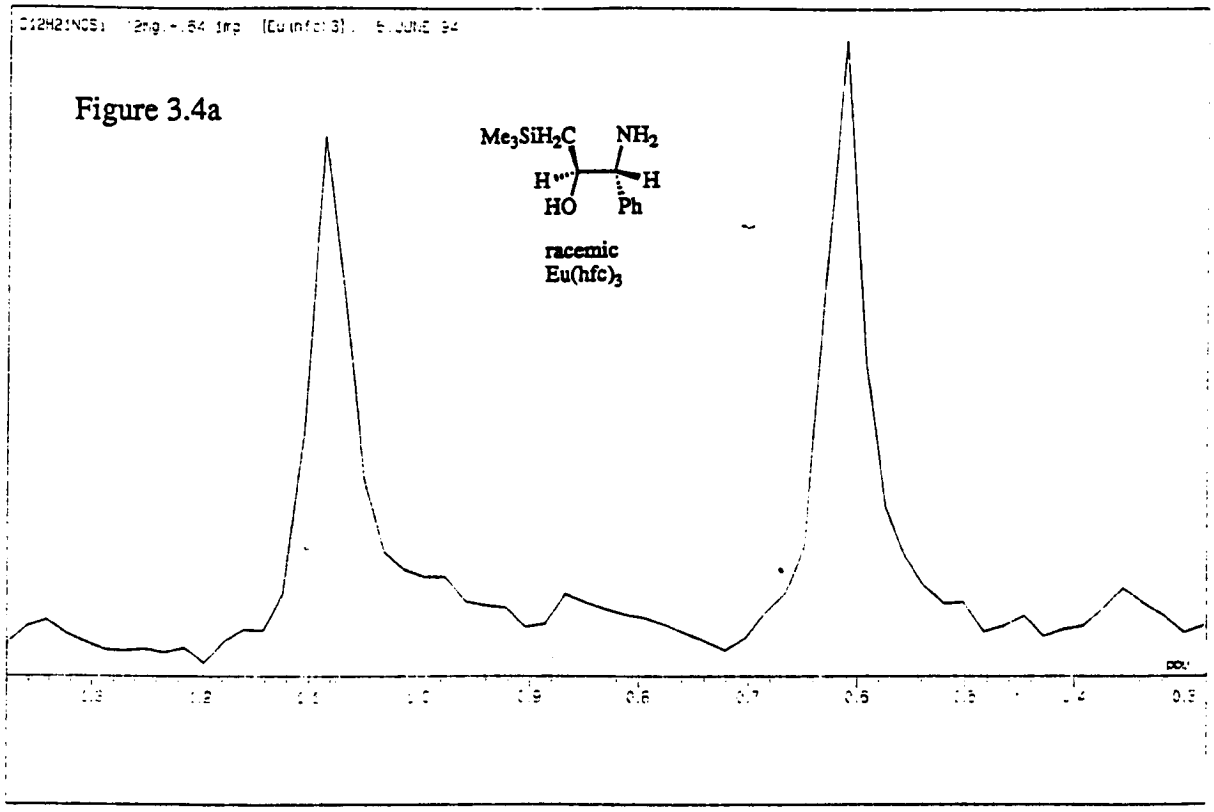
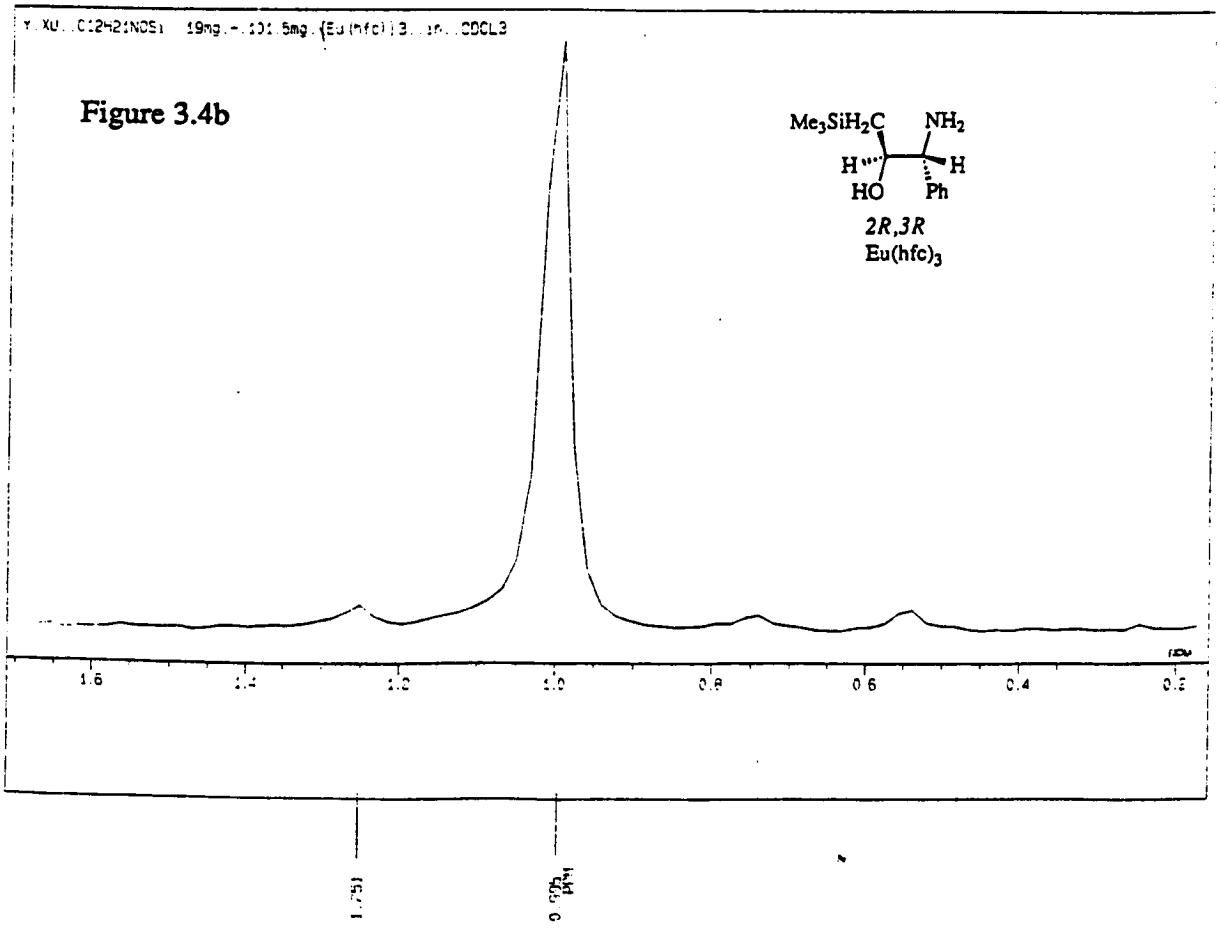


Figure 3.4b



3-*p*-toluenesulphonamide in the presence of 1 equivalent of $Eu(hfc)_3$ in $CDCl_3$ is shown in Figure 3.2b. The enantiomeric excess of this compound was easily shown to be 95% e.e..

The ^{13}C NMR spectrum of the silylmethyl groups of racemic 1-trimethylsilyl-3-phenylpropane-2,3-aziridine in the presence of $Eu(hfc)_3$ in $CDCl_3$ is shown in Figure 3.3a. The enantiomer separation of the carbons is reasonably good. The ^{13}C NMR spectrum of the silylmethyl groups of *2R,3R*-1-trimethylsilyl-3-phenylpropane-2,3-aziridine in $CDCl_3$ in the present of 1 equivalence of $Eu(hfc)_3$ is shown in Figure 3.3b. The enantiomeric excess of this compound was shown to be 95% e.e..

The ^{13}C NMR spectra of the silylmethyl groups of racemic 1-trimethylsilyl-3-phenylpropane-3-amino-2-alcohol in the presence of $Eu(hfc)_3$ in $CDCl_3$ is shown in Figure 3.4a . The enantiomer separation of the carbons is very clear. The ^{13}C NMR spectra of the silylmethyl groups of *2R,3R*-1-trimethylsilyl-3-phenylpropane-3-amino-2-alcohol in the presence of 1 equivalent of $Eu(hfc)_3$ in $CDCl_3$ is shown in Figure 3.4b. The enantiomeric excess of this compound was shown to be 95% e.e..

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Chapter 4

The Synthesis of Optically Active Trimethylsilylepoxides

Contents

§ 4.1 Introduction

Epoxides are widely recognized as extremely versatile synthetic intermediates.[1] The enhanced reactivity of these species, attributable to the inherent ring polarity and high ring strain, permits a range of nucleophilic ring openings, Lewis acid catalysed rearrangements, and isomerization reactions. The good accessibility of epoxides further contributes to their

usefulness. Enantiomerically pure epoxides have found widespread use as chiral building blocks in organic synthesis.[2]

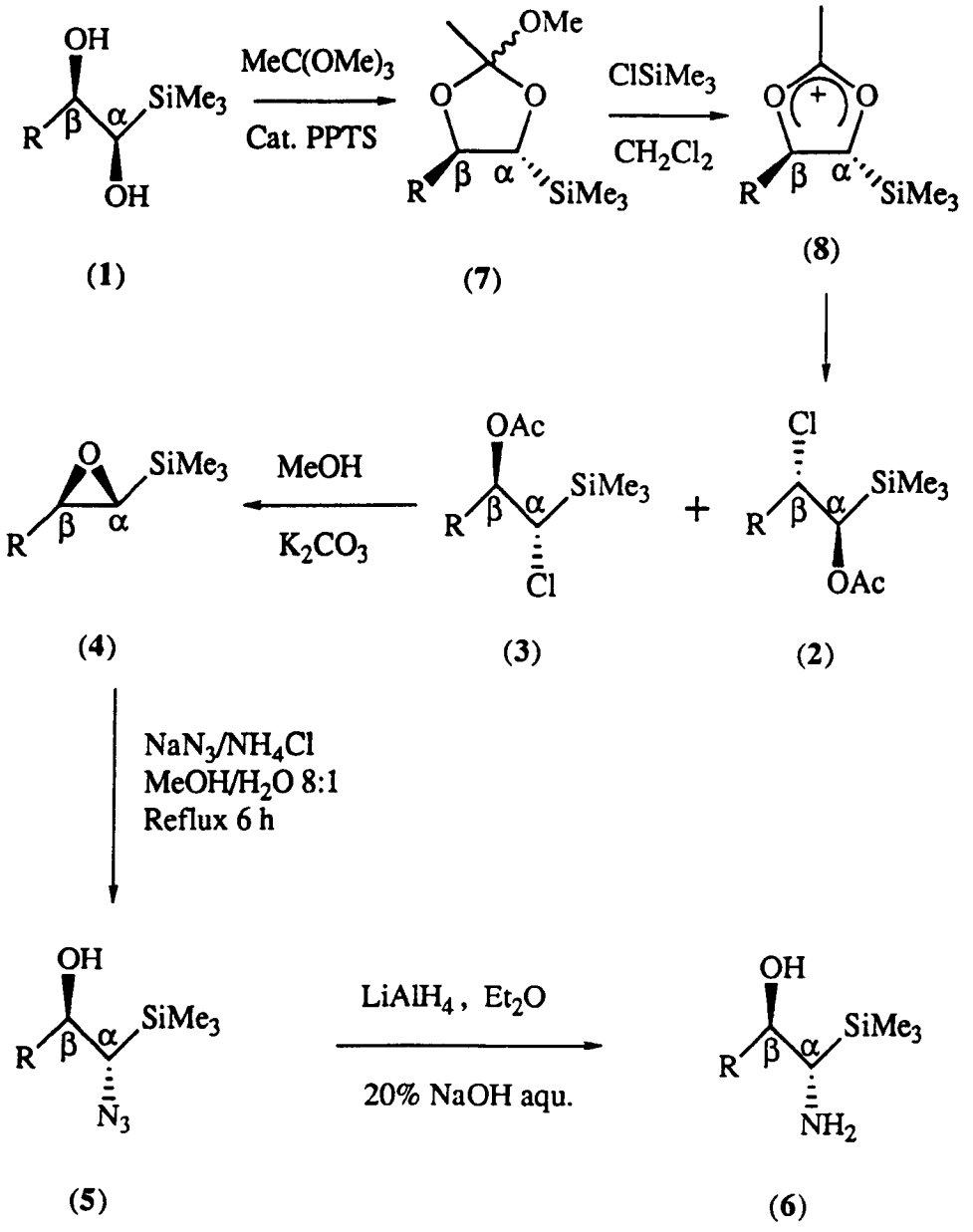
Silylated epoxides , first described in 1958,[3] were only reported occasionally[4] until the mid 1970's. Over the last twenty years there has been a great interest in the use of α, β-trimethylsilylepoxides as synthetic intermediates. Like simple epoxides, α, β-trimethylsilylepoxides undergo ring opening with a variety of reagents. However, the silicon exerts a powerful directing effect such that these ring opening reactions usually proceed with α-opening, that is, opening at the carbon bearing the silicon.[5] Like simple epoxides, α,β-trimethylsilylepoxides are easily prepared by epoxidation of carbon-carbon double bonds and by cyclization of silylated halohydrins. They can also be prepared from carbonyl compounds and by the silylation of oxiranyl anions.[4] To date asymmetric synthesis of silylated epoxides have been based on the Sharpless asymmetric epoxidation of silylated allylalcohols[6,7]. This has been developed by Chan to include alkenylsilanols[8].

The synthesis of silylated epoxides from the corresponding diols has not been reported. We have previously shown that trimethylsilyl cyclic sulphites and sulphates can act as epoxide-like building blocks. In our efforts to convert optically active vicinal silyldiols into synthetically more valuable intermediates, we examined how optically active trimethylsilylepoxides and aminoalcohols can be made from the corresponding diols[9].

§ 4.2 Synthesis of Trimethylsilylepoxides from Diols *via* Trimethylsilyl Halohydrin Esters

In early papers, a variety of reagents have been reported[10] for the conversion of organic diols into halohydrin esters. In 1958, Baganz and Domaschke reported the formation of a 2-haloethylester by treatment of 2-ethoxy-1,3-dioxolane, derived from 1,2-ethanediol and orthoformate, with acetyl halide under reflux conditions.[11] Later Newman *et al.* showed that the same transformation could be achieved by reacting orthoesters of 1,2-diols with trityl chloride or chlorotrimethylsilane.[12-16] This attractive acetoxonium ion chemistry has been successfully applied to organic synthesis.[13] The preparation of a silylepoxide via a

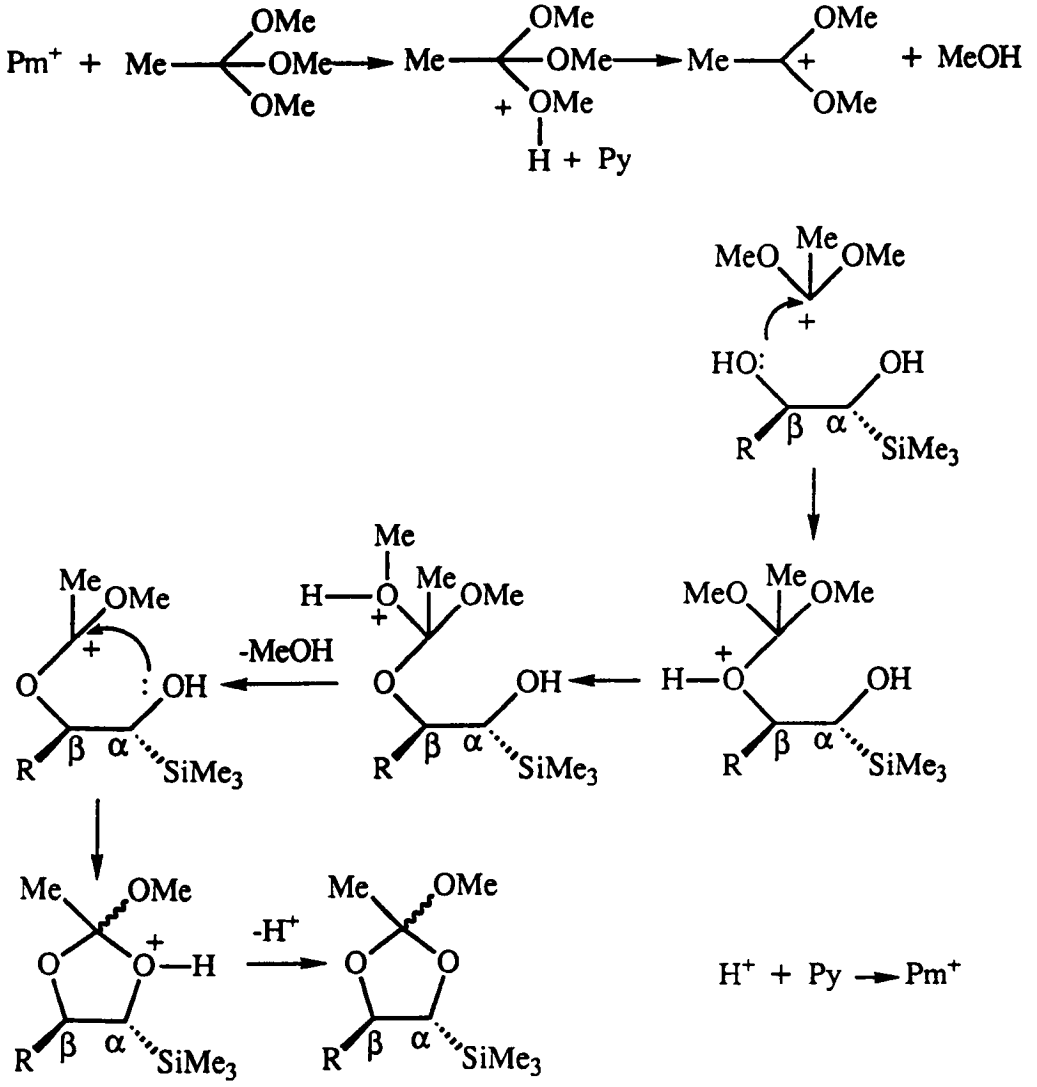
halohydrin by treatment with sodium hydroxide has been reported by Jankowski *et al.* in 1989.[17] The synthesis of the K-region arene oxides via



Scheme 4.1

dehydrohalogenation of chlorohydrin acetates by treatment with sodium methoxide in dichloromethane has been reported by Dansette and Jerina.[14] More recently, the cyclization of halohydrins by treatment with potassium carbonate in methanol has been reported by Sharpless at al.[10]

The nucleophilic ring opening of trimethylsilylepoxides can be easily achieved with sodium azide [18] and the resulting azido alcohols can be converted into aminoalcohols with lithium aluminium hydride. The general scheme for this reaction is illustrated in Scheme 4.1. Note that the optical purity is maintained through each step.



(8)

Pm = Pyridinium cation, Py = pyridine

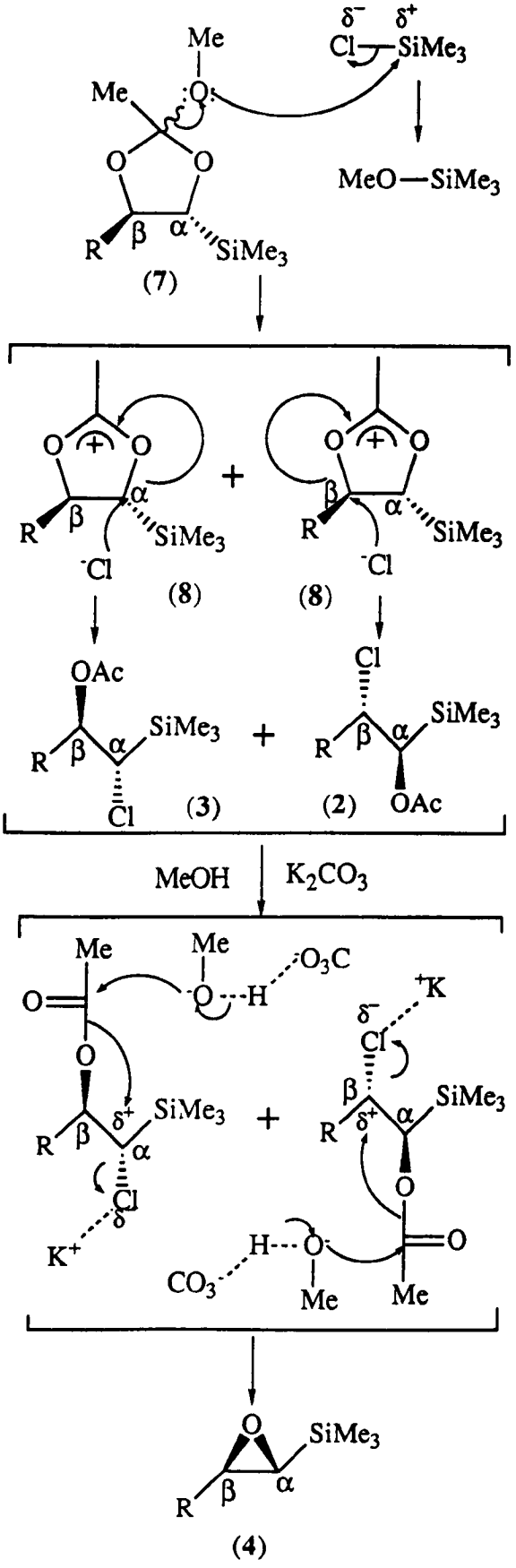
Scheme 4.2

Formation of the trimethylsilylated cyclic orthoester(8) from alkyl substituted trimethylsilyl-1,2-diols was carried out at room temperature in dichloromethane using 1% pyridinium *p*-toluenesulphonate (PPTS) as a catalyst. The mechanism for this conversion

(I): The oxygen lone pair from the cyclic silyl orthoester attacks the electrophilic silicon of the chlorotrimethylsilane.

(II): The cyclic silylacetoxonium ion formed is readily attacked by chloride ion. Nucleophilic additon leads to two acetoxy halide regeoisomers.

(III): The nucleophile is generated by the weak base, carbonate ion in dry methanol. This nucleophile attacks the electrophilic carbon of the carbonyl group. The oxygen bond from the carbonyl of the acetoxy group, is broken and leads to the negatively charged oxygen attacking the electron poor halide-bearing carbon forming an epoxide.



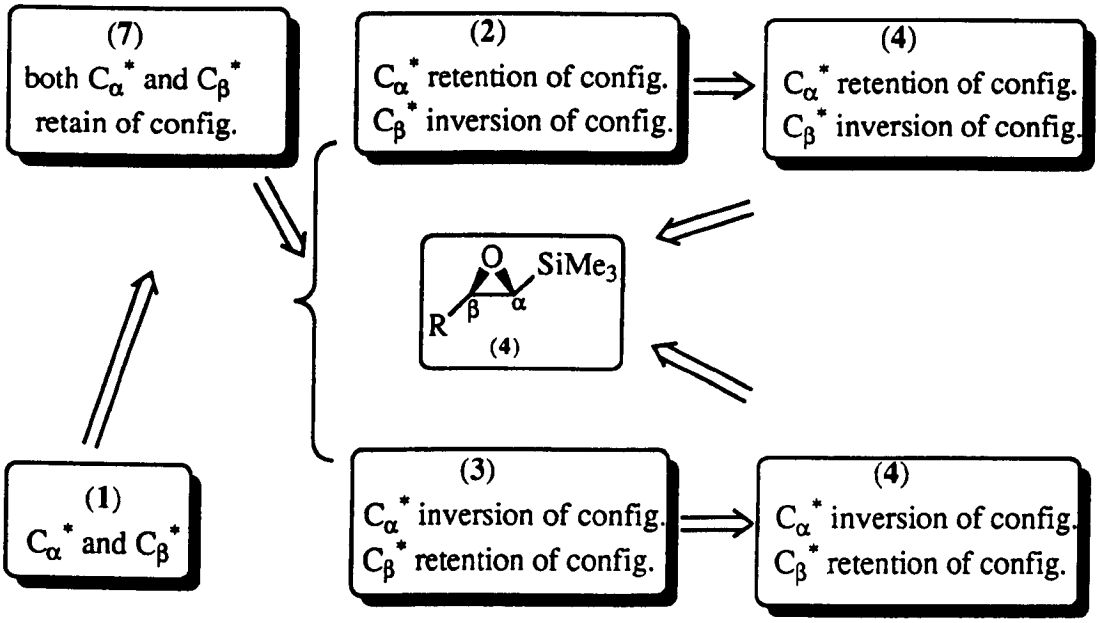
Scheme 4.3

is shown in Scheme 4.2. This cyclization is an equilibrium reaction that can be shifted in the direction of the higher boiling trimethylsilylated orthoester. The orthoester was activated by the pyridinium cation and the oxygen of the diol attacks the electrophilic carbon of the orthoester in a stepwise fashion as shown in Scheme 4.2.

The trimethylsilylepoxide can be made from the orthoester by treatment with TMSCl. The overall mechanism of epoxide formation is presented in Scheme 4.3.

The chirality transfer (Figure.4.1) from trimethylsilyl-1,2-diols to epoxides was carried out via several non racemization stages (Scheme 4.2, 4.3). The two stereogenic centres

Figure. 4.1



C_α and C_β on the silyl cyclic orthoester (7) were retained from the diol, both with retention of configuration. The two stereogenic centres C_α and C_β on the trimethylsilyl halohydrin ester regioisomer (2) were transferred from (7) with retention of configuration of C_α and with inversion of configuration of C_β. The silyl halohydrin ester regioisomer (3) was

made with inversion of configuration of C_α and with retention of configuration at C_β. The two stereogenic centres C_α and C_β of the trimethylsilylepoxide were both obtained from the silyl halohydrin ester regioisomers (**2**) and (**3**). If the trimethylsilylepoxide came from the trimethylsilyl halohydrin ester regioisomer (**2**) C_α retained its configuration and C_β inverted its configuration; if the epoxide was made from the trimethylsilyl halohydrin ester (**3**) C_α inverted its configuration and C_β retained its configuration.

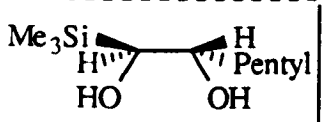
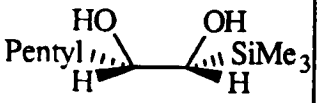
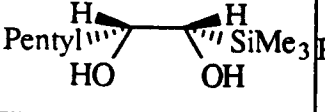
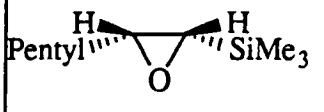
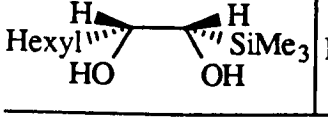
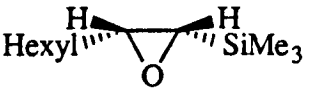
The optically active trimethylsilylepoxides produced are listed in Table 4.1 together with the predicted configurations. Usually, the *trans* trimethylsilylepoxides were obtained with high enantiomeric excess of up to 95% e.e.. The *cis* trimethylsilylepoxides were obtained with lower enantiomeric excess, about 61% e.e..

During the transformation of the silyldiol to the epoxide, a side reaction was observed. As shown in Scheme 4.4, a Peterson elimination occurred to give a dimethyl acetal (**12**). This side reaction can be minimized by the addition 15% triethylamine and performing the cyclization of the trimethylsilyl orthoester at 0°C.

The Peterson reaction is presumably catalysed by pyridinium ion to give the enol (**9**). Subsequently, this enol (**9**) is converted to the aldehyde and reacts with methanol to form a hemiacetal (**11**) which reacts further with methanol to give the final acetal (**12**) (Scheme 4.4).

So far, we have been able to obtain optically active α-trimethylsilyl-α,β-epoxides efficiently from their corresponding diols. However optically active β,γ-trimethylsilylepoxides have not been obtained owing to the competing Peterson elimination.

Table 4.1: Optically Active Trimethylsilylepoxides

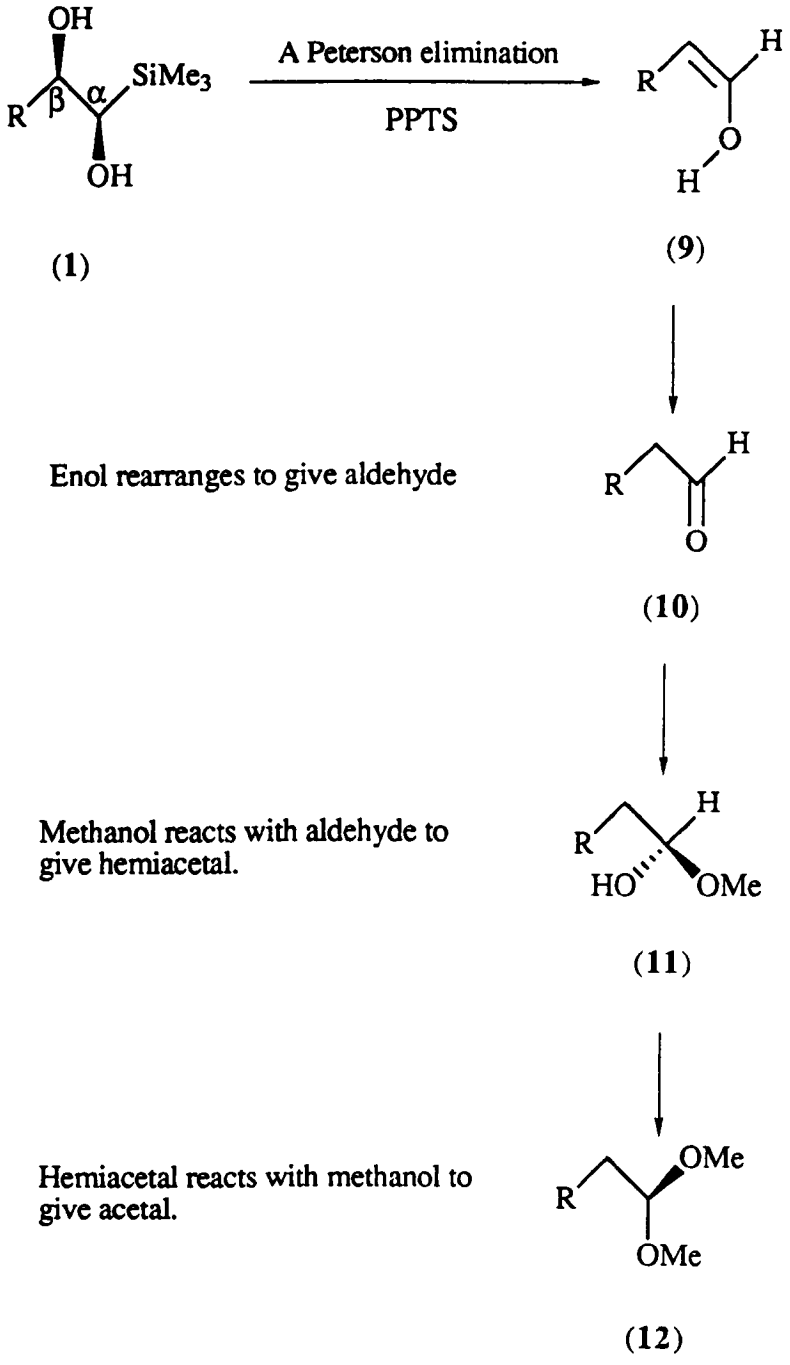
Trimethyls ilyl -1,2-diols	Trimethylsilylepoxides	Trimethylsilylepoxides			
		No.	% e.e.	yield%	config.*
		4aA	95†	62	*1R,2R*
		4aB	95†	63	*1S,2S*
		4bA	95#	65	*1R,2R*
		4bB	95#	64	*1S,2S*
		4cA	95#	63	*1R,2R*
		4cB	95#	65	*1S,2S*
		4dA	61#	60	*1R,2S*
		4dB	61#	62	*1S,2R*
		4eA	61#	61	*1R,2S*
		4eB	61#	62	*1S,2R*

* The absolute configuration are tentatively predicted by the Sharpless Mnemonic, however, they have not been confirmed.

† The enantiomeric excess was determined by glc using a Chiraldex G-PN 20m x 0.25mm chiral column.

The enantiomeric excess was determined by ^{13}C NMR in the presence of [Eu(hfc)$_3$].

Scheme 4.4



§ 4.3 Making Optically Active Trimethylsilyl Amino Alcohols from Trimethylsilylepoxides

Optically active trimethylsilylepoxides are very useful intermediates since they undergo a variety of nucleophilic ring openings under the strong directing and activating influence of the silyl group. We present one example which is a route to optically active silyl amino alcohols via an azide nucleophilic ring opening of the trimethylsilylepoxide.

The ring opening reaction of trimethylsilylepoxides by sodium azide was catalyzed by ammonium chloride and proceeded in a methanol-water solvent system under reflux for 6 hours to give the trimethylsilyl azido alcohols in about 90% yield. The electrophilic C_α and C_β carbon atoms on the epoxide (**15**) ring are readily attacked by the azide nucleophile. Under the directing effect of the silyl group, the azide ion only attacks the C_α carbon leading to 100% of the regioisomer (**14**) with no observable amount of the regioisomer (**13**) as shown in Scheme 4.5 and Table 4.2.

Scheme 4.5: Ring opening of trimethylsilylepoxide with sodium azide

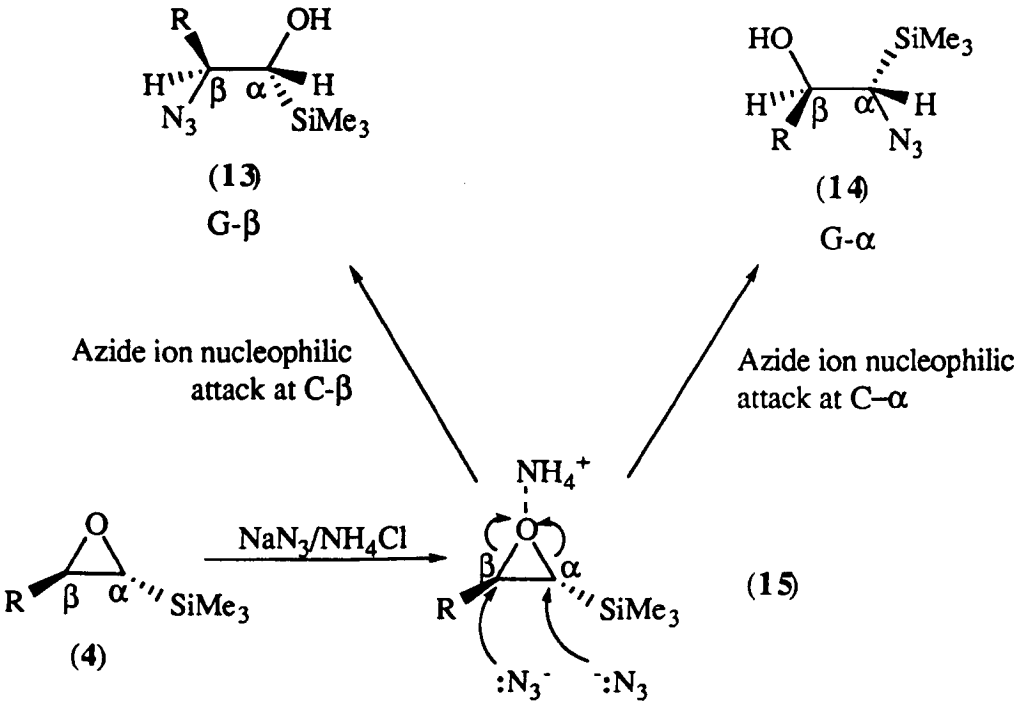


Table 4.2 : Regioselectivity of Silylazidoalcohol

Entry	Silylazidoalcohol		
	G-α yield	G-β yield	G-α / G-β
4a	81	0	100 : 0.0
4b	84	0	100 : 0.0
4c	87	0	100 : 0.0
4d	85	0	100 : 0.0
4e	86	0	100 : 0.0

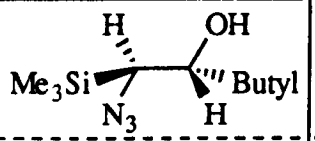
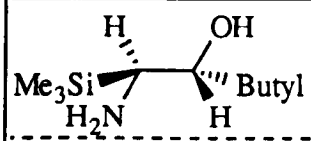
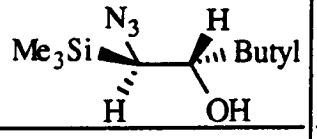
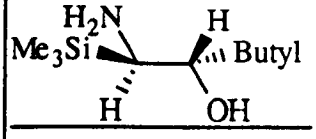
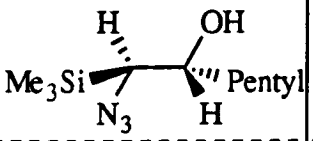
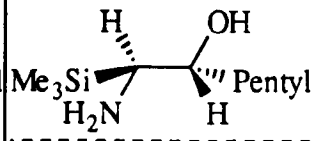
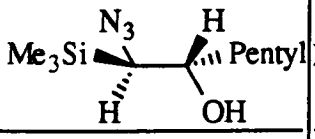
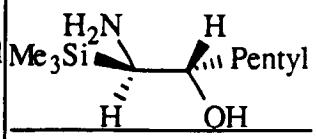
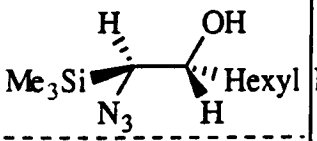
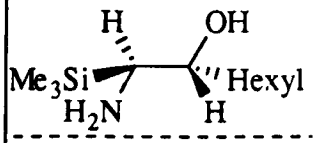
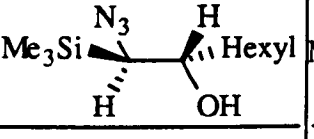
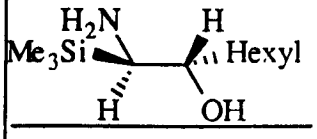
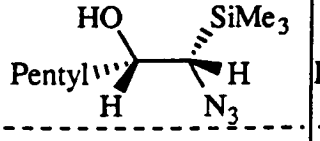
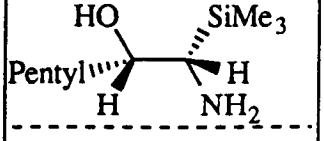
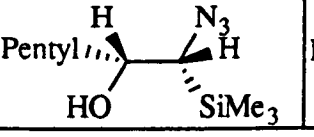
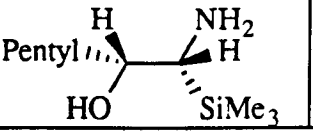
The regioisomer (**14**) of the trimethylsilyl azido alcohol is obtained with inversion of configuration of C_α and retention of configuration of C_β.

The regioisomeric ratio can be determined from the heteronuclei and homonuclei COSY 2D NMR spectra which clearly show a correlation between the protons on the hydroxy bearing carbon and the proton of the hydroxy group. The hydroxy bearing-carbon and the azido-bearing carbon can also be located by comparison between the H^1-H^1 COSY 2D NMR spectra and the C^1-H^1 COSY 2D NMR spectra.

The trimethylsilyl azido alcohols can be converted into trimethylsilyl amino alcohols by reaction with lithium aluminium hydride in dry diethyl ether followed by work up with 20% sodium hydroxide solution .

In this reaction, there is no bond breaking or forming at the two stereogenic centres C_α and C_β of the silyl amino alcohol. Thus the chirality of its precursor trimethylsilyl azido alcohol was maintained. A number of trimethylsilyl azido alcohols and amino alcohols with high enantiomeric excess of up to 95% e.e. with yields of up to 90% are shown in Table 4.3. The absolute configurations are deduced from the Sharpless mnemonic.

Table 4.3 : Optically active trimethylsilyl amino alcohols

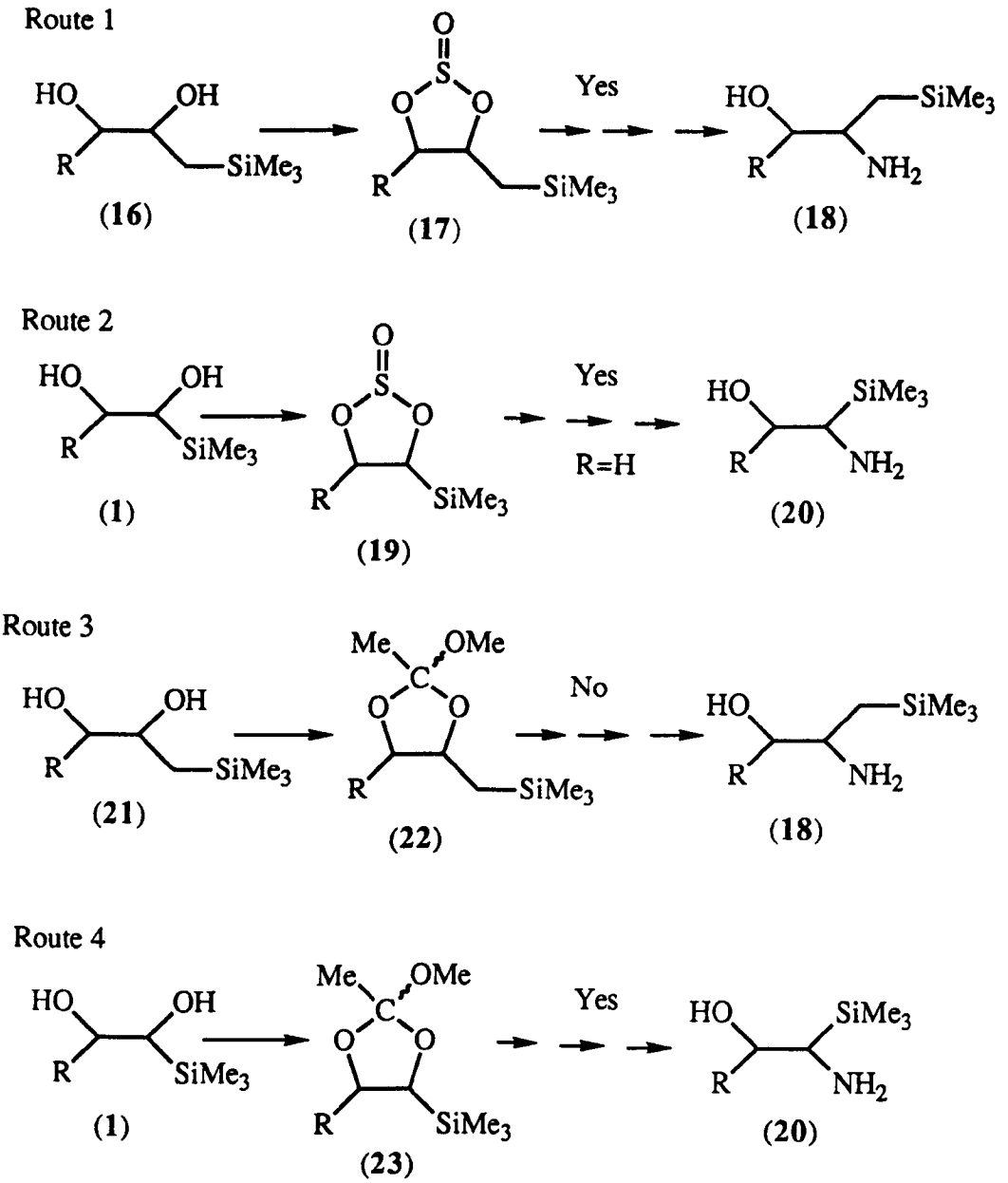
entry	Trimethylsilyl azido alcohols	Trimethylsilyl amino alcohols	Trimethylsilyl amino alcohols		
			%e.e.†	yield%	config.*
4aA			95	87	*1S,2R*
4aB			95	85	*1R,2S*
4bA			95	89	*1S,2R*
4bB			95	87	*1R,2S*
4cA			95	86	*1S,2R*
4cB			95	90	*1R,2S*
4dA			61	85	*1S,2S*
4dB			61	89	*1R,2R*

* The absolute configuration of trimethylsilyl amino alcohols are tentatively deduced from the Sharpless mnemonic.

† The enantiomeric excess was determined by ^{13}C NMR in the presence of [Eu(hfc)$_3$].

We have shown that the trimethylsilylated amino alcohols can be made from via the intermediate cyclic sulphites (**17**) and (**19**) via Routes 1 and 2(R=H), or from cyclic

orthoesters (23) via Route 4. These intermediates were prepared from the corresponding diols as shown in Scheme 4.6. The intermediates β,γ-cyclic orthoesters (22) could not be prepared by Route 3 due to the competing Peterson elimination.

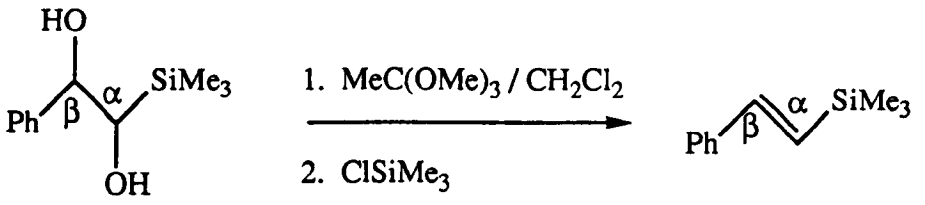


Scheme 4.6

The deoxygenation of vicinal silyl diols could be carried out without loss of the silyl group by using a modified method [21] which employs amide acetals as shows in Scheme 4.9.[22,23] This avoids the acid induced Peterson elimination.

§ 4.4 *trans*-2-Phenylvinylsilane formed from the trimethylsilyl orthoester in presence of chlorotrimethylsilane

When we tried to convert 1-phenyl-2-trimethylsilyl-1,2-ethanediol (**24**) to its corresponding halohydrin ester by reaction with orthoester and chlorotrimethylsilane, we obtained *trans*-2-phenylvinylsilane (**25**) (Scheme 4.7) in at least 65% yield. This reaction has been repeated many times, and the conformation about the double bond was confirmed by NMR.

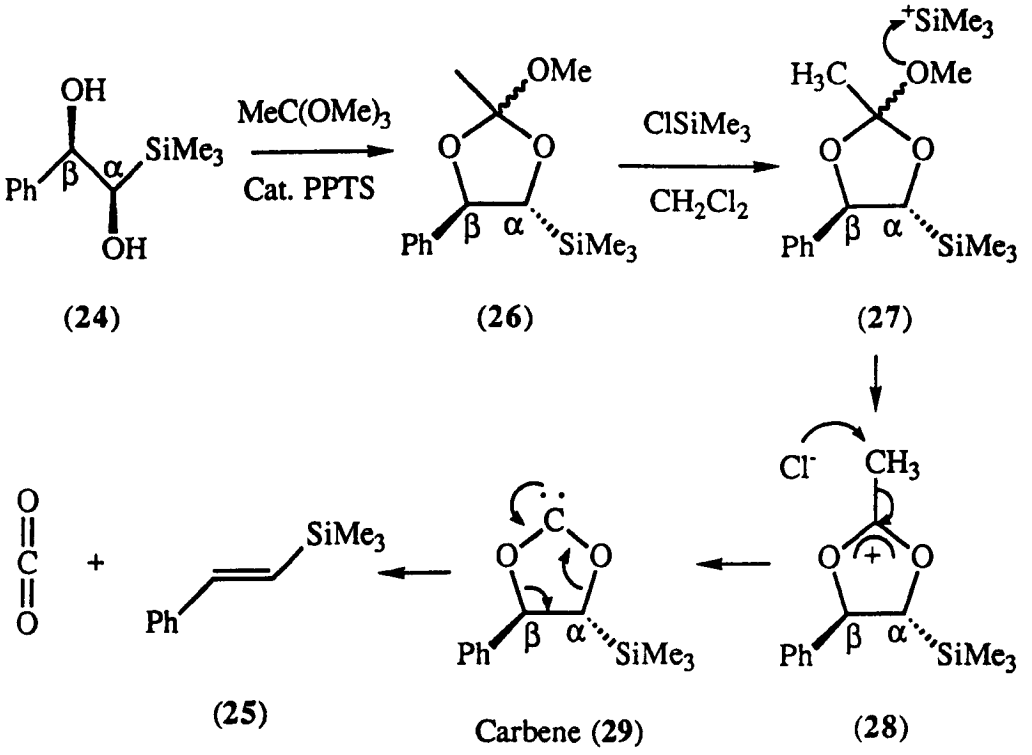


(**24**) (**25**), 65% yield

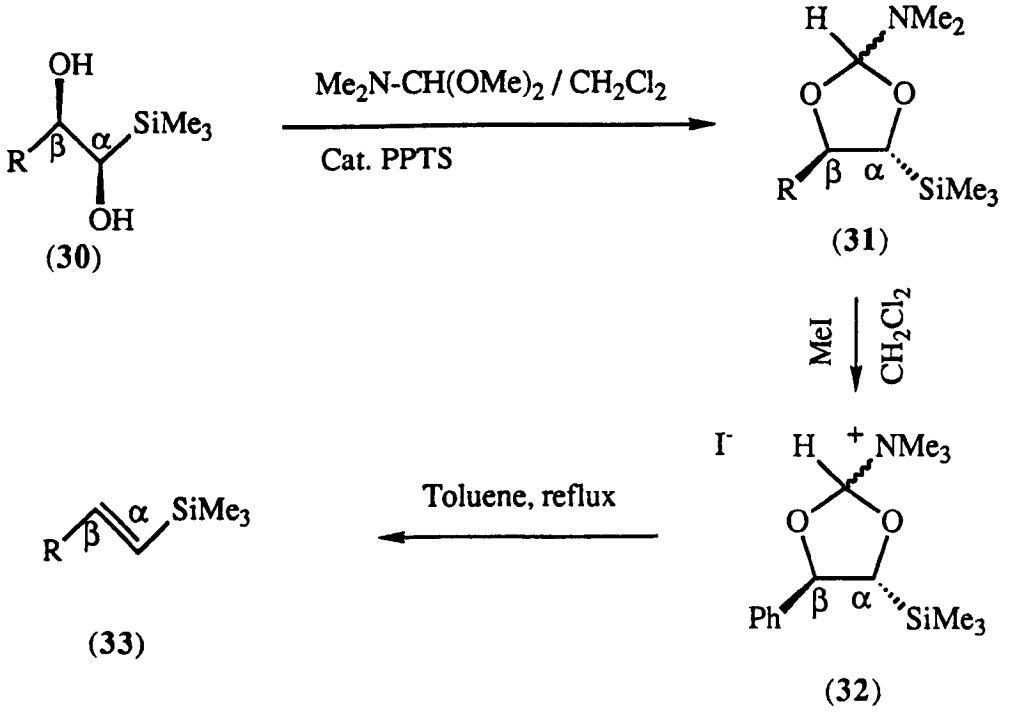
Scheme 4.7

Surprisingly, this Eastwood reaction [19,20,21] which involves elimination between the C_α and C_β does not affect the silyl group. This mechanism is shown in Scheme 4.8.

Eastwood reaction usually need a higher temperature. In this particular case, the reaction underwent under very mild conditions at the temperature of 0 to 20°C and was able to be completed within 1 hour. The cyclic trimethylsilylacetoxonium ion formed could be supposed to attacked at the methyl group of (**28**) by chloride ion to give carbene-intermediate (**29**) shown in Scheme 4.8. The carbene (**29**) would spontaneously decompose to give *trans*-2-phenylvinylsilane (**25**).



Scheme 4.8



Scheme 4.9

§ 4.5 Determination of the enantiomeric excess of trimethylsilylepoxides and amino alcohols

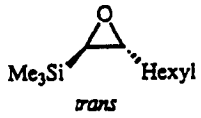
The enantiomeric excess of trimethylsilylepoxides and trimethylsilyl amino alcohols were determined from the ^{13}C NMR spectra in the presence of the europium chiral shift reagent $Eu(hfc)_3$. The ratio of compound to shift reagent was 1/1. No time is required for equilibration and the sample with the shift reagent can be run immediately on the NMR spectrometer. The separation of the enantiomers in the ^{13}C NMR spectra is very clear, particularly with the substituted trimethylsilylepoxides and trimethylsilyl amino alcohols. Some of the results are presented below:

The ^{13}C NMR spectra of racemic *trans*-β-hexyl-α,β-epoxysilane in $CDCl_3$ is shown in Figure 4.2a and with $Eu(hfc)_3$ in Figure 4.2b. All of the carbons including the six hexyl carbons and carbons on the silyl group give a pair of peaks for the racemic samples (Figure 4.2b). The ^{13}C NMR spectra of *1S,2S-trans*-β-hexyl-α,β-epoxysilane with 1 equivalent of $Eu(hfc)_3$ in $CDCl_3$ is shown in Figure 4.2c, and the *1R,2R-trans*-β-hexyl-α,β-epoxysilane shown in Figure 4.2d. In each enantiomer, all of the substituent carbons, including the six hexyl carbons and carbons on the silyl group, clearly show one single peak. The clearest region selected can easily be expanded to work out the enantiomeric excess (96% e.e.).

The ^{13}C NMR spectra of *cis*-β-hexyl-α,β-epoxysilane in $CDCl_3$ without shift reagent is shown in Figure 4.3a and *1S,2R-cis* -β-hexyl-α,β-epoxysilane with $Eu(hfc)_3$ is shown in Figure 4.3b. After expanding the peaks between 25-36ppm the enantiomeric excess was found to be 61% e.e..

The ^{13}C NMR spectra of racemic 1-amino-1-trimethylsilyloctan-2-ol in $CDCl_3$ is shown in Figure 4.4a and this racemate with $Eu(hfc)_3$ in Figure 4.4b and 4.4c. All of the substituent carbons including the six hexyl carbons and carbons on the silyl group, give a pair of peaks for the racemic samples (Figure 4.4b and 4.4c). The ^{13}C NMR spectra of

Figure 4.2a



trans

Figure 4.2b

Racemate
+Eu(hfc)3

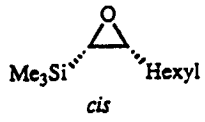
Figure 4.2c

1S,2S
(AD-mix-β)
+Eu(hfc)$_3$

Figure 4.2d

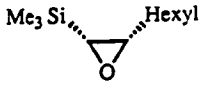
1R,2R
(AD-mix-β)
+Eu(hfc)$_3$

Figure 4.3a



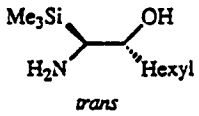
cis

Figure 4.3b



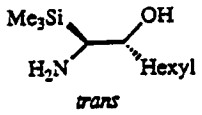
1S,2R
(AD-mix–α)
+Eu(hfc)$_3$

Figure 4.4a



trans

Figure 4.4b



trans
racemate
+Eu(hfc)$_3$

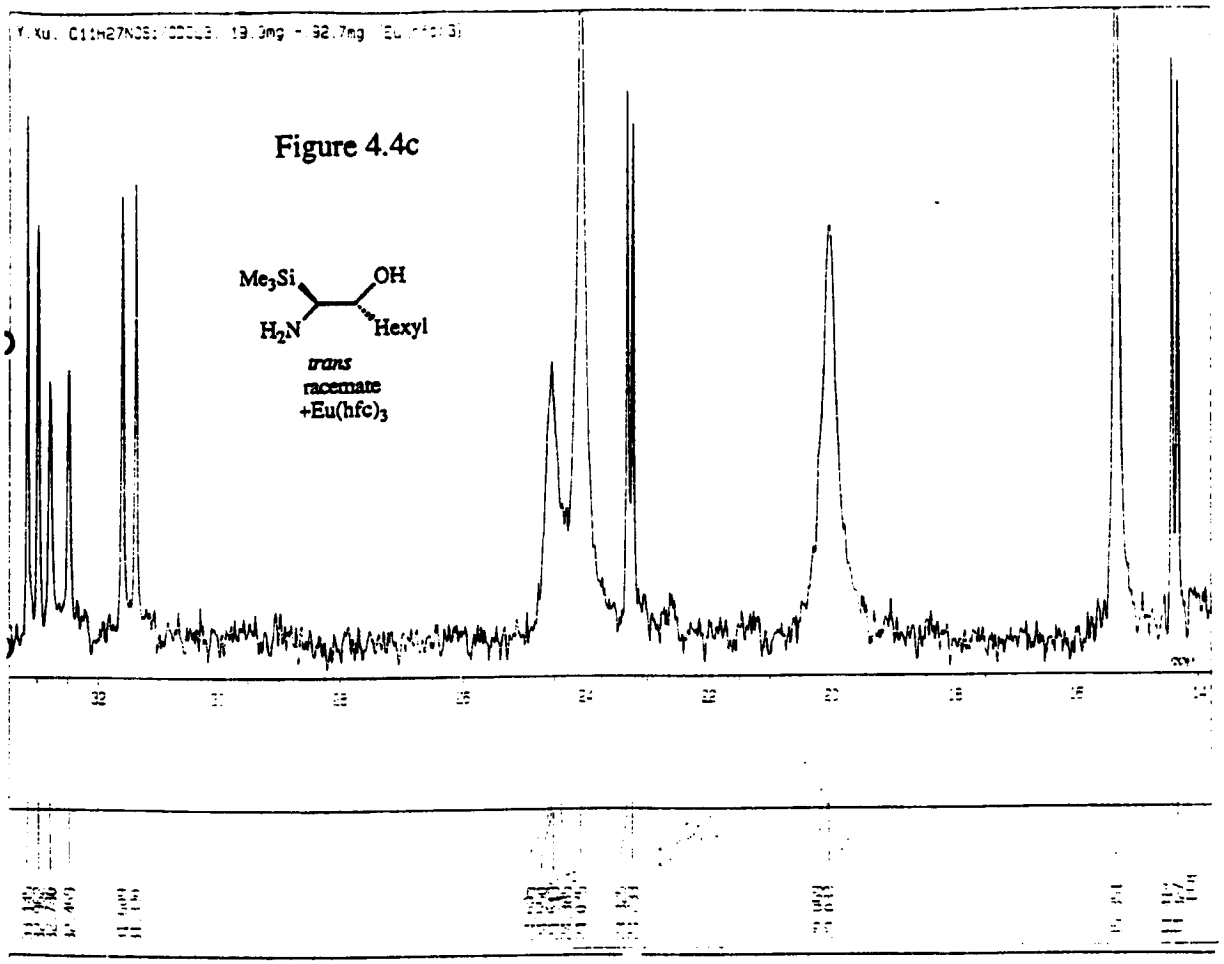


Figure 4.4c

trans
racemate
+Eu(hfc)$_3$

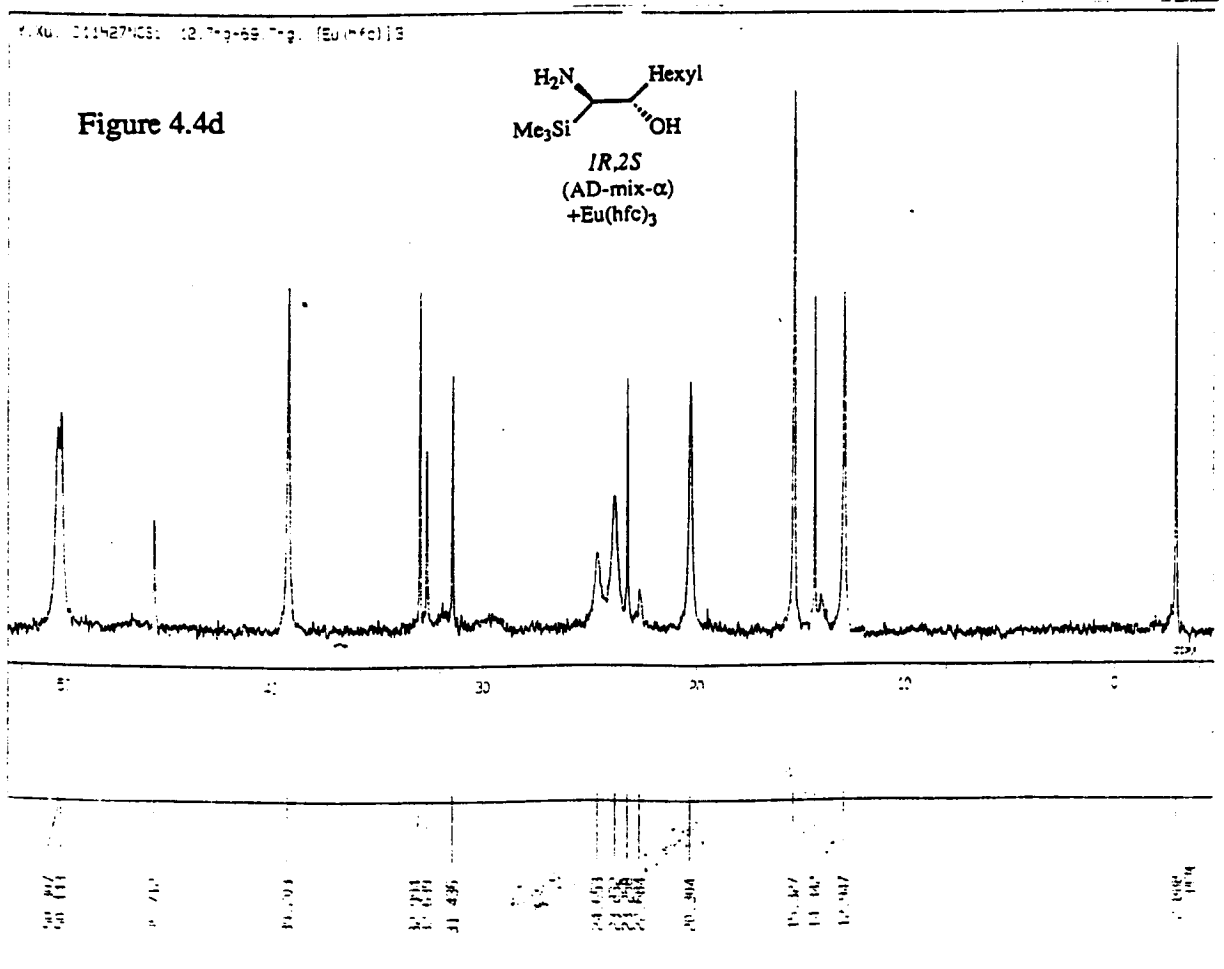


Figure 4.4d

1R,2S
(AD-mix-α)
+Eu(hfc)$_3$

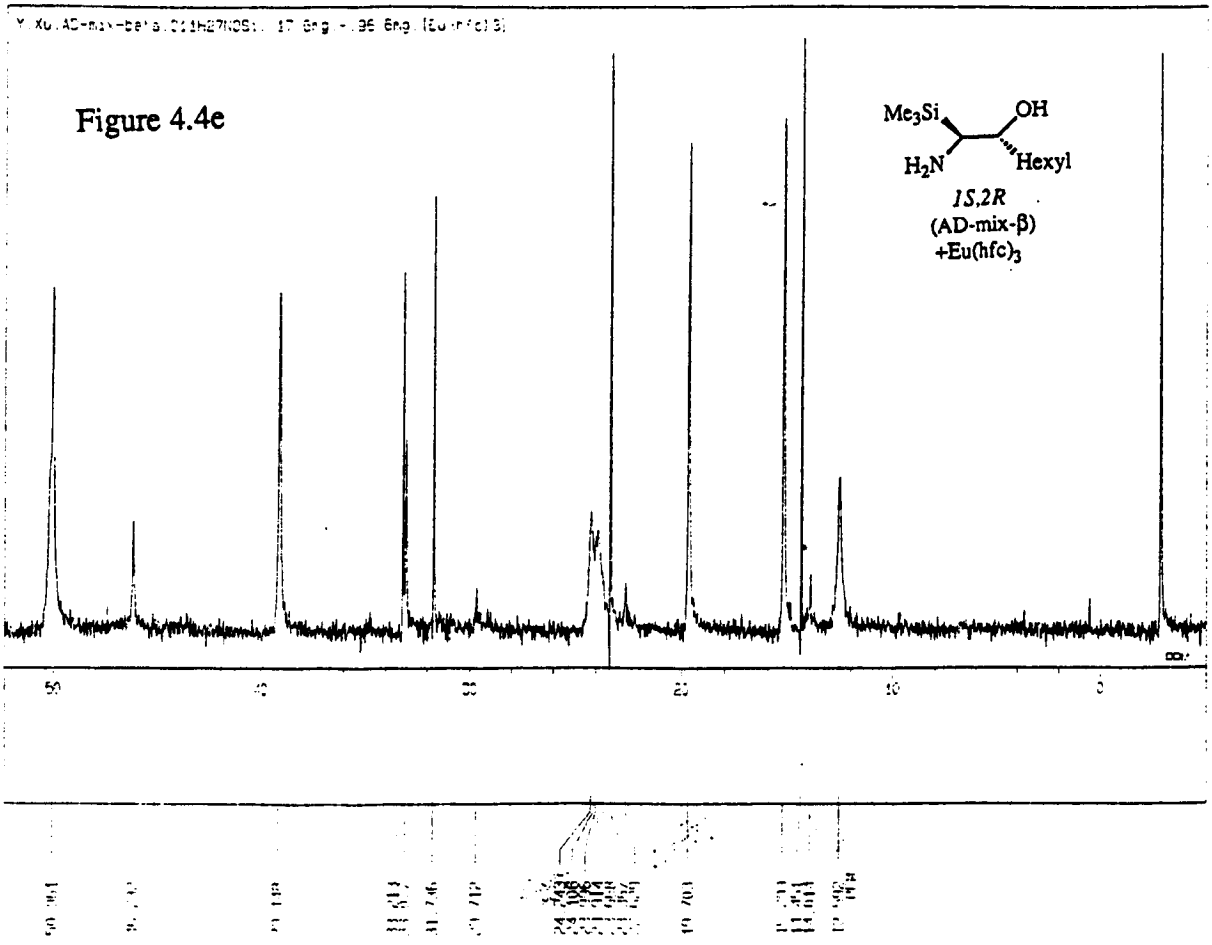


Figure 4.4e
Me3Si
OH
H2N
Hexyl
1S,2R
(AD-mix-β)
+Eu(hfc)3

1R,2S-1-amino-1-trimethylsilyloctan-2-ol with 1 equivalent $Eu(hfc)_3$ in $CDCl_3$ is shown as Figure 4.4d and *1S,2R*-1-amino-1-trimethylsilyloctan-2-ol is shown in Figure 4.4e.

All of the substituent carbons, including the six hexyl carbons and carbons on the silyl group for these two enantiomers, clearly show one single peak for each carbon. The clearest region selected can easily be expanded and to give the enantiomeric excess (96% e.e.).

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Chapter 5

Asymmetric Epoxidation of Vinyl- and Allylsilanes

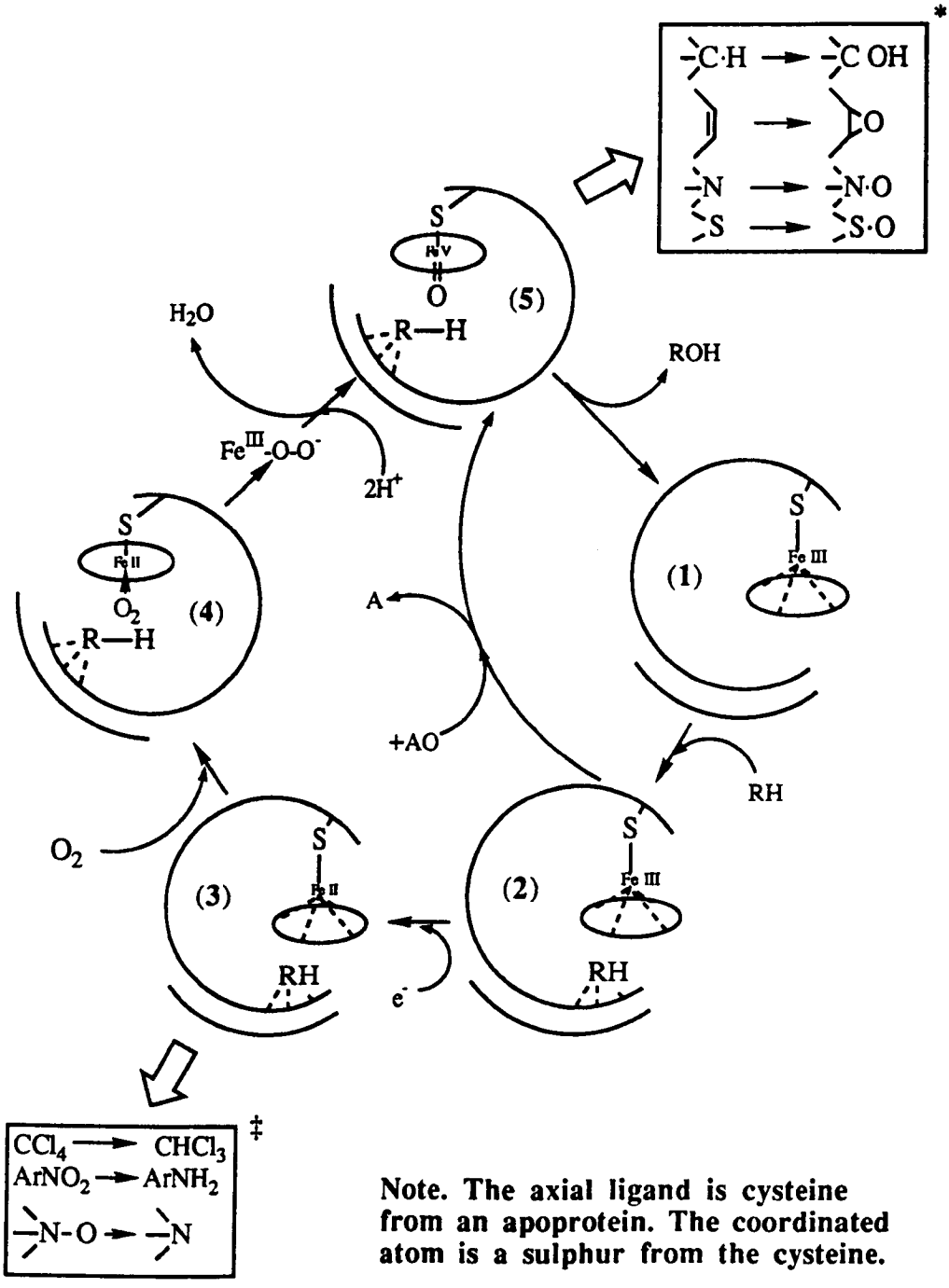
Contents

§ 5. 1 Survey of Methodology

One of the aims of the present work is to enantiomerically epoxidize unfunctionalized allyl- and vinylsilanes, that is allyl- and vinylsilanes with no polar groups attached. The most convenient approach is homogeneous chiral catalysis using fourth-generation asymmetric methods. Among this category, Jacobsen's epoxidation is likely to be the best choice, because there is no need for a polar group on the substrate to anchor the central metal. Our first attempt was to use *cis*-β-trimethylsilylstyrene as the substrate with a dichloromethane-water system, at 0°C, pH 11 with 0.5 mol of sodium hypochlorite and 0.04 equivalent manganese(III) salen complex. No reaction was observed after 16 hours. When *cis*-2-oct-1-enyltrimethylsilane was used as the starting material a tiny amount of epoxide was formed under the same conditions after 3 hours.

Tertiary amines have been shown to dramatically enhance the dihydroxylation of alkenes using osmium tetroxide. They accelerate the hydrolysis of the osmate ester rather than osmate ester formation (Chapter 1, 1.4). In the natural system, the P-450 monooxygenase, an axial ligand is often opposite to the oxo ligand (Scheme 5.1)[1].

Scheme 5.1, The need for an axial ligand in the natural system: P-450



Note. The axial ligand is cysteine from an apoprotein. The coordinated atom is a sulphur from the cysteine.

* The intermediate (**5**) is able to perform the hydroxylation of C-H bonds, the epoxidation of alkene double bonds and of aromatic rings, and the transfer of an oxygen to nitrogen atoms of amines and sulphur atoms of thioethers[1, 2 and 3].

‡ The intermediate (**3**) is able to transfer electrons to easily reducable compounds such as CCl_4 nitroaromatics,tertiary amine oxides or arene and to catalyse their reductions to $CHCl_3$, anilines, tertiary amines and arenes respectively[1, 4-7].

AO is a single oxygen donor.

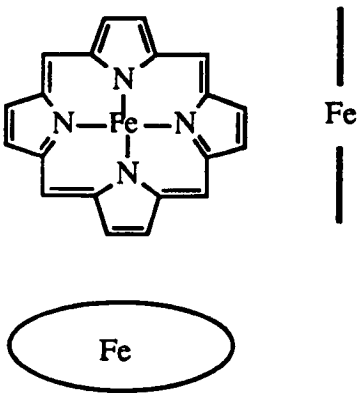
In the hemoprotein catalysis, the cofactor is an iron-porphyrin complex. The porphyrin is a chelate ligand and during the catalytic process, these ligands do not dissociate from the metal centre. This means that the chelate ligands cannot provide the necessary fine-tuning, for reaction and so, the axial ligand becomes important. Some hemoproteins which support this proposal are listed in Table 5.1[8-11].

Table 5.1, Hemoproteins with Iron Axial Ligands

Hemoprotein	Iron Axial Ligand	Function
Hemoprotein	**Histidine N**	O_2 transport
Prostaglandin synthase	**Histidine N**	Dioxygenation of arachidonic acid
Cytochrome P-450	**Cysteine S**	Monooxygenations $RH+O_2+2e^-+2H^+ \rightarrow ROH+H_2O$
Cytochrome a3	**Histidine N**	O_2 reduction $O_2+4e^-+4H^+ \rightarrow 2H_2O$
Catalase	**Tyrosine O**	$2H_2O_2 \rightarrow 2H_2O+O_2$ $H_2O_2+AH_2 \rightarrow A+2H_2O$

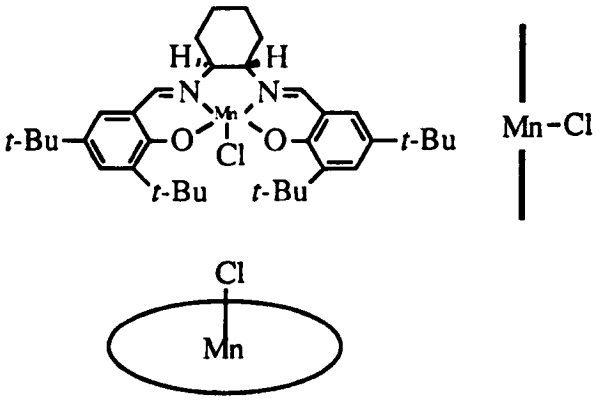
The similarity between porphyrins and salen [*N,N'*-**bis** (3,5-di-*tert*-butyl-**salicylidene**-1,2-cyclohexane**diamino**)] ligands is shown in Figure. 5.1. It is possible that an axial ligand such as a nitrogen, oxygen or sulphur containing compound will accelerate the catalytic process. This fine-tuning of the bond strengths between the ligands and the central metal will enable the central metal to either hold the substrate or release the product at the right times.

Figure. 5.1



(6)

Iron porphyrin complex (A heme ring)

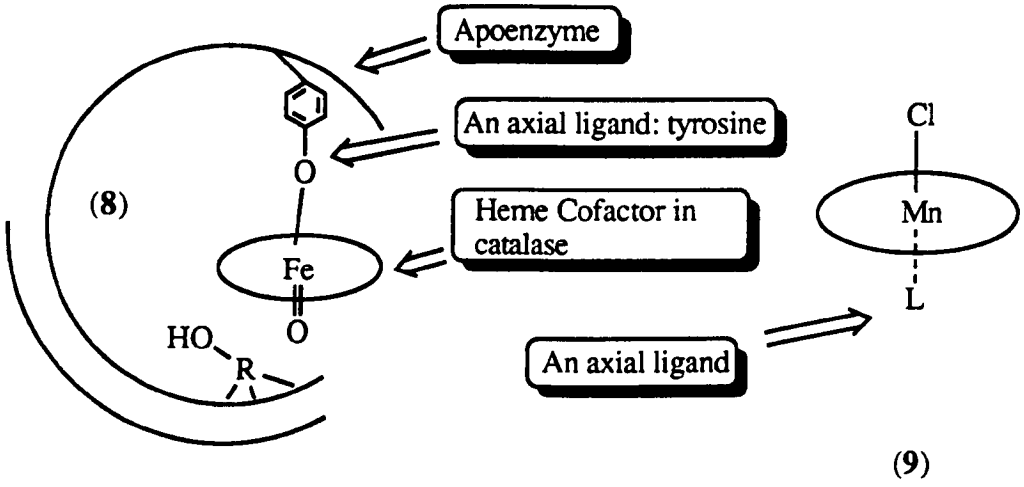


(1S,2S)

(7)

Mn(III) salen complex

Figure. 5.2, Comparison



Catalase

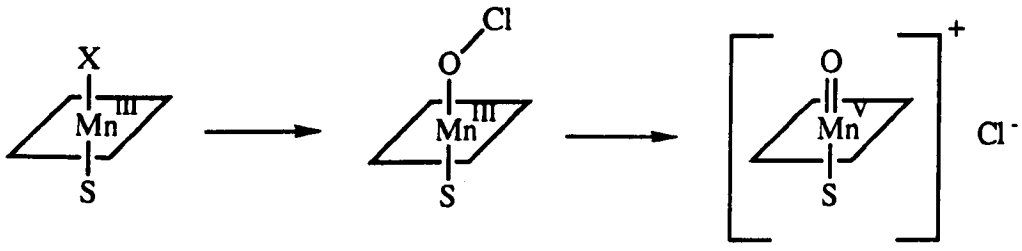
A Mn(III) salen catalyst

In Jacobsen's epoxidation system, most of the reactions are run with regular hypochlorite solutions [12-16], with dichloromethane, or ethyl acetate as the organic phase. These

solutions are highly basic, pH ca. 11, so the hypochlorite anion is the main species present, as shown in equation (1).

$$2NaOH + Cl_2 \rightleftharpoons NaOCl + NaCl + H_2O \qquad (1)$$

The equilibrium constant of hypochlorite formation is 7.5×10^5. By decreasing the pH value of the hypochlorite solution, hypochlorous acid, HOCl, gradually becomes the predominant species[17] and usually is the source of positive chlorine. So the pH value of the hypochlorite solution is one of the key factors in controlling the reaction, for instance, the epoxidation of aromatic hydrocarbons with NaOCl only occurs in the pH range 7-8[18].



(10) **(11)** **(12)**

Scheme 5.2

The proposed mechanism for manganese-oxo bond formation from a coordinated hypochlorite anion is shown in Scheme 5.2. The axial ligands of the manganese (III) salen species (**10**) are halide and the solvent, water. It is proposed that the halide group in (**10**) is exchanged for a hypochlorite anion to form (**11**). If the bond between the oxygen and chloride dissociates, the manganese (V) salen oxo complex (**12**) is formed which then performs the epoxidation[19-22].

§ 5.2 The Influence of Axial Ligands on the Epoxidation of Vinyl- and Allylsilanes

Jacobsen's catalyst is available from both Aldrich and Fluka chemical companies. However, the brown solid provided by Aldrich did not work very well for the epoxidation

of allyl- and vinylsilanes using known methods. In this work epoxidation of the allyl and vinylsilanes was carried out using both a manganese (III) salen complex prepared using a modified literature method which gave fine black crystals and a sample purchased from Aldrich chemical company.

In order to test the effect of axial ligands, a number of ligands have been used with manganese (III) salen complexes to catalyze epoxidation. These axial ligands include nitrogen donor ligands such as: pyridine (Py), 4-*N,N*-dimethylamino-pyridine (DMAP), *N*-methylimidazole (NMI), imidazole (IMD), the phase transfer catalyst (tetrabutylammonium bromide) (PTC), and oxygen donor ligands such as: 4-phenylpyridine *N*-oxide (PPNO), 1-benzyl-3-hydroxypyridinium chloride (BHPC), *N*-benzylquininium chloride (BQC), and water. The substrates used were *cis*-1-trimethylsilyl-1-octene (*cis*-TOE) and *cis*-1-trimethylsilyl-1-heptene (*cis*-THE). The catalyst used was *(R,R)-(-)-N,N'*-Bis(3,5-di-*tert*-butylsalicylidene-1,2-cyclohexane diamino-manganese(III) chloride. The epoxidation reaction was carried out at room temperature in sodium hypochlorite solution buffered at pH 11.5. The reactions were followed by Gas-chromatography, and the results are shown in Table 5.2.

The results confirm that the axial ligands affect the epoxidation of vinylsilanes. After one and a half hours, the yields of silylepoxides formed in the presence of a nitrogen-donor axial ligand, such as N-methylimidazole or pyridine, were five times higher than the yields obtained with water as the oxygen-donor axial ligand. Another dramatic change was observed in the *cis /trans* ratio of the α,β-epoxysilanes which were formed from the *cis*-alkenylsilanes. The *cis /trans* ratio increased from 2.54 with a PPNO axial ligand to 8.2 in the presence of pyridine as the axial ligand.

Significantly, water and alcohols are the least effective among the donor ligands.[23] The weak coordination of these ligands with manganese (**13**) (**14**) could lead to the formation of unreactive species such as an oxo dimer (**15**), which is in equilibrium with the effective

Table 5.2

Data	Conditions			GC Integration Area (%)*			Ratio,	Turnover No.
No.	Axial L.	Substrate	Time (h)	Olefin	*cis*-epox.	*trans*-epox.	*cis/trans*	TON†
1	Py, PTC	*cis*-THE	0.5	79	7.0	1.1	6.4	189
2	Py, PTC		1.0	63	16	2.1	7.6	144
3	Py, PTC		2.0	65	15	2.0	7.5	---
4	Py, PTC		3.0	27	34	4.1	8.3	81
5	Py, PTC		4.5	9.0	44	5.4	8.1	54
6	NMI, PTC	*cis*-TOE	1.5	59	20	3.0	6.7	123
7	NMI, PTC		3.5	60	21	3.1	6.8	3
8	NMI, PTC		5.5	60	22	3.3	6.7	0
9	NMI	*cis*-TOE	0.5	36	20	3.5	5.7	648
10	NMI		1.0	40	19	3.8	5.0	0
11	NMI		1.5	37	17	3.8	4.5	0
12	DMAP	*cis*-TOE	0.5	82	2.6	0.8	3.3	162
13	DMAP		1.0	63	9.4	1.6	5.9	172
14	DMAP		1.5	59	11	1.3	8.5	36
15	Py	*cis*-TOE	0.5	43	24	3.0	8.0	513
16	Py		1.0	19	32	4.1	7.8	216
17	Py		1.5	11	36	5.0	7.2	72
18	Py		4.0	3	33	5.6	5.9	72
19	IMD	*cis*-TOE	0.5	69	8.4	1.3	6.5	279
20	IMD		1.0	56	10	1.7	5.9	117
21	IMD		1.5	61	8.1	1.2	6.8	0
22	PTC	*cis*-TOE	1.5	79	6.4	2.5	2.6	126
23	PTC		3.5	62	10	4.1	2.4	51
24	PTC		5.5	61	11	4.3	2.6	3
25	PTC		19	50	13	5.3	2.5	4

To be continued.

Table 5.2 (continued)

Data	Conditions			GC Integration Area (%)*			Ratio,	Turnover No.
No.	Axial L.	Substrate	Time (h)	Olefin	*cis*-epox.	*trans*-epox.	*cis/trans*	TON†
26	Water	*cis*-TOE	1.5	90	2.8	1.6	1.8	30
27	Water		3.5	69	9.4	4.8	2.0	47
28	Water		5.5	58	13	6.4	2.0	25
29	Water		19	53	14	7.3	1.9	2
30	Water	*cis*-TOE	1.5	94	1.4	0.6	2.3	14
31	Water		3.5	92	2.0	1.0	2.0	4
32	Water		5.5	90	3.5	1.5	2.3	4
33	Water		22	70	14	6.8	2.1	4
34	BQC	*cis*-THE	0.5	96	2.0	0.6	3.3	---
35	BQC		1.0	91	2.9	0.8	3.6	---
36	BQC		1.5	94	3.0	0.9	3.3	---
37	BQC		3.0	92	2.6	0.8	3.3	---
38	BQC		5.0	88	3.2	0.9	3.6	---
39	BQC		8.5	91	3.3	1.0	3.3	---
40	BQC		16	90	3.4	1.0	3.4	---
41	BHPC	*cis*-THE	0.5	91	3.6	1.4	2.6	---
42	BHPC		1.0	92	5.6	2.0	2.8	---
43	BHPC		2.0	89	5.9	2.1	2.8	---
44	BHPC		3.0	86	5.6	2.0	2.8	---
45	BHPC		5.0	89	5.6	2.0	2.8	---
46	BHPC		8.5	89	5.7	2.1	2.7	---
47	PPNO	*cis*-THE	0.5	92	1.9	0.8	2.4	58
48	PPNO		1.0	92	3.6	1.3	2.8	---
49	PPNO		2.0	83	8.5	3.3	2.6	22
50	PPNO		3.0	74	12	4.9	2.4	32

To be continued

Table 5.2 (continued)

Data	Conditions			GC Integration Area (%)*			Ratio, Turnover No.	
No.	Axial L.	Substrate	Time (h)	Olefin	*cis*-epox.	*trans*-epox.	*cis/trans*	TON†
51	PPNO		5.0	72	16	6.2	2.6	4
52	PPNO		8.5	72	16	6.3	2.5	0
53	PPNO		16	71	16	6.3	2.5	0
54	Py	*cis*-TOE	0.5	93	2.0	0.5	4.0	50
55	Py		1.0	92	2.4	0.6	4.0	---
56	Py		1.5	90	3.2	0.8	4.0	14
57	Py		4.0	84	7.5	2.0	3.8	20
58	Py		6.0	78	12	3.3	3.6	11
59	Py		16	55	28	7.3	3.8	8

Note:

All of the data were obtained from glc using GC BP5 columns. The reactions related to the data No. 1 to No. 29 were carried out using the catalyst made by ourselves, 0.04 equivalent catalyst Mn(III) / olefin, 0.15 equivalent axial ligand / olefin, at room temperature. The reactions related to the data No. 30 to No. 59 were carried out using the same catalyst purchased from Aldrich, 0.05 equivalent catalyst Mn(III) / olefin, 0.2 equivalent axial ligand / olefin, at room temperature.

† The turnover number (**TON**) is defined as the number of product moles produced by one mole of catalyst during 18 hours. The calculation of the turnover number is as follows:

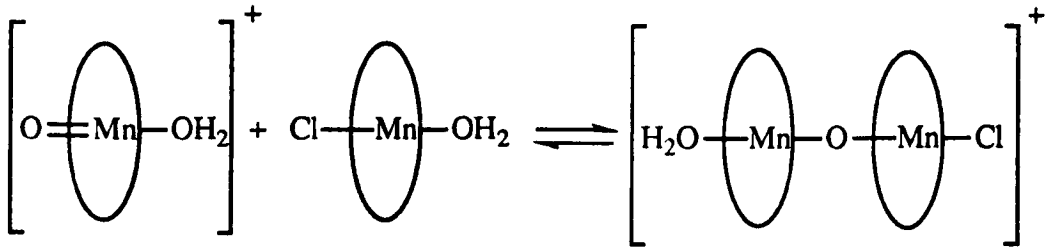
TON = Converted olefin (mol) ÷ Cat. (mol) ÷ T (hour) x 18

* The data in this column is directly obtained from the integration of the glc chromatogram, and Olefin% + *cis*-epox.% +*trans*-epox.% + impurities% = 100%.

catalyst, the Mn(V) salen complex.[24]

Pyridine is a strong donor ligand which occupies the apical position of the salen complex (**16**) and (**17**), and this coordination is very stable[24]. This enables the catalyst to stay in its

Scheme 5.3



(13) (14) (15)

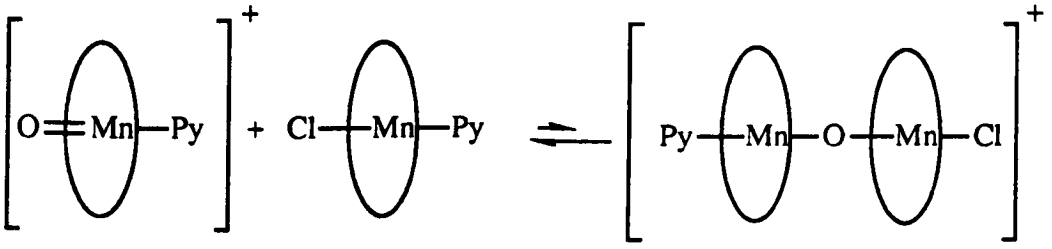
An active Mn(V) catalyst

Mn(III) salen with a weak coordinated axial ligand: water

An unreactive species

reactive form. Like pyridine, 4-phenylpyridine *N*-oxide, and pyridine *N*-oxide can form stable complexes by occupying the axial position of the manganese (III) salen complexes. However, they are weaker donors than pyridine. Addition of these oxygen donor ligands to the catalyst gives similar results to the pyridine. However, with some *cis* substrates, a larger proportion of the *trans* epoxides was obtained, as shown in Table 5.2.

Scheme 5.4



(16) (17) (18)

An active Mn(V) catalyst

Mn(III) salen with a strong coordinated axial ligand: pyridine

An unreactive species

The data from No. 1 to No. 5 and from No. 15 to No. 18 in Table 5.2 shows that the turnover number of the manganese (III) salen catalyst was decreased by addition of the phase transfer catalyst tetrabutylammonium bromide.

The data for the epoxidation of different of alkenes with Mn(III) salen complexes in the presence of PPNO are listed in Table 5.3.

Table 5.3 Epoxidation‡ of different alkenes

Data No.	Conditions Substrate	Time (h)	Olefin Conver.	Ratio of *cis*/*trans*	e.e. (%) *cis*-epo.	e.e. (%) *trans*-epo.	Epox. Yield%	Turnover No. TON
1.	*trans*-PTP†	1.0	36	0	--			130
2.		2.0	57	0	--			76
3.		3.0	71	0	--			22
4.		5.0	93	0	--			40
5.		8.0	100	0	--	42	92	8
6.	*trans*-PTP*	1.0	29	0	--			104
7.		2.0	29	0	--			---
8.		3.0	35	0	--			11
9.		5.0	38	0	--			5
10.		22.0	86	0	--	42	64	10
11.#	*trans*-TPYE			2.0	28	46		
12.	*cis*-T2NE†	1.0	36	9.8				130
13.		2.0	57	9.7				76
14.		3.0	68	11				40
15.		5.0	82	--				25
16.		8.0	83	12				1
17.		22.0	84	14	--	--	62	0
18.	*cis*-5DCEN†	1.0	12	4.4	--			43
19.		2.0	22	4.4	--			36
20.		3.0	27	4.4	--			18
21.		5.0	42	4.9	--			27
22.		8.0	49	4.7	--			8
22.		22.0	54	4.9	--	>95	41	1
24.	*cis*-TOE†	1.0	11	2.5				40

to be continued.

Table 5.3 Epoxidation‡ of different alkenes (continued)

Data	Conditions		Olefin	Ratio of	e.e. (%)	e.e. (%)	Epox.	Turnover No.
No.	Substrate	Time (h)	Conver.	*cis*/*trans*	*cis*-epo.	*trans*-epo.	Yield%	TON
25.		2.0	17	2.5				22
26.		3.0	17	2.5	58	95		---
27.		5.0	18	2.6				---
28.		8.0	20	2.5			14	2
29.	*trans*-TOE†	22.0	8	--			0.	---
30.	*cis*-THE†	1.0	5	2.7				18
31.		2.0	14	2.6				32
32.		3.0	23	2.5	58	95		32
33.		5.0	26	2.6				5
34.		8.0	27	2.6				1
35.		16.0	27	2.5			23	0
36.	*cis*-THE*	6.0			51	95		
37.©	AS	8.0	100				81	

‡ All of the data were obtained from glc on GC BP5 columns except No.36. All of the reactions except No. 6 to 10 were carried out under the following conditions: 0.05 equivalent catalyst Mn(III) / olefin, 0.2 equivalent axial ligand / olefin, 5 mmol (1 equiv.) olefin, and 200 mg undecane as internal standard which was used to calibrate the conversion of the olefins at room temperature. The catalyst was purchased from the Aldrich chemical company. The enantiomeric excess of epoxides was determined using a Chiraldex G-PN 20M x 0.25 mm column. *cis*-5DCEN: *cis*-5-decene; *trans*-PTP: *trans*-1-phenyl-3-trimethylsilylpropene; *cis*-T2NE: *cis*-1-trimethylsilyl-2-nonene; *cis* -TOE: *cis*-1-trimethylsilyl-1-octene; *trans*-TOE: *trans*-1-trimethylsilyl-1-octene; *cis*-THE: *cis*-1-trimethylsilyl-1-heptene.

† The reaction was in the presence of 4-phenylpyridine-*N*-oxide.

* The reaction was in the presence of water as the only axial ligand.

\# This is a published result from Jacobsen's group.

© The No.36 was obtained by work up the final reaction mixture, due to decomposition of the epoxide on the column.

The enantiomeric selectivity of the Mn(III) salen complexes in the epoxidation of alkenes has been investigated by Jacobsen's group.[15,24,25] Table 5.3 shows that *cis*-allyl and vinylsilanes were converted into the *cis*-epoxysilane with poor enantioselectivity but gave the *trans*-epoxysilanes with very high enantioselectivity. Unfortunately, strong nitrogen donor ligands such as pyridine, *N*-methylimidazole, and 4-*N*-dimethylaminopyridine formed mainly the *cis* epoxide with little *trans*-epoxysilane.

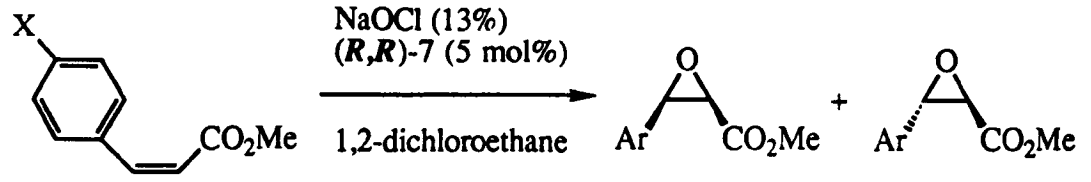
Although the use of water, and alcohols as axial ligands of manganese (III) salen catalyst does not accelerate the epoxidation reaction, the proportion of the *trans* - epoxysilane, which was formed in high enantiomeric excess, was significantly larger than when strong nitrogen donors, such as pyridine, were used as ligands. Oxygen donor ligands such as pyridine-*N*-oxide, phenylpyridine-*N*-oxide and triphenylphosphine oxide were found to accelerate salen complex catalyzed epoxidation about ten years ago.[18] Recently, aminoalcohol quaternary amine salts such as *N*-benzylquininium chloride (BQC) have been used as effective additives for asymmetric epoxidation catalyzed by manganese salen complexes[15]. However, as Table 5.2 shows, these did not work well with *cis*-alkenylsilanes.

§ 5.3 Discussion of Epoxidation of Vinyl- and Allylsilanes

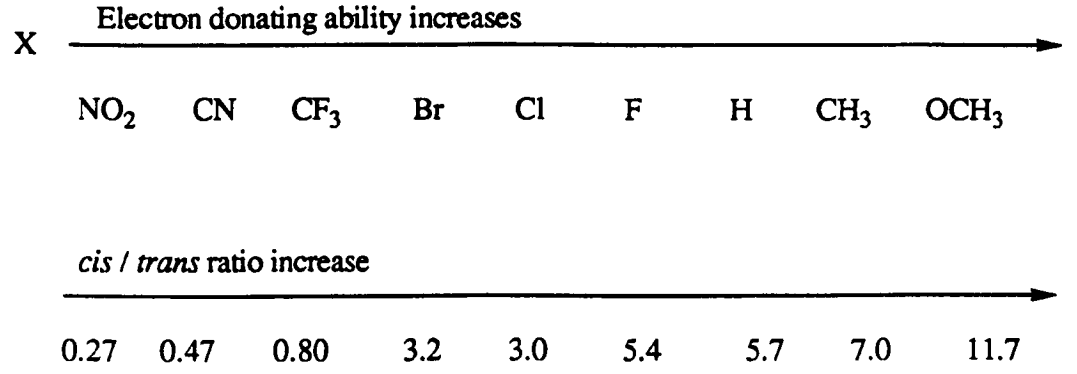
5.3.1 The influence of electronic properties on the epoxidation of alkenes

The asymmetric epoxidation of substituted *cis*-methyl cinnamate derivatives with Mn(III) salen complex (7), in Scheme 5.5, has been investigated by Jacobsen's group[24]. The results demonstrated that the electronic properties of an alkene can substantially affect the *cis* / *trans* isomer ratio of the epoxides obtained from it.

When the substituent X was an electron withdrawing group such as NO_2, the electron density of the double bond will decrease; and this was associated with the formation of more *trans*-epoxide.



(19) **(20)** **(21)**



Interaction between the oxygen and the two carbons of olefin becomes more equal

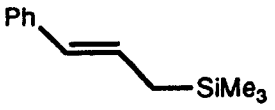
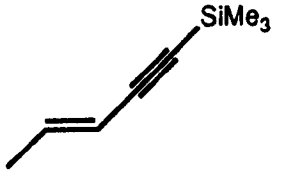
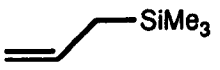
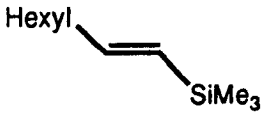
(22) **(23)**

Scheme 5.5

When the substituent X is an electron donating group such as a methoxy, the electron density of the double bond will increase, and this was associated with an increase in the proportion of *cis*-epoxide produced.

5.3.2 Different type of alkenes and their behaviour during epoxidation with Mn(V) salen complexes.

Table 5.4: Different type of alkenes

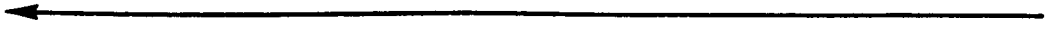
(24)		*trans*-PTP: *trans*-1Phenyl-3-trimethylsilylpropene
(25)		*cis*-T2NE: *cis*-1-trimethylsilyl-2-nonene
(26)		*trans*-TPYE: 1-Trimethylsilylpent-1-yn-*trans*-3-ene
(27)		*cis*-TOE: *cis*-1-trimethylsilyl-1-octene
(28)		*cis*-THE: *cis*-1-trimethylsilyl-1-heptene
(29)		*cis*-5DCEN: *cis*-5-Decene
(30)		AS Allylsilane
(31)		*trans*-TOE: *trans*-1-trimethylsilyl-1-octene

The range of alkenes used in this study are listed in Table 5.4. Their behaviour during epoxidation with Mn(V) salen complex under the same conditions is shown in Table 5.3 and Scheme 5.6: The epoxidation of electron rich alkenes such as *cis*-1-trimethylsilyl-2-nonene (*cis*-T2NE)[26] is easier than the epoxidation of electron deficient alkenes such as *cis*-1-trimethylsilyl-1-octene[26] (*cis*-TOE). Also, the epoxidation of *cis* alkenes such as *cis*-1-trimethylsilyl-1-octene (*cis*-TOE) was easier than *trans* alkenes such as *trans*-1-trimethylsilyl-1-octene (*trans*-TOE), possibly because the approach of *cis* alkenes is less sterically hindrered.

Scheme 5.6: Different type of alkenes and their behaviour during epoxidation with Mn(V) salen complexes (see Table 5.3).

The electron density of double bonds of alkenes increases

trans-PTP, AS, *cis*-T2NE, *cis*-5DCEN, *cis*-THE, *cis*-TOE, (*trans*-TYE), *trans*-TOE



The reactivity of alkenes towards epoxidation increases

The possibility of inversion of alkene from *cis-trans or trans-cis* on conversion to epoxide increases

Steric hindrance of alkenes increase

Three *cis* alkenes are listed in the Table 5.5. Alkene (**25**) possesses an electron rich double bond owing to the carbon silicon bond pushing electrons into the allyl system.[26] Alkene (**27**) is considered electron deficient because electron density on the double bond may be lost through a donor-acceptor interaction with the vacant 3d orbitals on the silicon[26]. So, alkene (**29**) is more electron rich than (**27**). As in Jacobson's work the *cis /trans* ratio of epoxides increases as the electron density of the alkenes increases.

Table 5.5

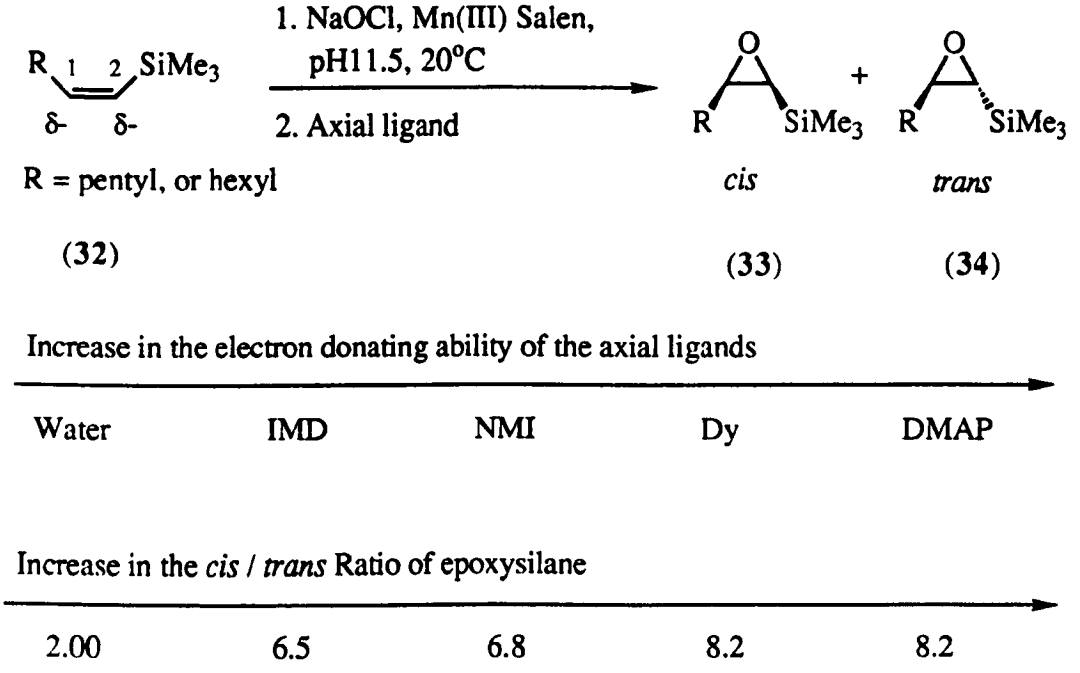
Substrates	*cis* / *trans*
(25) 	10
(29) 	5
(27) 	2.5

5.3.3 Consideration of the influence of axial ligands on catalyst activity

The effect of axial ligands on the epoxidation of *cis*-1-trimethylsilyl-1-octene (*cis*-TOE) and *cis*-1-trimethylsilyl-1-heptene (*cis*-THE) with (7) has been presented, with the turnover numbers (TON), in Table 5.2. For consistency we consider the data (No. 1 to No. 29) obtained from reactions using the recrystalised Mn(III) salen complex (black fine crystals) as catalyst. When pyridine was used as an axial ligand (a nitrogen donor) the turnover number reached about 500 (data No. 15, Table 5.2) in the first 30 minutes of the reaction. When water was used as an axial ligand (an oxygen donor) the turnover number was less than 50 (data No. 26 and 27) at the beginning of the reaction. This confirms that the activity of the Mn(III) salen catalyst can be changed significantly by using different axial ligands. Similarly, the *cis* / *trans* ratio of the epoxides produced from the electron deficient and electron rich alkenes can be changed dramatically by using different axial ligands as shown in Scheme 5.7.

The Aldrich sample of the Mn(III) salen complex was a brown solid (with slight smell of 4,6-di-*tert*-butyl-salicylaldehyde, the starting material for making the quadridentate chelate ligand). This was used as the catalyst to obtain the data after No. 29 in the Table 5.2. The activity of the Aldrich catalyst can be compared with that of our sample using the data No. 54 to 59 against No. 15 to 18. In both cases the pyridine was employed as the axial

ligand, and the turnover numbers, after 30 minutes of the reaction, were 50 (with 5% of the Aldrich catalyst) against 500 (with 4% of our catalyst) (Table 5.2). The *cis* / *trans* ratios changed from 4, with 5% of the Aldrich catalyst, to 8, with 4% of our catalyst. One reason for this difference between the activities of the catalyst may be that the Aldrich sample contained oxygen donor impurities. These may have arisen from degradation of the



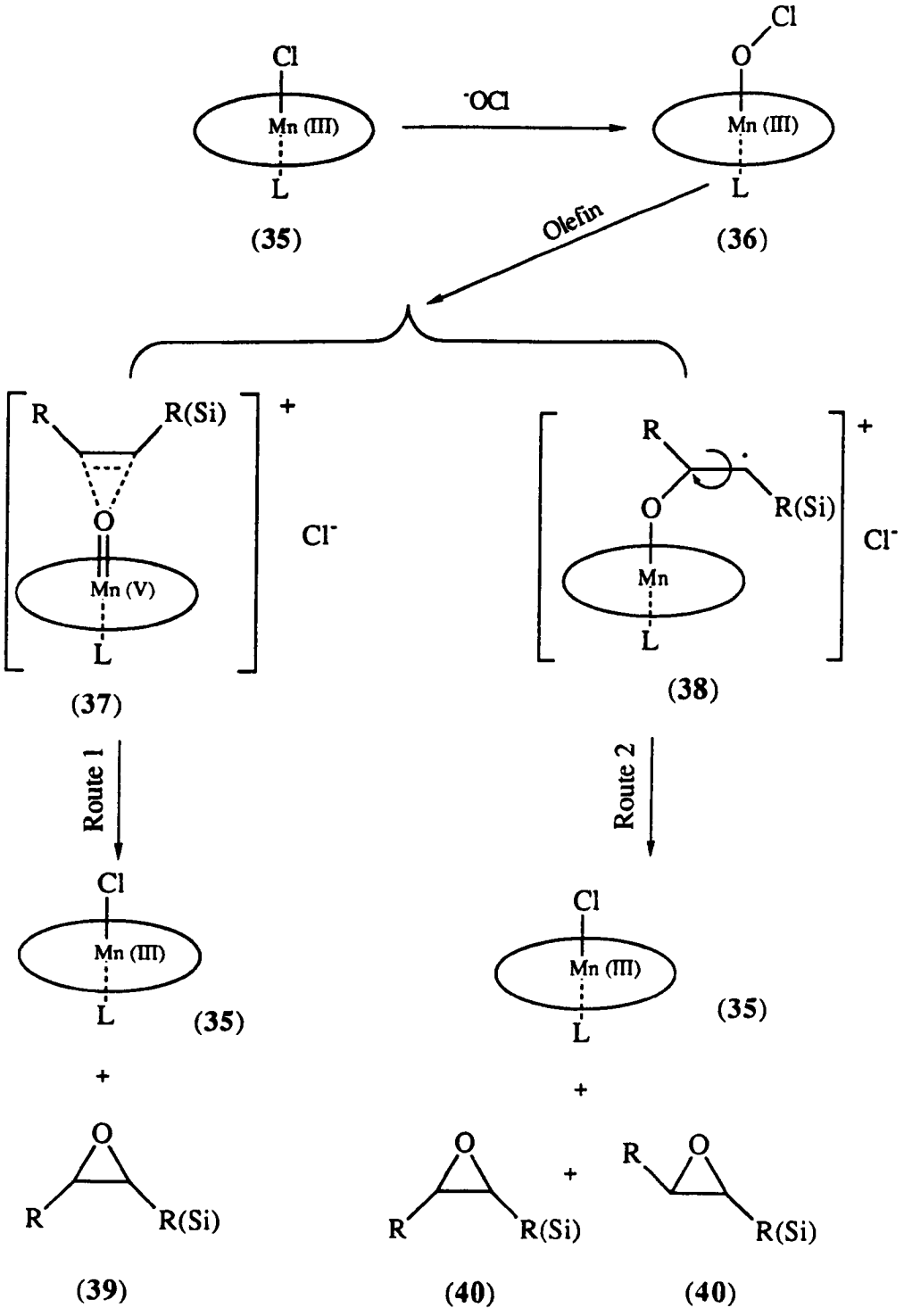
Scheme 5.7 The influence of the axial ligands

chiral salen ligand, *(S,S)- or (R,R)-(-)-N,N'*-Bis(3,5-di-*tert*-butylsilicylidene-1,2-diaminocyclohexane, in the catalyst preparation. Like the oxygen donor ligands BQC and BHPC, these impurities decreased the activity of the catalyst, as shown in Table 5.2 data No. 34 to 46.

Another very effective strong oxygen-donor ligand is *p*-phenylpyridine-*N*-oxide PPNO which has donor properties similar to pyridine.

5.3.4 Reaction steps of the epoxidation

Based on the work of Jacobsen, we propose the following mechanism for the Mn (III) salen catalysed epoxidation of alkenes.



Scheme 5.8

In practice, the electron rich alkenes are easier to oxidise mainly following direct insertion route 1, and the electron deficient alkenes are more difficult to oxidise, normally following the route 2. The *cis* / *trans* partitioning in the epoxide depends on the lifetime of species (**38**). Jacobsen proposed that electron deficient alkenes will stabilise the species (**38**). Rotation followed by ring closure then leads to the *trans* isomer.

§ 5.4 Determination of Enantiomeric Excess of Chiral Epoxides by Chiraldex G-PN

5.4.1 Introduction

Recent developments in high-resolution Gas-Chromatography using chiral cyclodextrin (α, β and γ) derivatives as chiral stationary phases seems to provide an ideal method for the enantiomeric analysis of stable, volatile compounds. Cyclodextrins are a homologous series of nonreducing cyclic oligosaccharides made up of six (α) or more (seven: β, eight: γ) (α)-D-glucopyranose units linked together by α-1,4-glycoside bonds [27,28] (Figure 5.3).

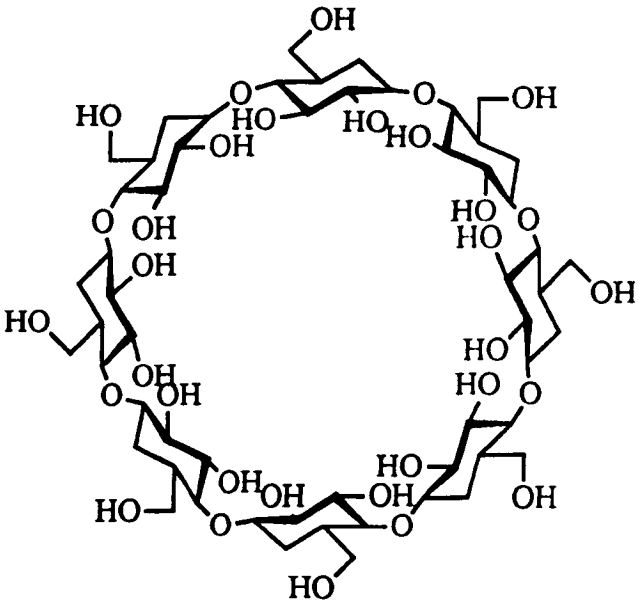


Figure 5.3, γ-cyclodextrin

Cyclodextrins are obtained from starch by the enzymatic degradation of the glucose units using cycloglycosyltransferases of *Klebsiella pneumonia, Bacillus macerans,* or other types of bacillus. This reaction results in the detachment of one turn from the starch helix accompanied by cyclization. The relative quantities of the individual cyclodextrins obtained depends on the type of enzyme employed and can be influenced by the addition of organic compounds.[29]

A wide range of racemates can be resolved by gas-chromatographic separation using cyclodextrin derivatives. They include strongly polar chiral diols, free carboxylic acids, derivatized amino acids, carbohydrates, aminoalcohols and less polar and non polar compounds such as metal coordination compounds, lactones, epoxides, esters, pyrans, furans, halohydrocarbon and cyclic, bicyclic and heterocyclic compounds. In all cases, molecules that are identical in constitution but differ only in their configurations are discriminated by means of the chiral stationary phase, thereby allowing chromatographic enantiomer separation. The interaction necessary for this to occur can be strong or weak[30] and can consist of an inclusion process and / or other chemical interactions.

A number of different contributions have been considered to explain the host-guest interactions in cyclodextrins:[30-34] (1) steric fit by conformational change of the guest molecule and/or the cyclodextrin molecule (induced fit) during the molecular inclusion process,[35-37] (2) hydrogen bonding,[38,39] (3) van der Waals interactions (London dispersion forces and dipole-induced-dipole interactions), (4) hydrophobic interactions, (5) dipole-dipole interactions, (6) charge-transfer interactions, (7) electrostatic interactions, (8) release of "high-enthalpy" water molecules from the cyclodextrin cavity, (release of solvent molecules from the cyclodextrin cavity with a gain in entropy, (10) relief of the ring strain of the macrocycle.

Chiraldex G-PN employs γ-chiral cyclodextrin propionate intermediates as a chiral stationary phase and gives good enantiomeric separation (α>1.01) of epoxides, lactones and alkyl alcohols >C_4 (best).

5.4.2 Chiral Analysis of Silylepoxides

The advantage of using Chiraldex G-PN over Chiraldex G-TA for the analysis of chiral silyl epoxide is that it avoids the possibility of tiny traces of trifluoroacetic acid vapour, which might lead to the decomposition of silylepoxides. The G-PN column was used with a GC/MS (Varian 3400GC coupled to a Finnigan MAT Ion Trap Detector), so that the enantiomers could be identified directly.

The separation of a sample of *cis-(2S,3R)*-1-trimethylsilylheptane-1,2-epoxide using Chiraldex G-PN at 90°C is presented as an example in Figures 5.4a, 5.4b, 5.4c and 5.4d. The enantiomer separation value α (Figures 5.4a, 5.4b) can be calculated as follow:

$$\alpha = R^e_L / R^e_S = 560 / 530 = 1.0566$$

R^e_L comes from the enantiomer with the larger retention time and R^e_S comes from the other enantiomer with the smaller retention time. Figure 5.4a and 5.4b show that in this enantiomer enriched sample, the retention time R^e_S of *cis-(2S,3R)*-1-Trimethylsilylheptane-1,2-epoxide was 530 seconds and the retention time R^e_L of *cis-(2R,3S)*-1-trimethylsilylheptane-1,2-epoxide was 560 seconds.

The enantiomeric excess (e.e.%) can be obtained from the integration areas. The e.e.% of the major enantiomer, *cis-(2S,3R)*-1-trimethylsilylheptane-1,2-epoxide, is calculated as follow:

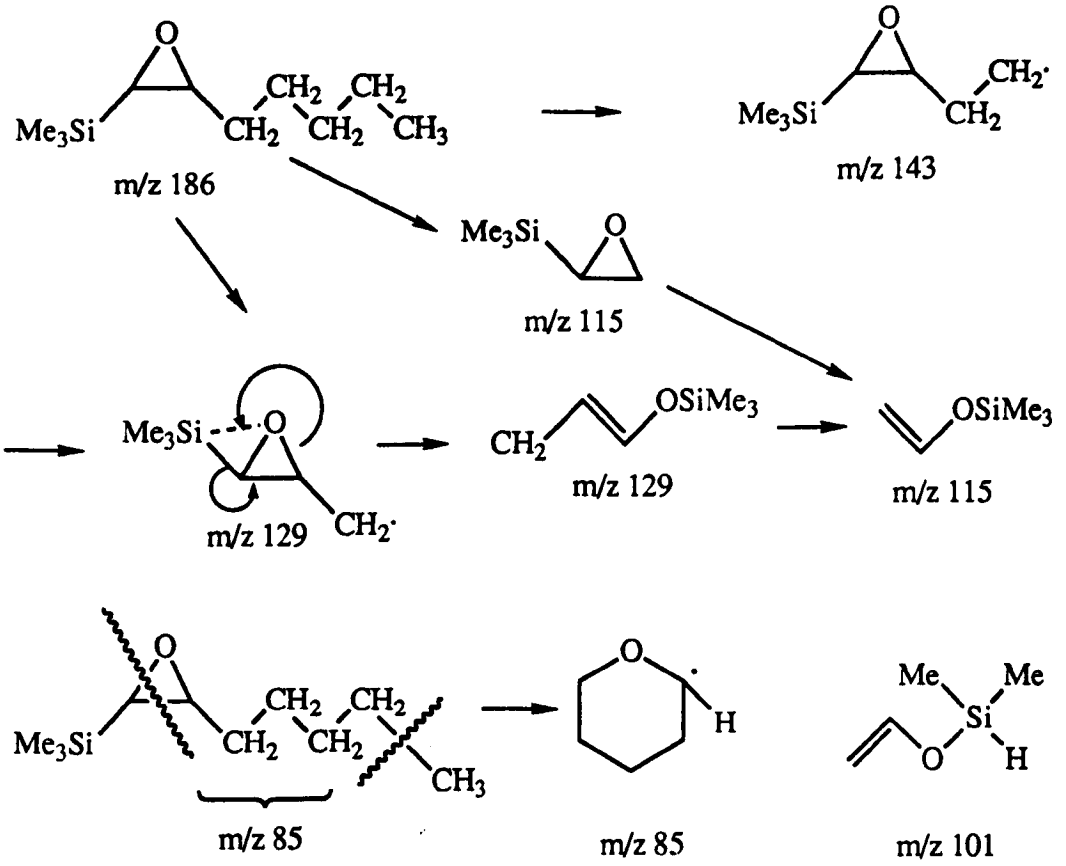
$$\text{e.e.\%} = 100\{(A-B) / (A+B)\}$$

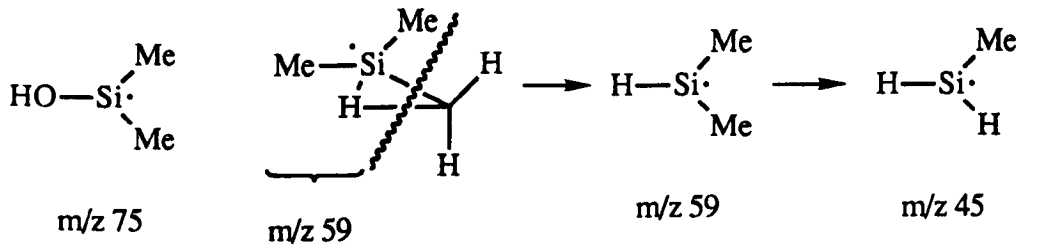
$$= 100\{(337345-79870) / (337345+79870)\}\% = 61.7\%$$

A is the integration area of the major enantiomer and **B** is the integration area of its antipode.

The structure of both enantiomers can be confirmed by MS as shown in Figure 5.4c and 5.4d. The typical fragments from both enantiomers are m/z (EI+) 186 (<1%, M^+), 143

(4%, $C_7H_{15}OSi$), 129 (20%, $C_6H_{13}OSi$), 115 (5%, $C_5H_{11}OSi$), 101 (5%, C_4H_9OSi), 85 (5%, C_5H_9O), 75 (27%, C_2H_7OSi), 73 (100%, $SiMe_3$), 59 (19%, $HSiMe_2$), 45 (20%, CH_5Si), 43 (15%, C_3H_7) and may be explained as shown in Scheme 5.9.





$Me_3Si^{\cdot}$

m/z 73

C_3H_7

m/z 43

Scheme 5.9

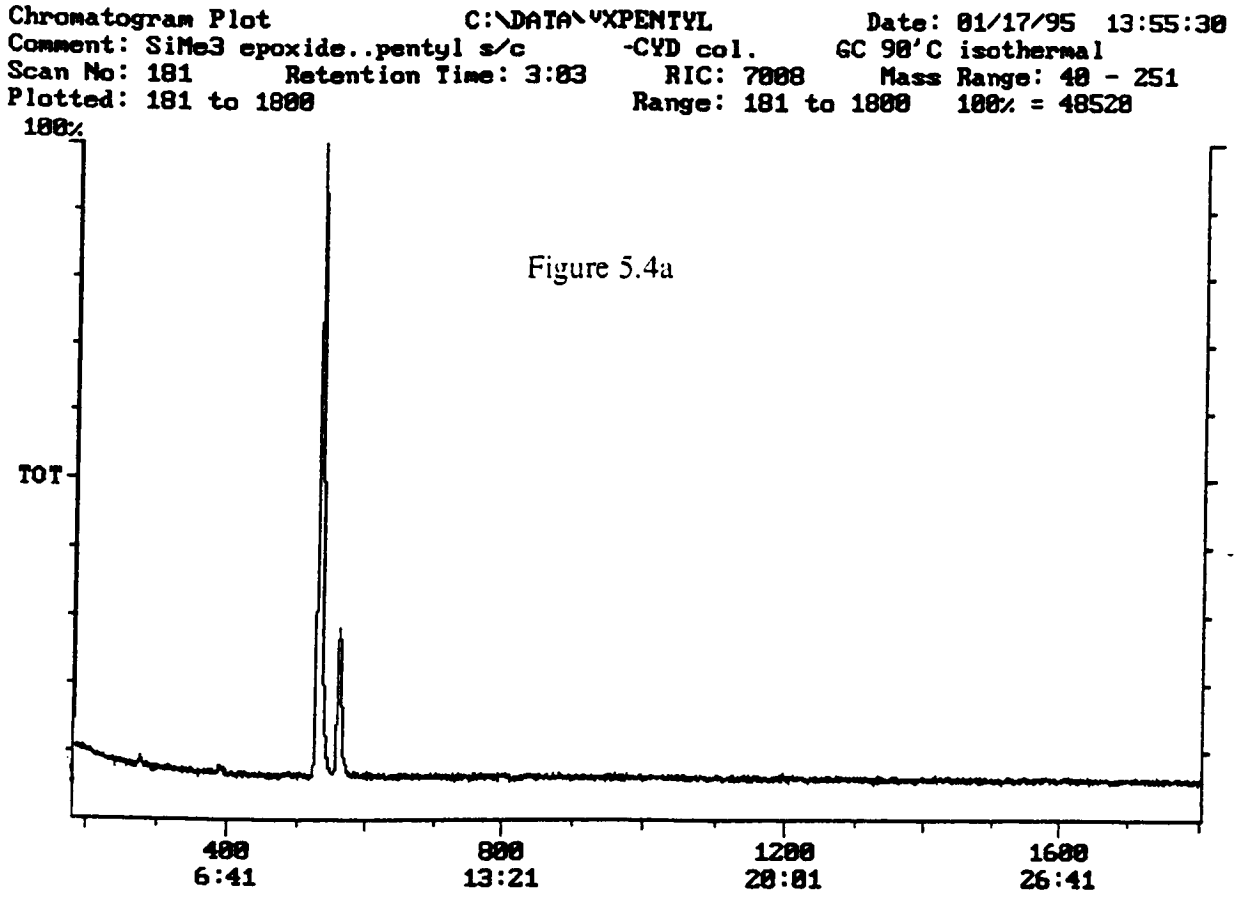


Figure 5.4a

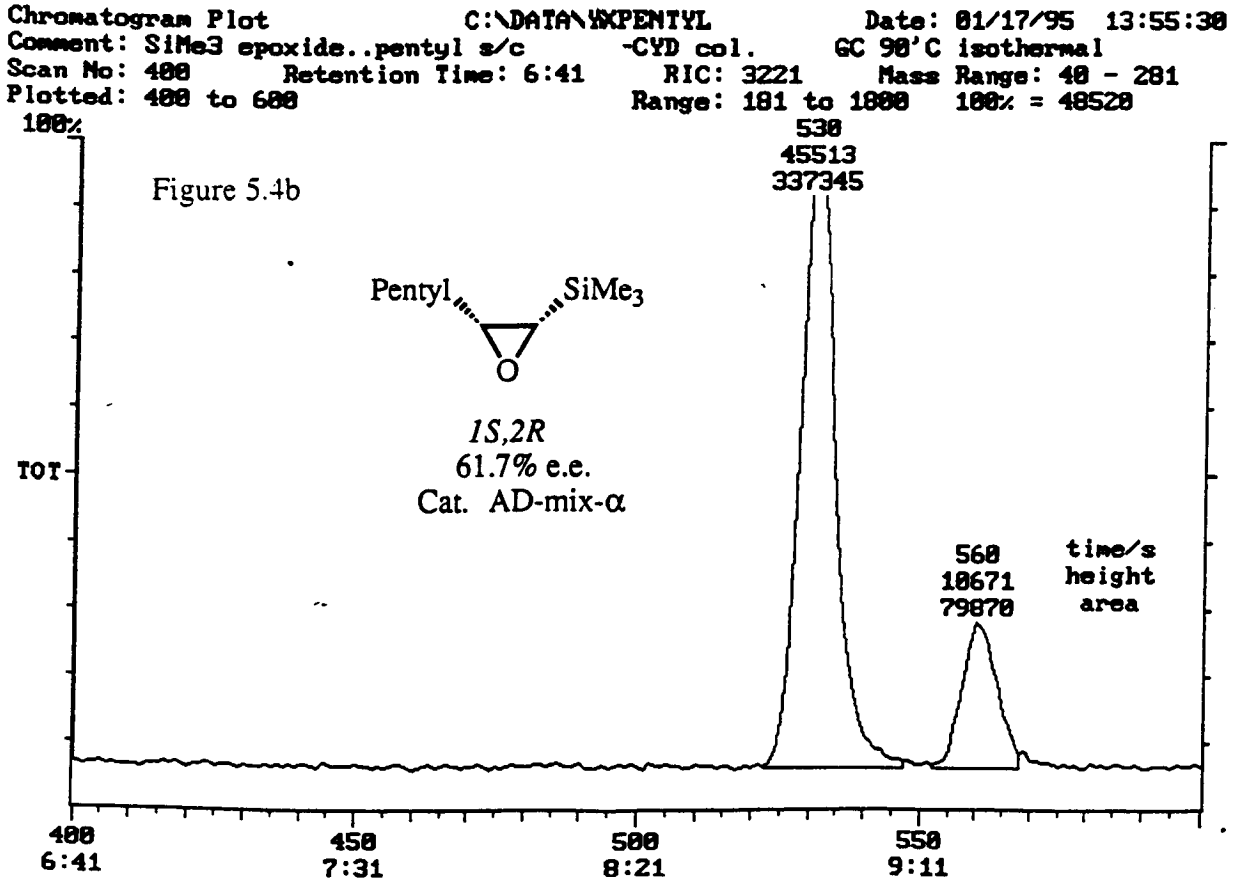


Figure 5.4b

1S,2R
61.7% e.e.
Cat. AD-mix-α

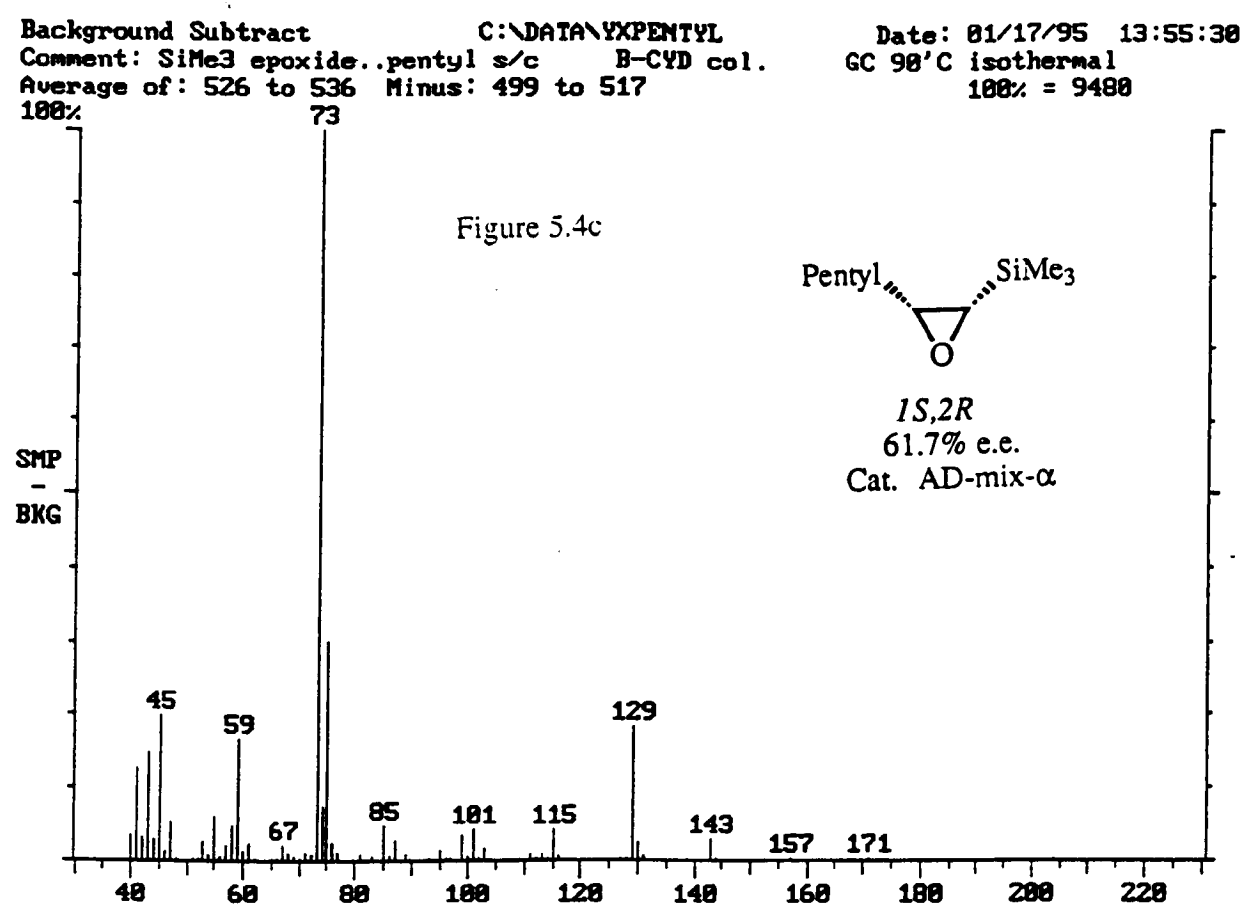


Figure 5.4c

1S,2R
61.7% e.e.
Cat. AD-mix-α

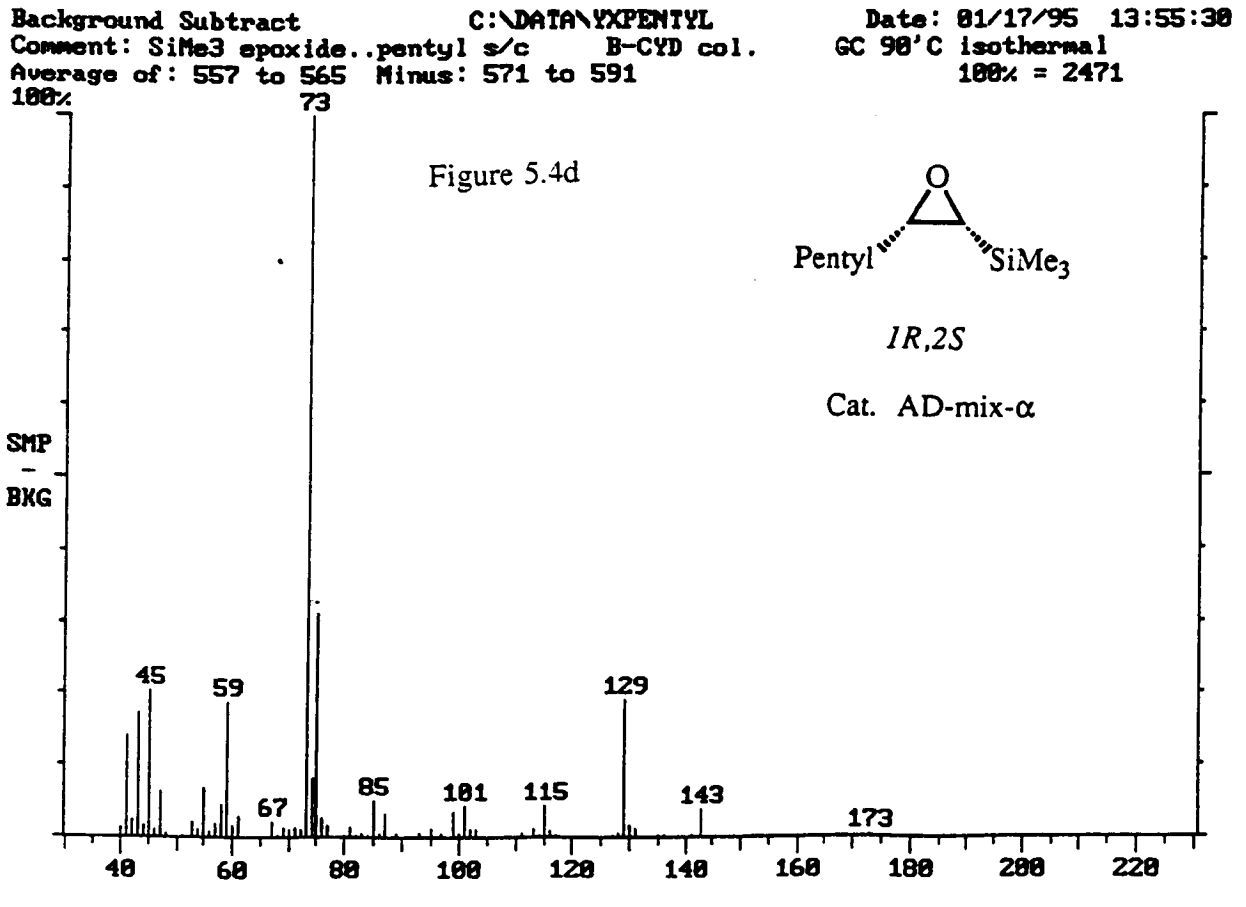


Figure 5.4d

1R,2S

Cat. AD-mix-α

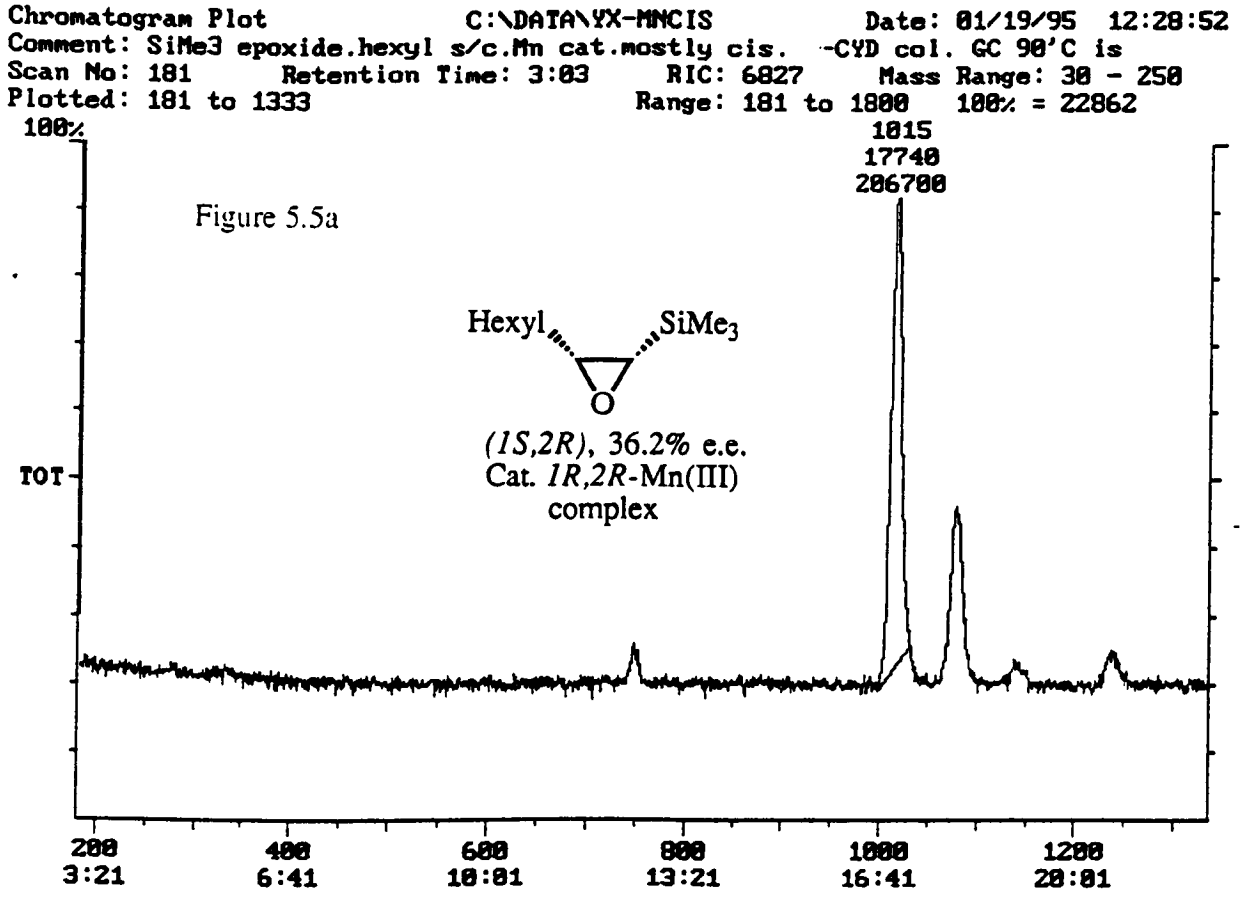
5.4.3 Some Clues to the Configuration of the Silylepoxides

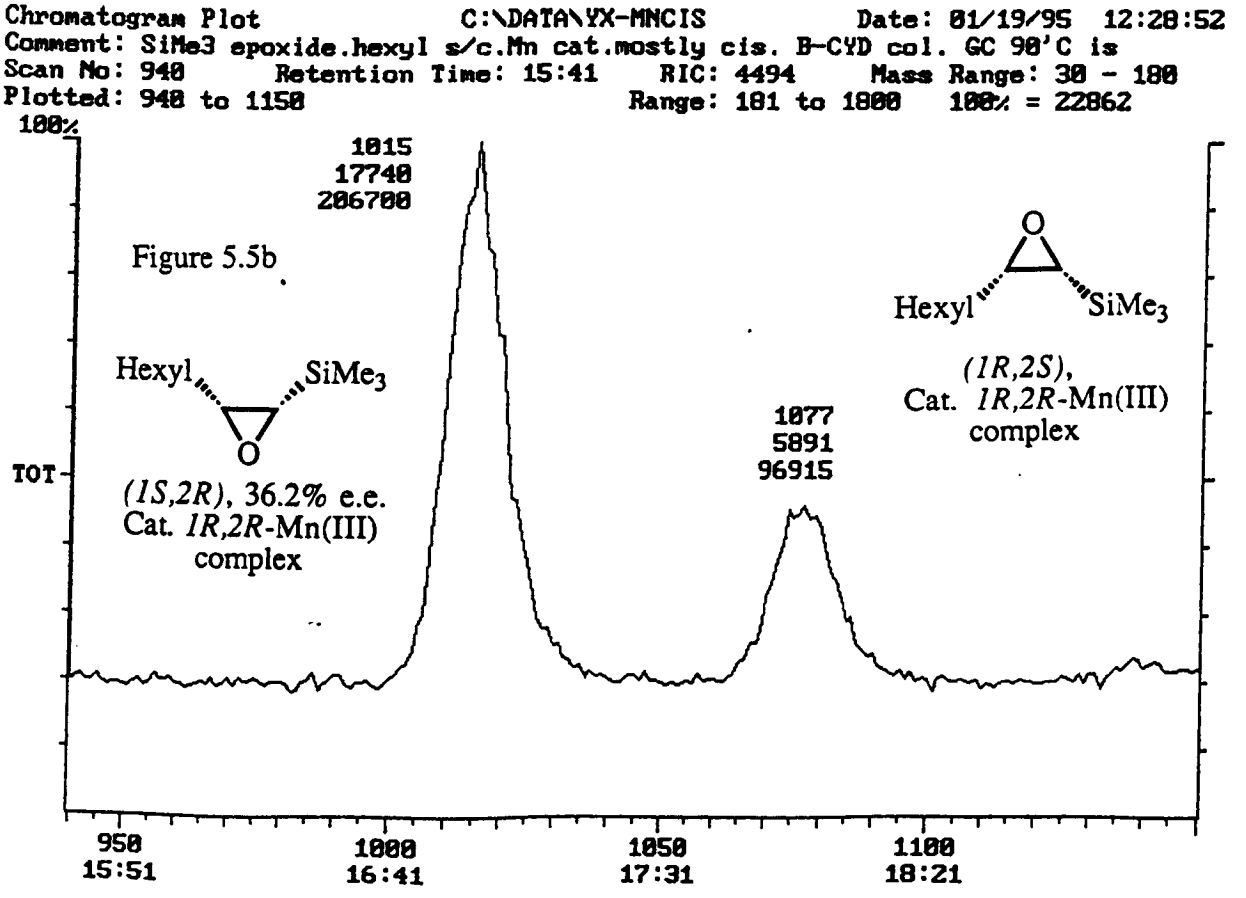
The configurations of the silylepoxides made from the epoxidation of allyl- and vinylsilanes by Mn (III) salen complexes are not known. However, the chromatograms obtained by the chiral analysis of epoxides using chiral GC can give some clues to their configuration by comparison with known compounds.

The *cis*-1-trimethylsilyloctane-1,2-epoxide was made from epoxidation of cis-1-trimethylsilyloct-1-ene using a *1R,2R*-Mn(III) salen complex. The results of the chiral analysis of this epoxide using Chiraldex G-PN and the corresponding MS spectra are shown in Figures 5.5a. 5.5b, 5.5c, 5.5d. The enantiomeric excess of the major *cis* enantiomer was 36.2% with a retention time of 1015 seconds. The same epoxide was made from the chiral diol where the configuration is predictable using Sharpless's mnemonic. Its e.e. value obtained using chiral GC was 62.1%. The chromatogram and the related MS are presented in Figures 5.6a, 5.6b, 5.6c, 5.6d, 5.6e, 5.6f. The major enantiomer of the epoxide was the *cis-(1S,2R)*-1-trimethylsilyloctane-1,2-epoxide with a retention time of 1024 second. Comparison of Figures 5.5a, 5.5b and Figures 5.6a, 5.6b, show that the major *cis* enantiomer of the epoxide produced by the *1R,2R*-Mn(III) salen catalysis is the same as that produced by chirality transfer from the diol using AD-mix-α, that is, the *1S,2R* configuration.

A pair of enantiomers with retention times of 705, and 756 seconds (Figure 5.6a) may be the *trans*-1-trimethyloctane-1,2-epoxide. This was confirmed with MS (Figure 5.6c, 5.6d). One enantiomer of the *trans* epoxide with a retention time of about 750 seconds can be also seen in Figure 5.5a

The chiral analysis of *trans*-1-trimethylsilyl-3-phenylpropane-2,3-epoxide made from its allylsilane using a *1R,2R*-Mn(III) salen complex catalysed epoxidation is presented in Figures 5.7a, 5.7b, 5.7c. The e.e. is 41.5%, however, its configuration is not known.


Chromatogram Plot C:\DATA\YX-MNCIS Date: 01/19/95 12:28:52
Comment: SiMe3 epoxide.hexyl s/c.Mn cat.mostly cis. -CYD col. GC 90'C is
Scan No: 181 Retention Time: 3:03 RIC: 6827 Mass Range: 30 - 250
Plotted: 181 to 1333 Range: 181 to 1800 100% = 22862
100%
TOT
1015
17740
206700
Figure 5.5a
Hexyl
SiMe3
O
(1S,2R), 36.2% e.e.
Cat. 1R,2R-Mn(III)
complex
200
3:21
400
6:41
600
10:01
800
13:21
1000
16:41
1200
20:01


Chromatogram Plot C:\DATA\YX-MNCIS Date: 01/19/95 12:28:52
Comment: SiMe3 epoxide.hexyl s/c.Mn cat.mostly cis. B-CYD col. GC 90'C is
Scan No: 940 Retention Time: 15:41 RIC: 4494 Mass Range: 30 - 180
Plotted: 940 to 1150 Range: 181 to 1800 100% = 22862
100%
TOT
1015
17740
206700
Figure 5.5b
Hexyl
SiMe3
O
(1S,2R), 36.2% e.e.
Cat. 1R,2R-Mn(III)
complex
1077
5891
96915
O
Hexyl
SiMe3
(1R,2S),
Cat. 1R,2R-Mn(III)
complex
950
15:51
1000
16:41
1050
17:31
1100
18:21

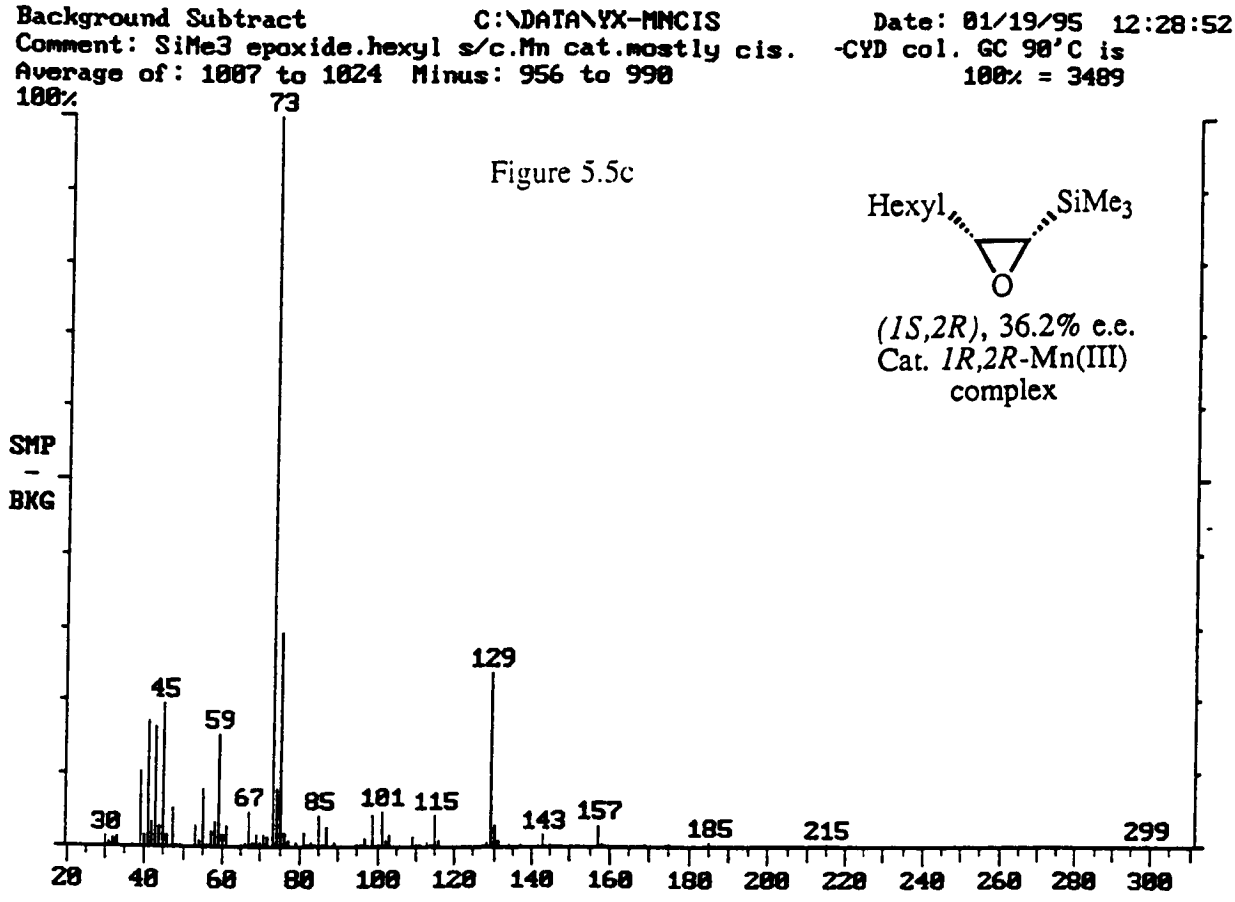


Figure 5.5c

(1S,2R), 36.2% e.e.
Cat. *1R,2R*-Mn(III) complex

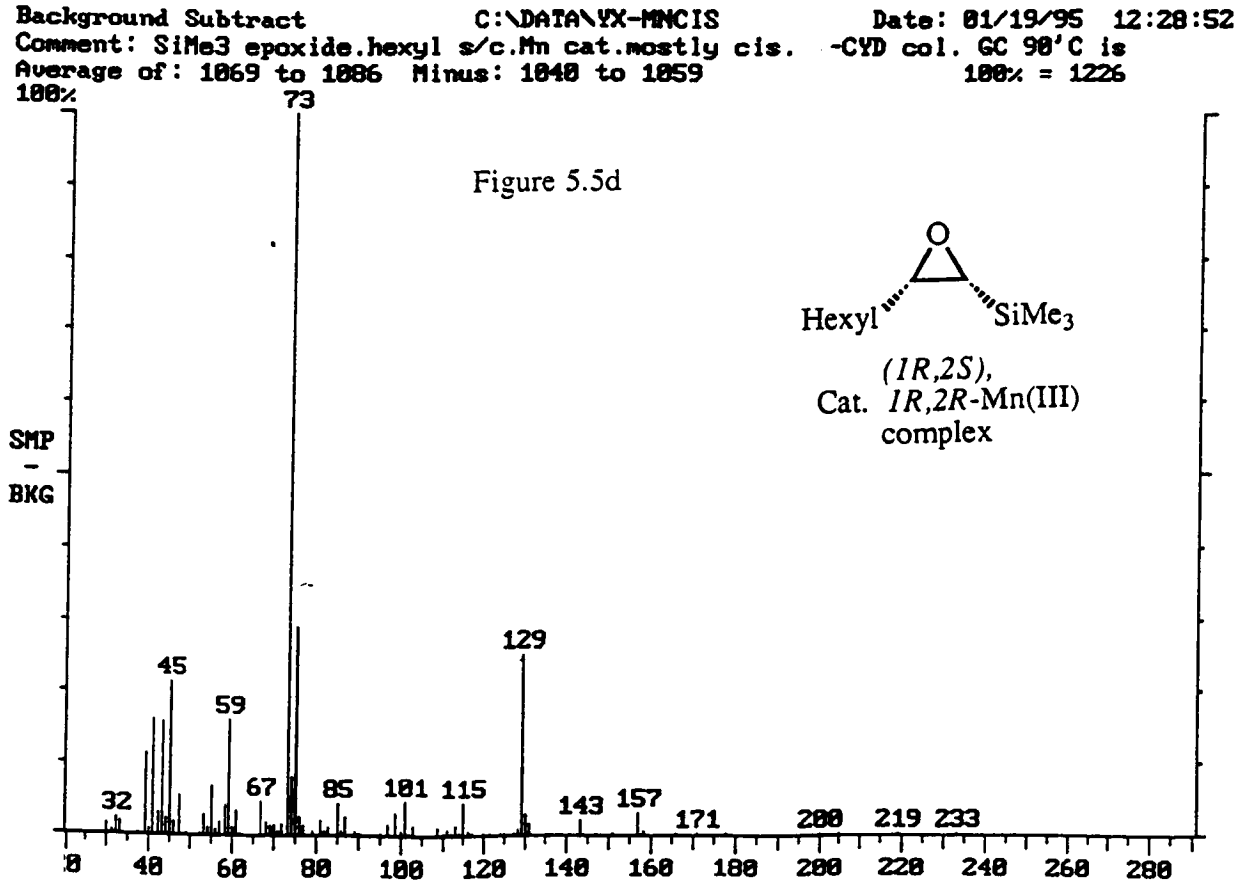
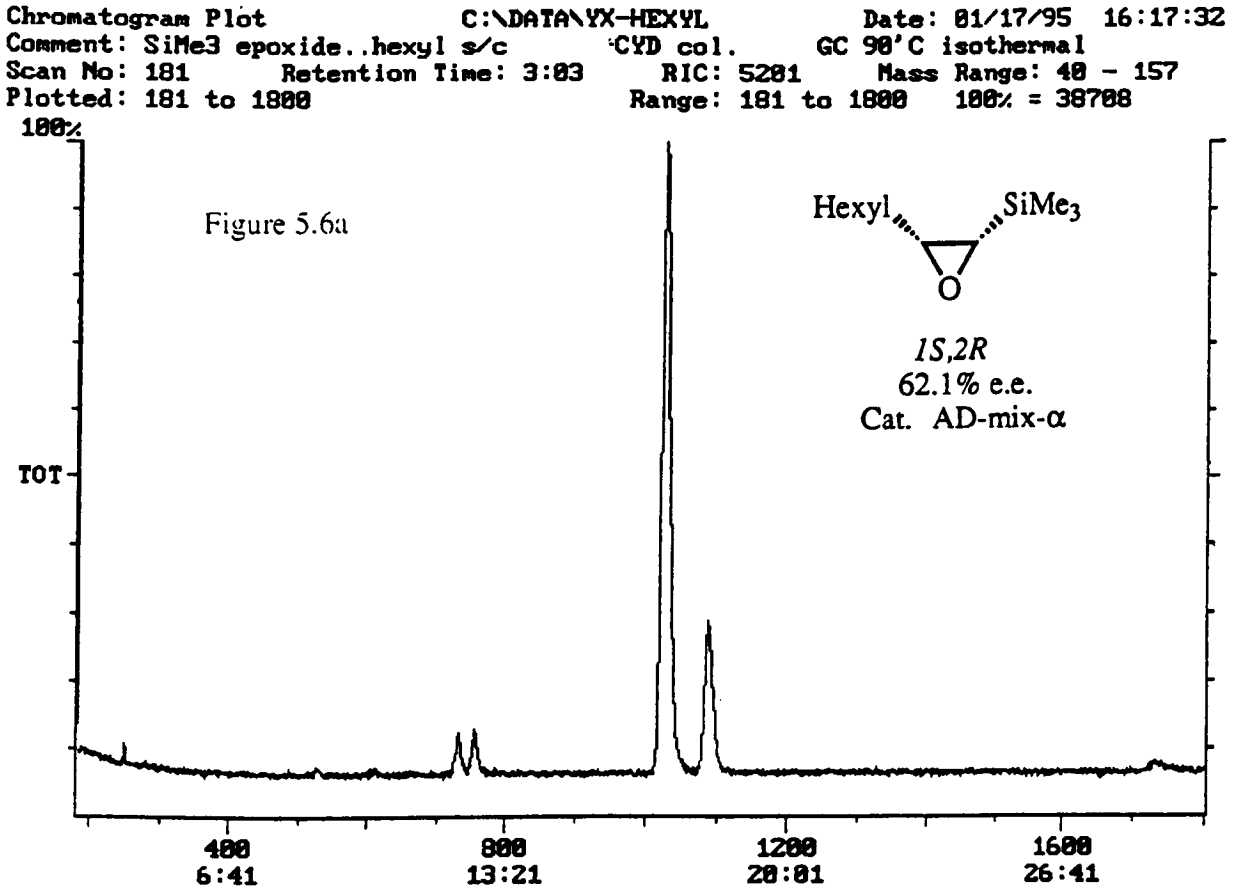
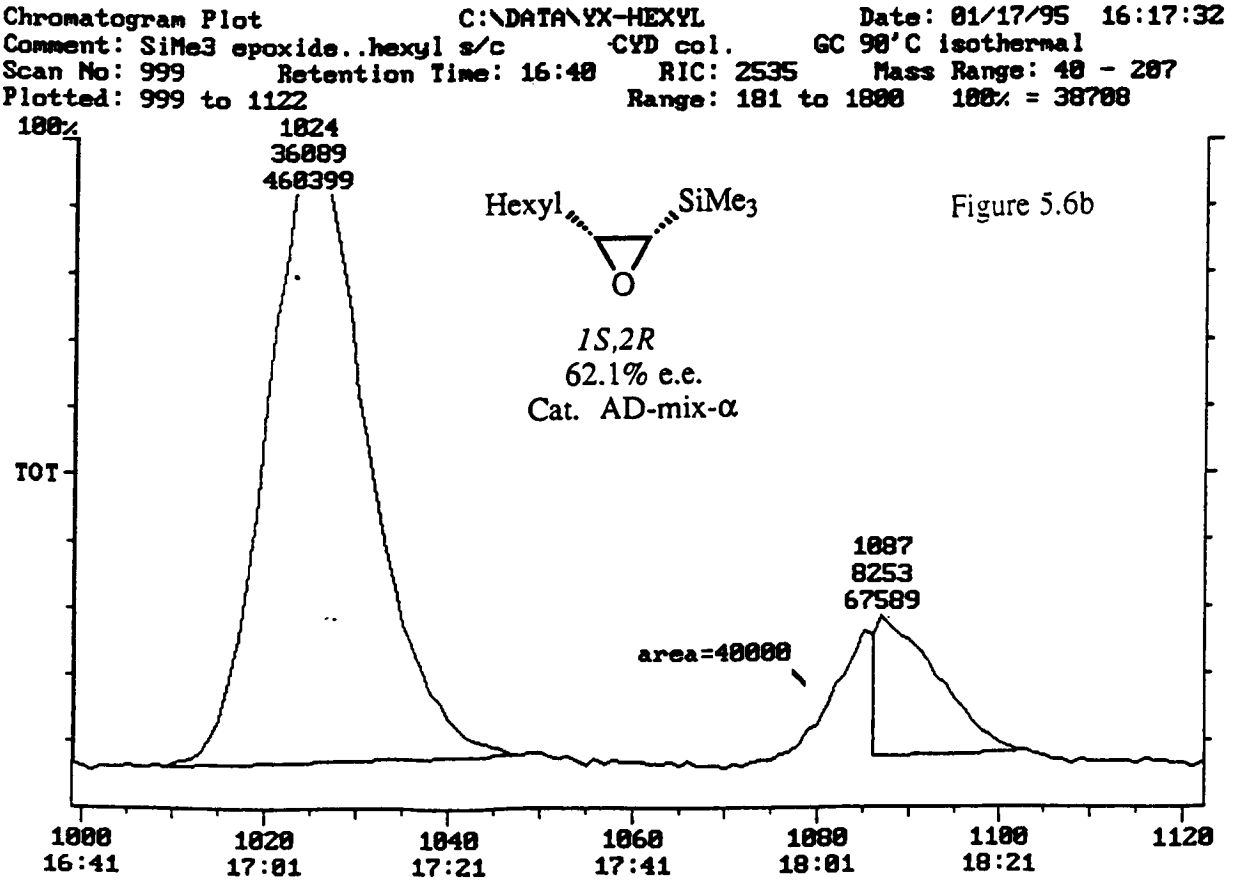


Figure 5.5d

(1R,2S),
Cat. *1R,2R*-Mn(III) complex


Chromatogram Plot C:\DATA\YX-HEXYL Date: 01/17/95 16:17:32
Comment: SiMe3 epoxide..hexyl s/c CYD col. GC 90'C isothermal
Scan No: 181 Retention Time: 3:03 RIC: 5201 Mass Range: 40 - 157
Plotted: 181 to 1800 Range: 181 to 1800 100% = 38708
100%
TOT
Figure 5.6a
Hexyl
SiMe3
O
1S,2R
62.1% e.e.
Cat. AD-mix-α
400
6:41
800
13:21
1200
20:01
1600
26:41


Chromatogram Plot C:\DATA\YX-HEXYL Date: 01/17/95 16:17:32
Comment: SiMe3 epoxide..hexyl s/c CYD col. GC 90'C isothermal
Scan No: 999 Retention Time: 16:40 RIC: 2535 Mass Range: 40 - 207
Plotted: 999 to 1122 Range: 181 to 1800 100% = 38708
100%
1024
36089
460399
Hexyl
SiMe3
O
Figure 5.6b
1S,2R
62.1% e.e.
Cat. AD-mix-α
TOT
1087
8253
67589
area=40000
1000
16:41
1020
17:01
1040
17:21
1060
17:41
1080
18:01
1100
18:21
1120

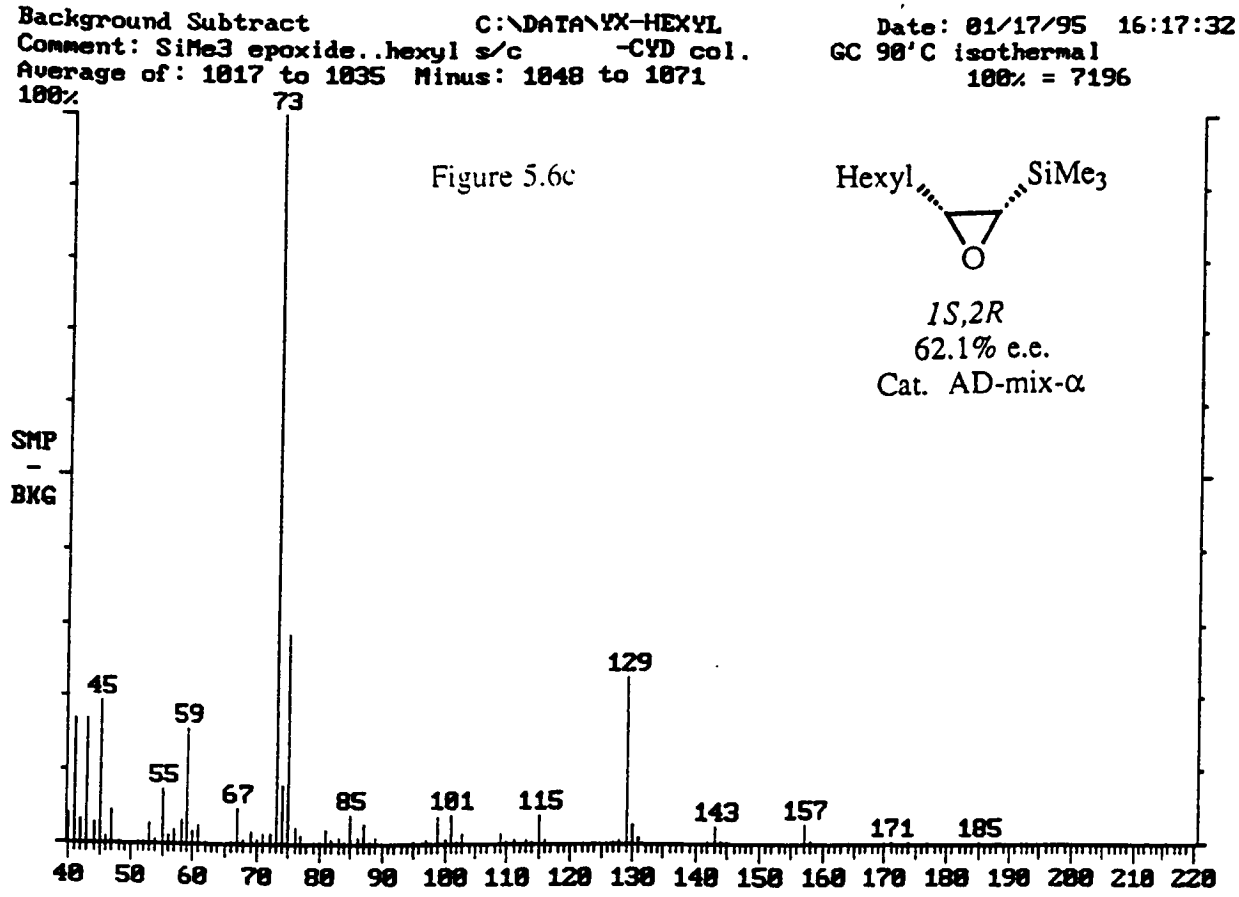


Figure 5.6c

1S,2R
62.1% e.e.
Cat. AD-mix-α

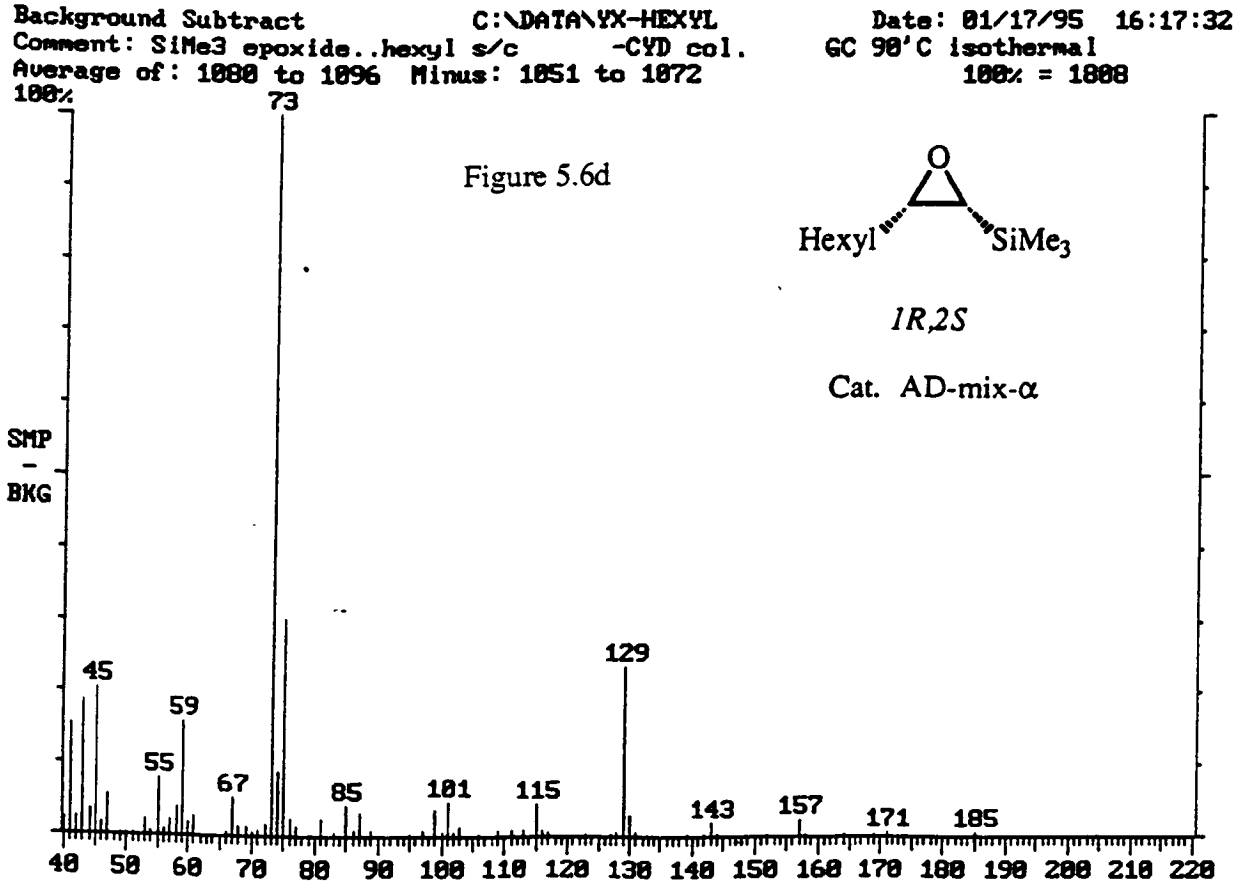


Figure 5.6d

1R,2S

Cat. AD-mix-α

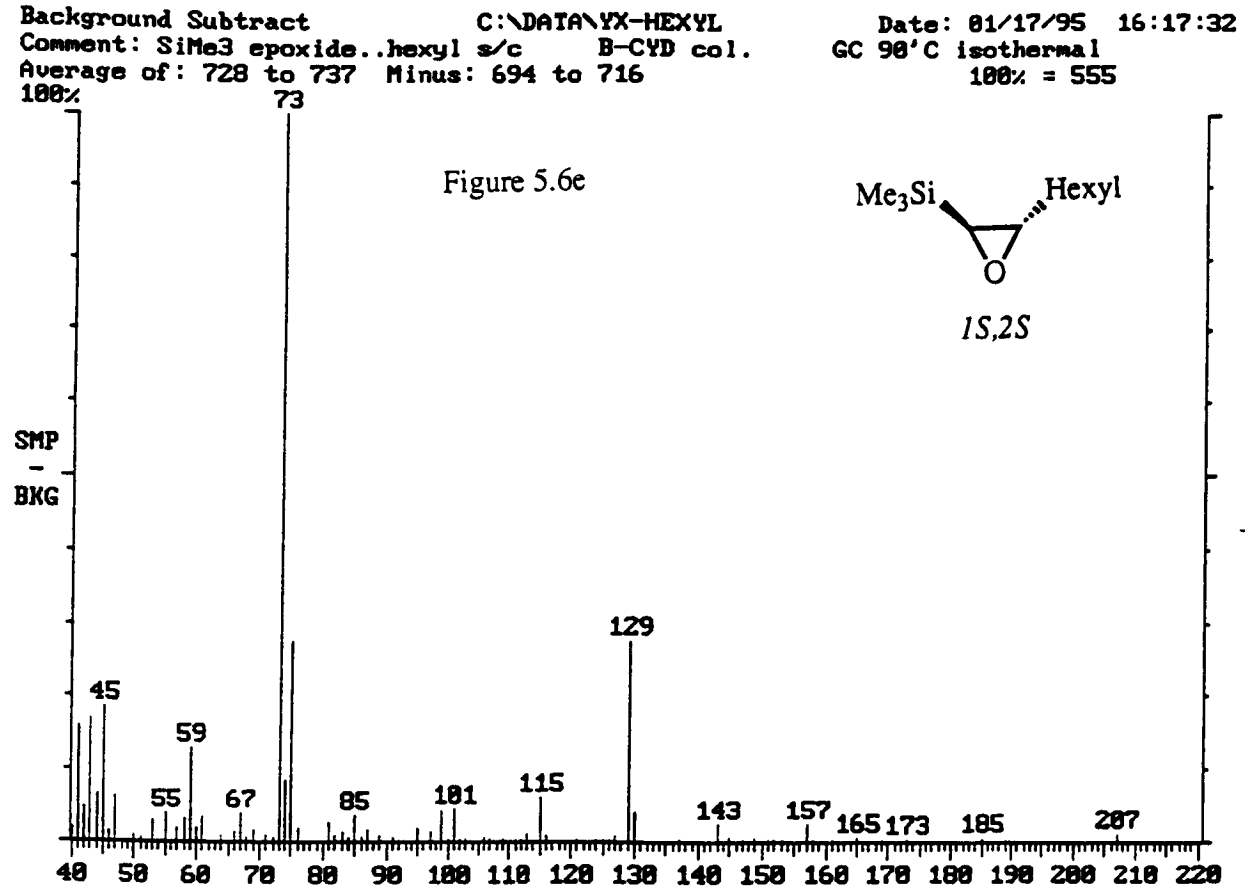


Figure 5.6e

1S,2S

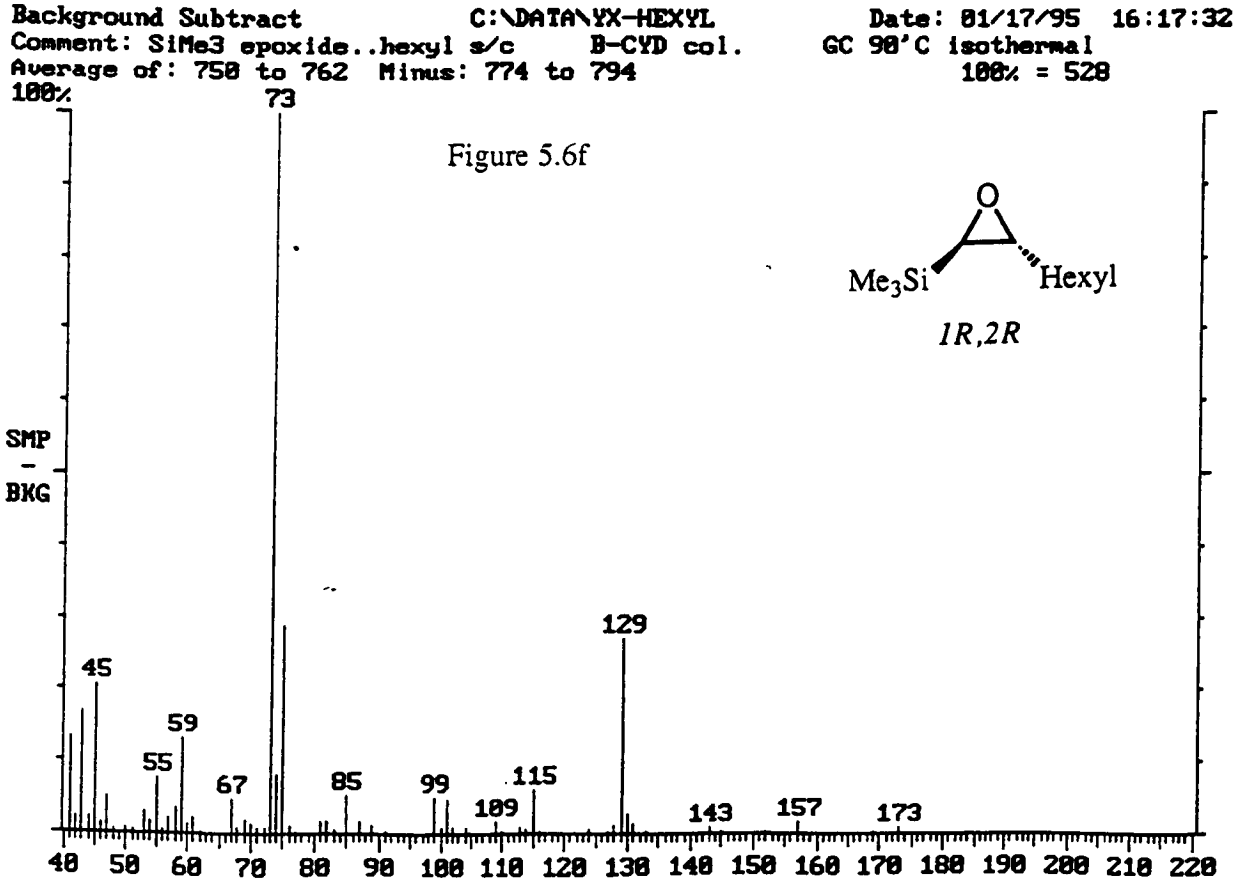


Figure 5.6f

1R,2R

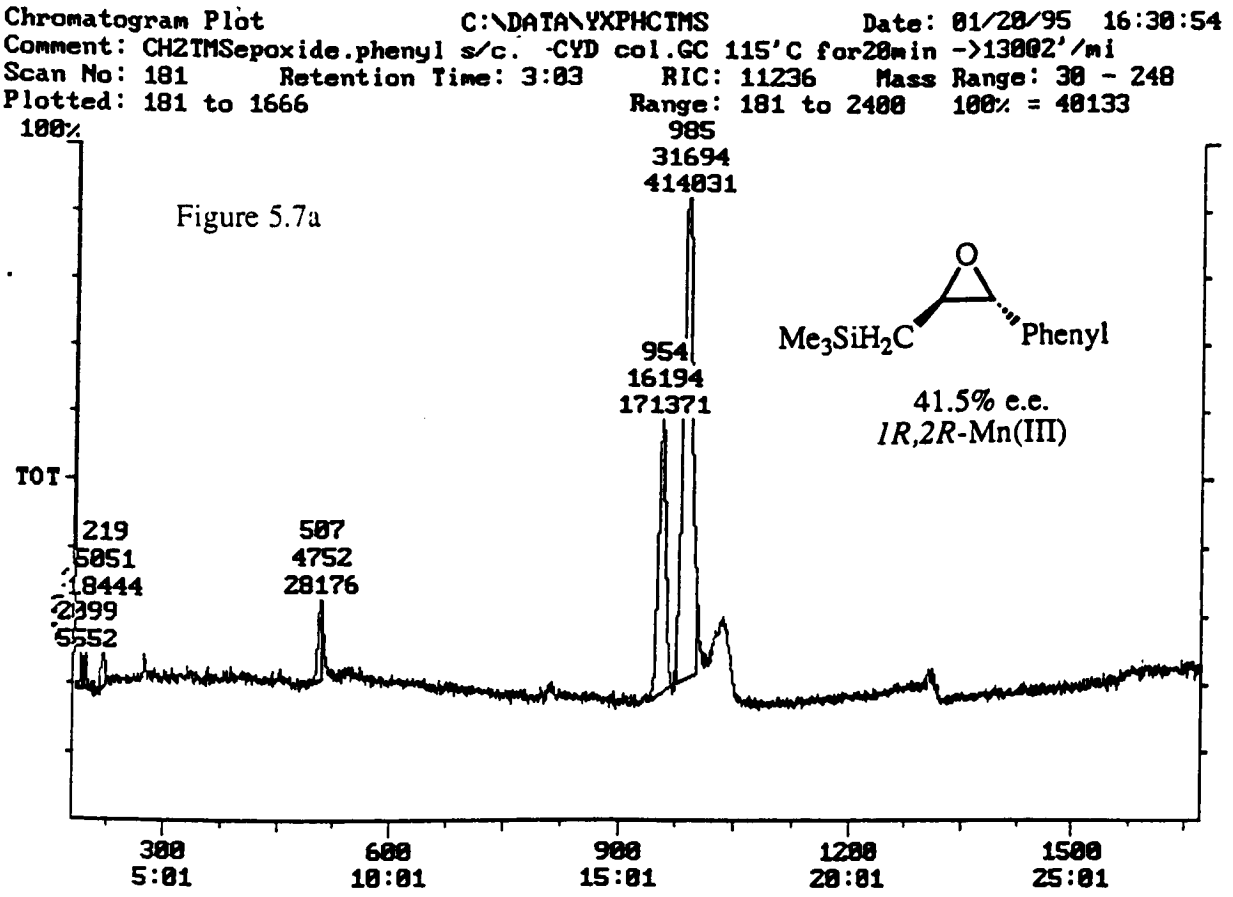

Chromatogram Plot C:\DATA\YXPHCTMS Date: 01/20/95 16:30:54
Comment: CH2TMSepoxide.phenyl s/c. -CYD col.GC 115'C for20min ->13002'/mi
Scan No: 181 Retention Time: 3:03 RIC: 11236 Mass Range: 30 - 248
Plotted: 181 to 1666 Range: 181 to 2400 100% = 40133
100%
TOT
985
31694
414031
954
16194
171371
219
5051
18444
2099
5552
507
4752
28176
Me3SiH2C
Phenyl
41.5% e.e.
1R,2R-Mn(III)
300
5:01
600
10:01
900
15:01
1200
20:01
1500
25:01

Figure 5.7a

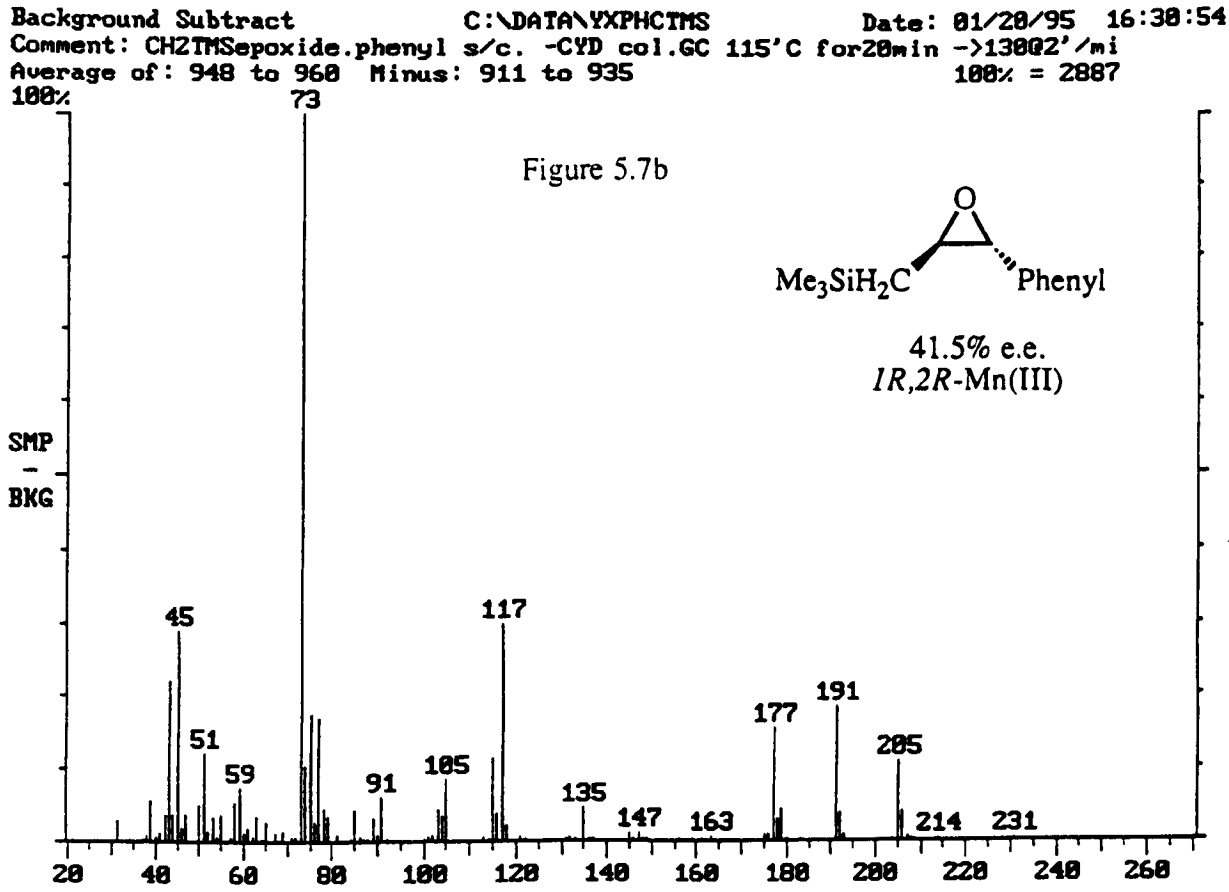


Figure 5.7b

41.5% e.e.
1R,2R-Mn(III)

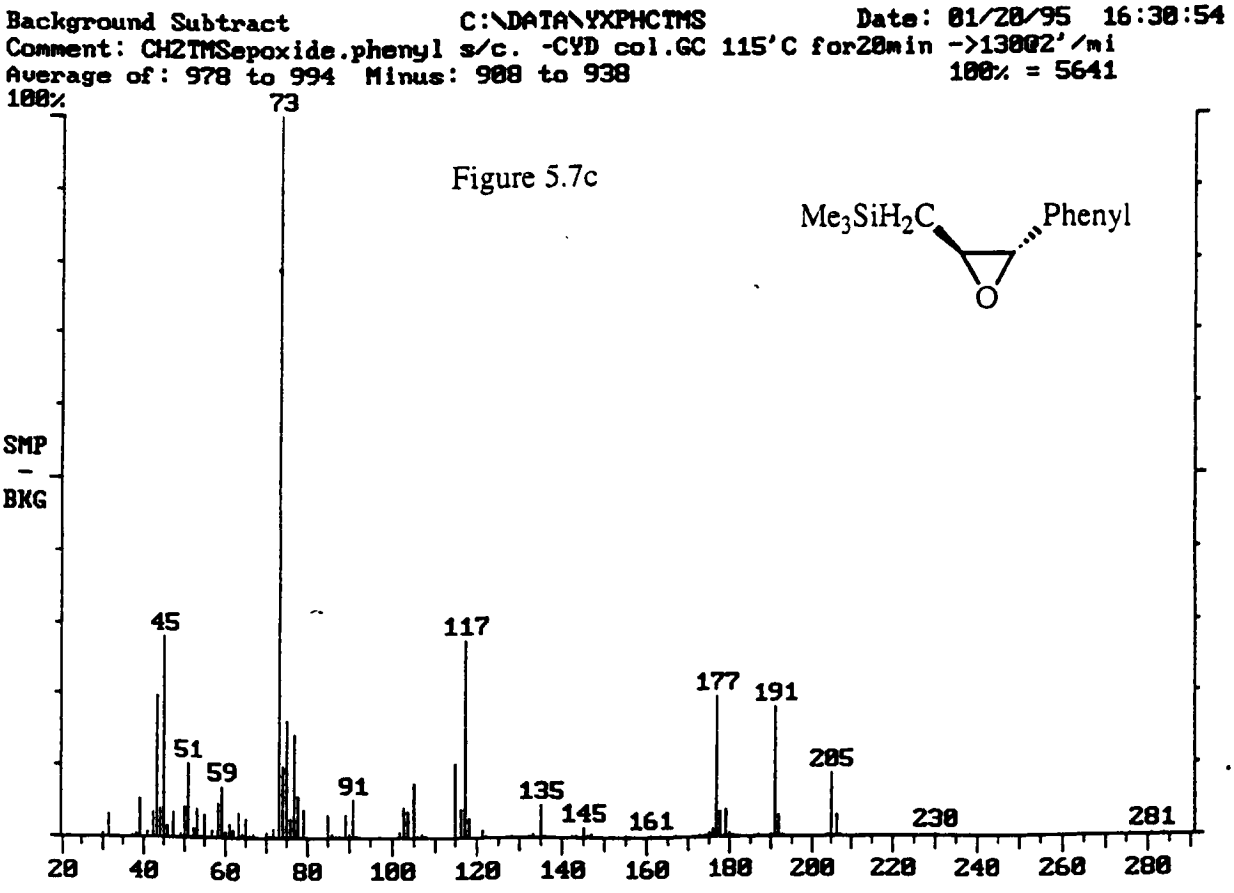
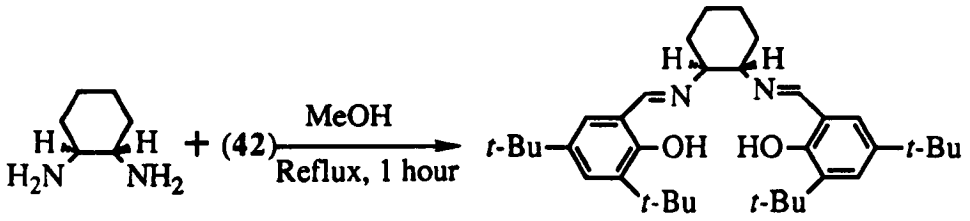


Figure 5.7c

§ 5.5 Preparation of chiral ligands and manganese (III) salen complexes

The chiral Schiff base ligands, [salen], *(S,S)- or (R,R)-(-)-N,N'*-bis(3,5-di-*tert*-butylsalicylidene-1,2-diaminocyclohexane (**44**) can be prepared as a yellow solid [12, 40, 41]



(1S,2S)

(43)

(1S,2S)

(44)

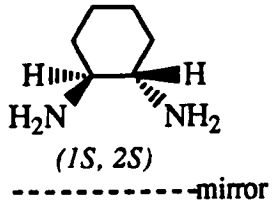
A salen ligand

Scheme 5.10

by the reaction of *(S,S)-* or *(R,R)-trans*-1,2-cyclohexanediamine (**43**)[41] and 4,6-di-*tert*-butyl-salicylaldehydes (**42**)[40,43] in methanol or ethanol as shown in Scheme 5.10. The pure*(S,S)-* or *(R,R)-trans*-1,2-cyclohexanediamine (**43**) can be resolved[42] from their racemate using tartaric acid. This very cheap method is shown in Scheme 5.11. Pure enantiomers are also commercially available.

Scheme 5.11 Resolution of *trans*-1,2-Diaminocyclohexane

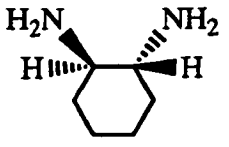
a. trans -1,2- Diaminocyclohexane (chxn)



(1S, 2S)

(1S, 2S)-(+)-1,2-Diaminocyclohexane

----------mirror



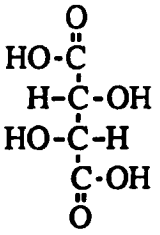
(1R, 2R)

(1R, 2R)-(-)-1,2-Diaminocyclohexane

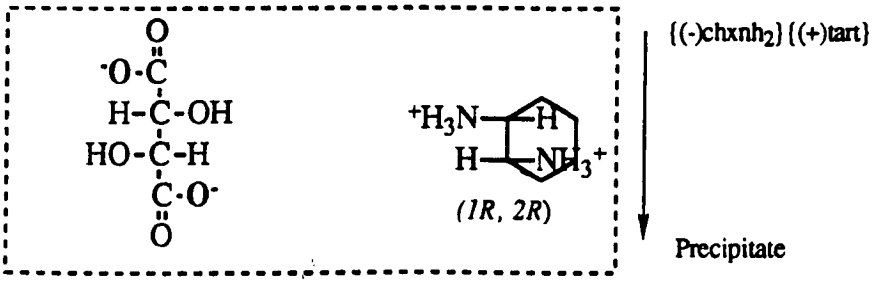
Scheme 5.11 to be continued

Scheme 5.11 continue

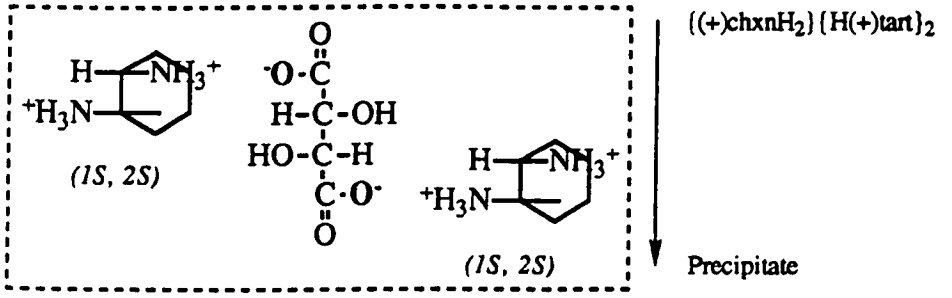
b. *(2R,3R)* L-Tartaric acid or (+)-Tartaric acid [(+)tart]



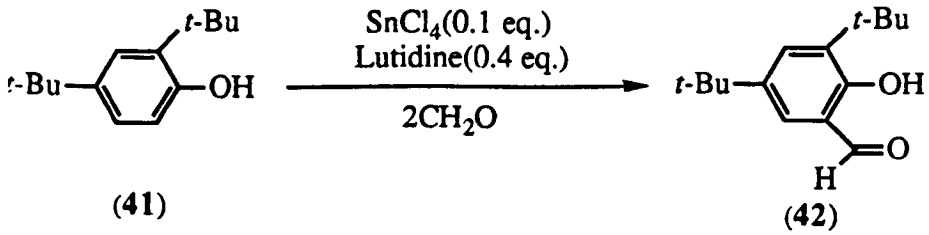
c.Resolution of (-)chxn



d. Resolution of (+)chxn

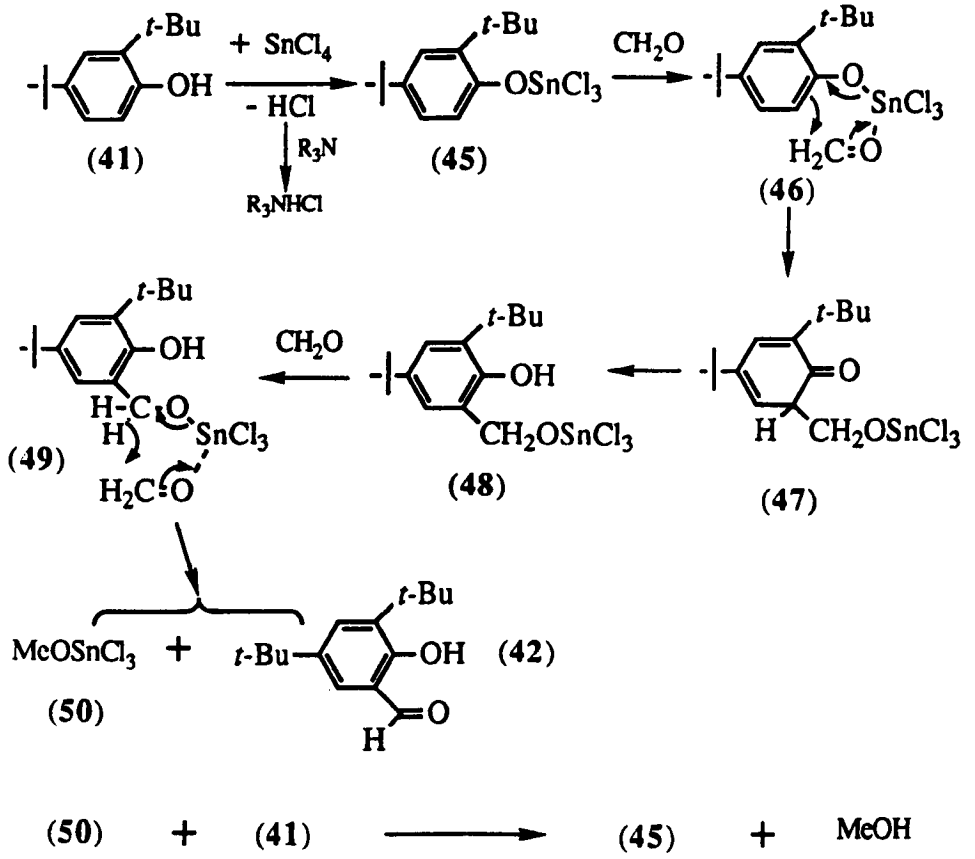


4,6-Di-*tert*-butyl-salicylaldehydes (**42**) can be made on a large scale[40,43] by the reaction of 2,4-di-*tert*-butylphenol (**41**) and paraformaldehyde. This is catalyzed by Tin (IV) chloride in the presence of lutidine, as shown in Scheme 5.12. The mechanism of the reaction is presented in Scheme 5.13.



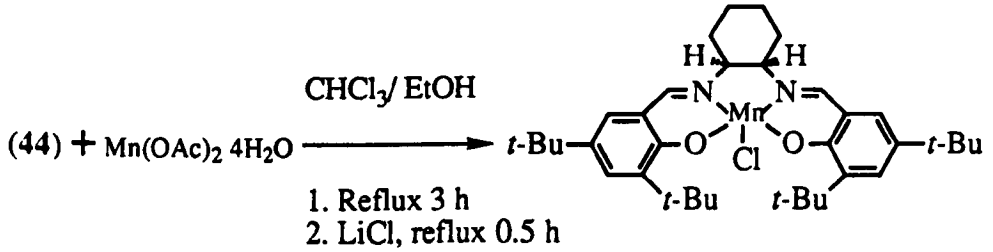
(**41**) (**42**)

Scheme 5.12



Scheme 5.13

Preparation of the manganese (III) salen complexes such as *(S,S)*- or *(R,R)-(-)-N,N'*-bis (3,5-di-*tert*-butylsalicylidene-1,2-cyclohexanediamino manganese (III) chloride (**53**) [12,40,41] (shown in Scheme 5.14) was carried out in excellent isolated yields by reaction of (**44**) with excess $Mn^{II}(OAc)_2 4H_2O$ in air followed by treatment of the resultant brown



(7)

Mn(III) salen complex

Scheme 5.14

solution with LiCl in chloroform / ethanol (or methanol) : 1 / 6. This circumvents the manipulation of the highly sensitive Mn(II) intermediates and the use of one-electron oxidants to carry out the Mn (II) to Mn (III) conversion. The Mn (III) salen complexes (**7**) are thermally stable, and can be stored indefinitely in the solid state without any precautions to exclude light, air, or moisture.

The solid state Mn (III) salen complexes can be recrystallized from ethanol or methanol by gradual addition of water to give the fine black crystals which are more reactive than the crude product.

An analogue of the manganese (III) salen complexes, an iron (III) salen complex, was made from the reaction of chiral ligands (**44**) and iron trichloride in diethyl ether, refluxing for 1 hour. The iron (III) salen complex, which is a black powder, proved much less reactive than the manganese analogue in the catalytic epoxidation reactions of allyl and vinyl silanes.

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Chapter 6
Experimental

Contents

§ 6.1 General

^{1}H, and ^{13}C NMR spectra were recorded in deuterated chloroform using Jeol 90, and EX400MHz NMR spectrometers. Residue protic solvent $C\underline{H}Cl_3$ (δ_H=7.26ppm) was used as a ^{1}H internal reference. The ^{13}C resonance of $CDCl_3$ (δ_C=77.00ppm) was used as a ^{13}C internal reference. ^{1}H, ^{13}C, DEPT, ^{1}H-^{1}H COSY 2 D, ^{13}C-^{1}H COSY 2D, and NOE NMR technology have been used for structure elucidation of compounds. Infra-red spectra were obtained as thin films using sodium chloride plates or KBr discs with a Nicolet 205 FT-IR spectrometer or a Perkin-Elmer 1710 FT-IR spectrometer with a Perkin-Elmer 7500 professional computer. Mass spectra were run on a VG20-250 quadrupole instrument equipped with an Ion Tech Fast Atom Bombardment (FAB) gun. GC/MS were obtained using a Varian 3400 GC coupled to a Finnigan MAT Ion Trap Detector. Enantiomeric excesses (e.e.) were determined by ^{13}C, ^{1}H NMR spectra in the presence of the chiral europium shift reagent [Eu(hfc)$_3$]. The enantiomeric excesses of silylepoxides was determined using a Chiraldex G-PN 20m X 0.25mm chiral GC column. The regioselectivities of the silylazidoalcohols were determined by ^{1}H-^{1}H COSY 2-D and ^{1}H-^{13}C COSY 2-D NMR spectra. The GC chromatograms were run on a Perkin-Elmer 8410 gas chromatography with a BP-5 (12m X 0.32mm, SE52/54, 1.0 μ film) column.

The dry solvents were prepared as below:

Methanol and Ethanol

The drying reagent sodium alkoxide was prepared in situ. Metallic sodium (5-10 g) was added carefully to 500 ml of methanol or ethanol in a 1 litre one-necked flask with cotton wool in place of the quickfit stopper, because of the generation of hydrogen. After all sodium was converted to the alkoxide, more of the alcohol was added (200 ml) and the mixture refluxed for three hours. The alcohol was distilled and collected in a particularly dry flask under nitrogen.

THF

The THF (1500 ml) in a 2 litre flask was stirred vigorously with pellets of sodium hydroxide (50 g) for a few days. The mixture stood for few hours, the clear predried THF (700 ml) was transferred to a dry flask (1000 ml). Sodium metal (about 5 g) was added with some benzophenone (2 g). The mixture was then refluxed under nitrogen. The solution gradually turned from yellow to green to a deep blue. The refluxing was continued for about three hours, and then on distillation the dried THF was collected using a predried flask.

Diethyl ether

Sodium metal (5-7 g) was added with some benzophenone (2 g) to 1-1.5 litres of diethyl ether in a 2 litre one-necked flask. The mixture was then refluxed under nitrogen. The solution gradually turns from yellow to green to a deep blue. The refluxing was continued for about three hours, and then on distillation the dried diethyl ether can be collected using a predried flask.

Dichloromethane

30 g of calcium hydride was added to 1.5 litres of dichloromethane in a 3 litre one necked flask, which was equipped with a double face condenser and a calcium chloride drying

tube. The mixture was left to stand in a fume cupboard for at least 24 hours. It was then refluxed for 3 hours before collection by distillation.

Hexane, Heptane

Sodium metal (5 g) was added to hexane or heptane (800 ml) and left to stand for at least 24 hours before distillation. The hexane or heptane was then refluxed for 3 hours and then collected by distillation.

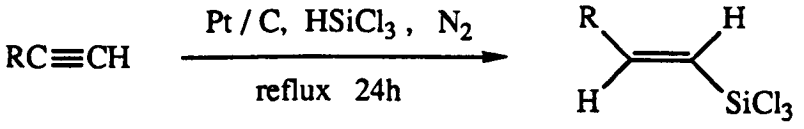
Dimethyl formamide (DMF)

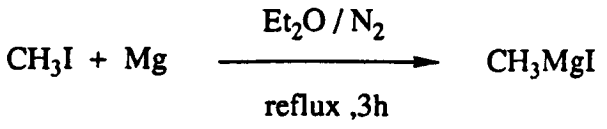
Sodium hydroxide pellets (20 g) were added to DMF (150 ml) and left to stand for at least two days. The mixture was then distilled at 50 °C under a vacuum of about 1-3 mm Hg.

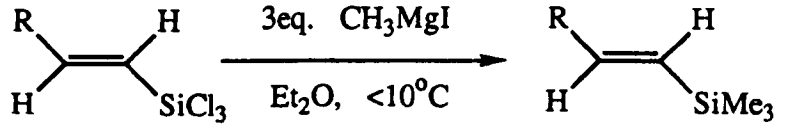
§ 6.2 Synthesis of allyl- and vinylsilanes

Terminal, *cis*, *trans*, and trisubstituted allyl- and vinylsilanes were very important starting materials for most of the experiments in this project. They were prepared by the typical procedures shown below:

6.2.1 Preparation of *trans*-vinylsilanes [1,2]







General Procedure for the preparation of *trans*-1-trichlorosilyl-1-alkene [1,2] All apparatus must be thoroughly dried in a hot (>120°C) oven before use. The alkyne (0.3 mol) was added over a 15-minute period to a rapidly stirred, refluxing suspension of 1.2 g of 5% platinum-on-activated carbon in 81 g. (0.6 mol) of the trichlorosilane under nitrogen. The mixture was stirred at reflux for 24 hours and then the trichlorosilane removed under vacuum to yield the vinyltrichlorosilane. It was used without further purification.

Preparation of *trans*-1-trichlorosilyl-1-hexene [1,2]: See the general procedure. using 0.3 mol, 24.645 g, 34.468 ml of 1-hexyne. The crude yield of the product is 100%. NMR (ppm), $\delta_H(CDCl_3)$ 0.92 (3H, t, J 7.4 Hz, CH_3), 1.56-1.30 (4H, m, CH_2), 2.30-2.24 (2H, m, CH_2), 5.80 (1H, dt, J 18.6 Hz, J 1.6 Hz, CH), 6.70 (1H, dt, J 18.6 Hz, J 6.4 Hz, CH), $\delta_C(CDCl_3)$ 14.33 (1C, CH_3), 22.65 (1C, CH_2), 30.28 (1C, CH_2), 36.01 (1C, CH_2-CH) ,122.18 (1C, CH-Si), 157.85 (1C, CH-CH_2).

Preparation of *trans*-1-trichlorosilyl-1-heptene [1,2]: See the general procedure. using 0.3 mol, 28.851 g, 39.360 ml of 1-heptyne. The crude yield of the product is 100%. NMR (ppm) $\delta_H(CDCl_3)$ 0.93 (3H, t, CH_3), 1.28-1.39 (4H, m, CH_2), 1.40-1.54 (2H, m, CH_2), 2.25-2.31 (2H, m, CH_2), 5.81 (1H, dt, J 18.4 Hz, J 1.8 Hz, CH-Si), 6.72 (1H, dt, J 18.4 Hz, J 6.4 Hz, CH), $\delta_C(CDCl_3)$ 14.48 (1C, CH_3), 22.98 (1C, CH_2), 27.92 (1C, CH_2), 31.82 (1C, CH_2), 36.33 (1C, CH_2), 122.25 (1C, CH-Si), 157.84 (1C, CH_2).

Preparation of *trans*-1-trichlorosilyl-1-octene[1,2]: See the general procedure. using 0.3 mol, 33.060 g, 44.257 ml of 1-octyne. The crude yield of the product is 100%. NMR (ppm) $\delta_H(CDCl_3)$ 0.90 (3H, t, J 6.6 Hz, CH_3), 1.56-1.05 (8H, m, CH_2), 2.29-2.21 (2H, m, CH_2), 5.80 (1H, d, J 18.6 Hz, CH), 6.70 (1H, dt, J 18.6 Hz, J 6.3 Hz, CH), $\delta_C(CDCl_3)$ 14.55 (1C, CH_3), 23.04 (1C, CH_2) 28.12 (1C, CH_2), 29.26 (1C, CH_2), 32.07 (1C, CH_2), 36.33(1C, CH_2-CH), 122.16 (1C, CH-Si), 157.93 (1C, CH-CH_2).

General procedure for the preparation of *trans*-Vinyltrimethylsilane[1,2]: All apparatus must be thoroughly dried in a hot (>120°C) oven before use. The methyl magnesium iodide (1.035 mol, 1.15 equivalent) was made from iodomethane (1.035 mol, 64.4 ml, 1.15 equivalent) and magnesium turnings (1.35 mol, 32.8 g, 1.5 equivalent) in 1.2 litre of dry diethyl ether in a 3 litre three neck round bottomed flask. Vinyltrichlorosilane (0.3 mol, 1 equivalent) was added dropwise into the well stirred solution over 30 minutes at 0°C followed by stirring for three hours at room temperature. The reaction mixture was quenched with saturated ammonium chloride solution at 0°C. After separation, the aqueous layer was extracted with ether (100 ml). The combined ethereal layers were dried over $MgSO_4$, then filtered through a 3 cm silica gel column. Removal of the ether give the crude *trans*-vinyltrimethylsilane which was purified by distillation.

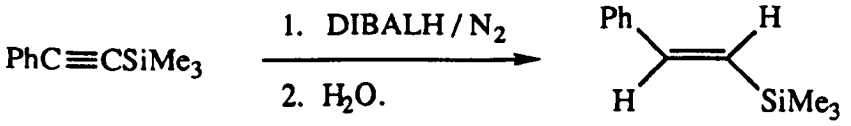
Preparation of *trans*-1-trimethylsilyl-1-hexene[1,2]: See the general procedure, using 0.3 mol, 65.283 g, of *trans*-1-trichlorosilyl-1-hexene. The yield of the product is 69% after distillation. υ_{max}(neat film)/cm^{-1}, 2957.7 (s, C-H), 2928.5 (s, CH_3), 2901.3, (m, CH_2), 2874.8 (CH_3), 2861.5 (CH_2), 1617.6 (m, C=C), 1248.2(s, SiMe), 989.0 (m, CH), 865.14 (s, $SiMe_3$), 837.33 (s, $SiMe_3$); NMR (ppm), δ_H ($CDCl_3$) 0.06 (9H, s, $SiMe_3$), 0.90 (3H, t, J 7.3 Hz, CH_3), 1.42-1.27 (4H, m, CH_2), 2.13-2.08 (2H, m, CH_2), 5.62 (1H, dt, J 18.8 Hz, J 0.8 Hz, CH-Si), 6.03 (1H, dt, J 18.8 Hz. J 6.4 Hz, CH), δ_C ($CDCl_3$) -0.65 (3C, $SiMe_3$), 14.48 (1C, CH_3), 22.76 (1C, CH_2), 31.41 (1C, CH_2), 36.94 (1C, CH_2-CH), 129.97(1C, CH-Si), 147.87 (1C, CH-CH_2); m/z(EI) 156 (3%, M^+), 141 (100, M-CH_3), 114 (35, $C_6H_{14}Si$), 99 (22, $C_5H_{11}Si$), 85 (25, $C_4H_{11}Si$), 83 (10, C_6H_{11}), 81 (24, C_6H_9), 73 (74, $SiMe_3$), 59(100, C_2H_7), 45 (21, C_3H_9), 43 (21, C_3H_6), 28 (16, C_2H_2); (Found: C, 68.99, H, 12.92. $C_9H_{20}Si$ requires C 69.14, H 12.89%).

Preparation of *trans*-1-trimethylsilyl-1-heptene[1,2]: See the general procedure, using 0.3 mol, 68.289 g of *trans*-1-trichlorosilyl-1-heptene. The yield of the product is 65% after distillation. υ_{max}(neat film)/cm^{-1}, 2957.5 (s, CH), 2928.0 (s, CH_3) ,2901.7 (m,

CH_2) 2874.6 (m, CH_3) ,2858.7 (m, CH_2), 1617.8 (m, C=C), 1466.9 (w, CH), 1459.2 (w, CH_2), 1248,0 (s, SiMe), 989.9 (m, CH), 867.8. (s, $SiMe_3$), 837.1 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ 0.05 (9H, s, $SiMe_3$), 0.89 (3H, t, J 6.8 Hz, CH_3), 1.43-1.26 (6H, m, CH_2), 2.14-2.07 (2H, m, CH_2), 5.62 (1H, d, J 18.6 Hz, CH-Si), 6.03(1H, dt, J 18.6 Hz, J 6.4 Hz, CH), $\delta_C(CDCl_3)$ -0.65 (3C, $SiMe_3$), 14.55 (1C, CH_3), 23.06 (1C, CH_2) , 28.91 (1C, CH_2), 31.96 (1C, CH_2), 37.23 (1C, CH_2-CH), 129.93 (1C, CH-Si), 147.93 (1C, CH-CH_2); ; m/z(EI) 170 (1.5%, M^+), 155 (100%, M-CH_3), 127 (3%, $C_7H_{15}Si$), 114 (18%, $C_6H_{14}Si$), 99 (20%, $C_5H_{11}Si$), 95 (21%, C_7H_{11}), 85 (13%, C_6H_{13} / C_4H_9Si), 73 (95%, $SiMe_3$), 59 (100%, C_2H_7Si) 43 (22%, C_3H_7),28 (18%, C_2H_4); (Found: C 70.38, H 12.92, $C_{10}H_{22}Si$ requires C 70.50, H, 13.02%).

Preparation of *trans*-1-trimethylsilyl-1-octene [1,2]: See the general procedure, using 0.3 mol, 73.698 g of *trans*-1-trichlorosilyl-1-octene. The yield of the product is 71% after distillation. υ_{max}(neat film)/cm^{-1} 2957 (s, CH), 2927 (s, CH_3), 2873.8 (m, CH_3), 2856.7 (m, CH_2), 1617.7 (m, C=C), 1247.7 (SiMe), 987.6 (m, CH), 863.23 (s, $SiMe_3$), 837.4 (s, $SiMe_3$); NMR (ppm): δ_H ($CDCl_3$) 0.05 (9H, s, $SiMe_3$), 0.89 (3H, J 7.3 Hz, CH_3), 1.43-1.26 (8H, m, CH_2), 2.15-2.08 (2H, m, CH_2), 5.62 (1H, dt, J 18.8 Hz, J 1.6 Hz, CH-Si), 6.03 (1H, dt, J 18.8 Hz, J 6.4 Hz, CH), $\delta_C(CDCl_3)$ -0.65 (3C, $SiMe_3$), 14.61 (1C, CH_3), 23.15 (1C, CH_2), 29.20 (1C, CH_2), 29.42 (1C, CH_2), 32.29 (1C, CH_2), 32.29 (1C, CH_2), 129.97 (1C, CH-Si), 147.43 (1C, CH-CH_2); m/z(EI) 184 (37%, M^+), 169 (100%, M-CH_3), 141 (2%, $C_8H_{17}Si$), 125 (2%, $C_7H_{14}Si$), 114 (38%, $C_6H_{14}Si$), 109 (30%, C_8H_{13}), 99 (40%, $C_5H_{11}Si$), 85 (26%, C_6H_{13}), 73 (94%, $SiMe_3$), 59 (100%, C_2H_7Si), 43 (28%, C_3H_7); (Found: C 71.36, H 13.00, $C_{11}H_{24}Si$ requires C 71.65, H 13.12%).

Preparation of *trans*-styryltrimethylsilane [3]



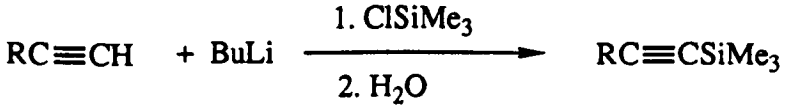
Procedure : All apparatus was thoroughly dried in a hot (>120 °C) oven for at least 24 hours before use. The 250-ml three-necked round-bottomed flask was equipped with a double face condenser with a nitrogen inlet with a bubbler, a dropping funnel with a septum, and a magnetic stirrer bar. The flask was flushed with a slow stream of nitrogen by removal of the stoppers on the side arms of the flask one after another, for at least 15 minutes. Then, the flask was charged with 9.8g (56 mmol) of trimethyl (phenylethynyl)silane and 20 ml of dry hexane. The addition funnel was charged with 40 ml of hexane. The transfer of pure diisobutylaluminium hydride (DIBALH) is readily accomplished by first pressurising the reagent cylinder with dry, high-purity nitrogen before filling the syringe. 8.0 g (56 mmol, 10 ml) of pure DIBALH was measured using a syringe and transferred to the addition funnel via a rubber septum. The solution of DIBALH in hexane was then added dropwise to the silane over 15 minutes. The reaction mixture was heated at 55-67°C for 3 hours, cooled and then cautiously treated with 7.1 ml of water. After filtration, the solvent was removed from the filtrate, and the residue distilled to yield 9.4 g.(96%) of *trans*- styryltrimethylsilane, bp 90-91°C at 13 mm Hg. υ_{max}(neat film/cm^{-1}) 3078.9 (w, Ar CH), 3060.4 (w, Ar CH), 3024.4 (w, Ar CH), 2990.0 (w, Ar CH), 2955.9 (s, CH), 2897.2 (w, CH_3), 1605.8 (m, C=C), 1574.5 (w, C=C), 1494.1 (w, C=C), 1447.6 (w, C=C), 1247.6 (s, SiMe), 988.6 (m, CH), 866.7 (s, $SiMe_3$), 843.4 (s, $SiMe_3$), 755.7 (s, CH, Ar), 723.5 (m, CH, Ar), 690.3 (m, CH, Ar); NMR(ppm) $\delta_H(CDCl_3)$ 0.17 (9H, s, $SiMe_3$),.6.50 (1H, d, J 19.6 Hz, CH-Si), 6.89 (1H, d, J 19.6 Hz, CH-Ph),.7.24-7.47 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.75 (3C, $SiMe_3$), 126.82 (2C, CH, Ph), 128.51 (1C, CH, Ph), 129.00 (2C, CH, Ph), 130.01 (1C, CH-Si), 138.82 (1C, *t*-C, Ph), 144.05 (CH-Ph); m/z(EI) 176 (35%, M^+), 161 (100, M^+-Me), 145 (70, M^+-2Me-H), 135 (40, $C_8H_{12}Si$), 105 (25,C_8H_9), 77 (22, C_6H_5), 73 (46, $SiMe_3$), 59 (36, $HSIMe_3$), 43 (18, C_3H_7); (Found: C 74.31, H 9.02, $C_{11}H_{16}Si$ requires C 74.93, H 9.15%).

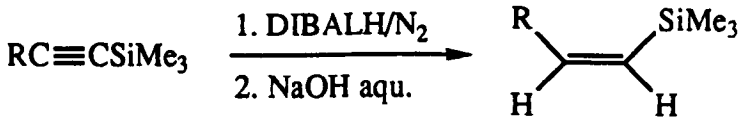
6.2.2 Synthesis of *cis*-vinylsilanes

Preparation of *cis*-styryltrimethylsilane [3]

Procedure : All apparatus were thoroughly dried in a hot (>120°C) oven for at least 24 hours before use. The 250-ml three-necked round-bottomed flask was equipped with a double face condenser with a nitrogen inlet with a bubbler, a dropping funnel, and a magnetic stirrer. After thorough degassing and flushing with nitrogen, the flask was charged with 9.8 g (56 mmol) of trimethyl(phenylethynyl)-silane and 20 ml of dry hexane. The addition funnel was charged with 40 ml of hexane and 8.0 g. (56 mmol) of pure diisobutylaluminium hydride. 4.8 g (56 mmol) of anhydrous, degassed *N*-methyl-pyrrolidine was slowly added via a syringe to the hydride solution (slight exotherm) and the resulting solution added dropwise to the silane. The reaction mixture was heated at 55-67°C for 3 hours, cooled and cautiously treated with 3.1 ml of water. After filtration, the solvent was removed from the filtrate, and the residue distilled to yield 9.4 g.(96%) of *cis*-styryltrimethylsilane, bp 50-52°C at 0.2mm Hg. NMR (ppm) $\delta_H(CDCl_3)$ 0.06 (9H, s, $SiMe_3$), 5.45 (1H, d, J 15.2 Hz, CH-Si), 7.24-7.32 (5H, m, Ph), 7.38 (1H, d, J 15.2 Hz, CH-Ph), $\delta_C(CDCl_3)$ 0.65 (1C, $SiMe_3$), 127.79 (1C, CH, Ph), 128.38 (1C, CH, Ph), 128.60 (2C, CH, Ph), 133.35 (1C, CH-Si), 140.59 (1C, *t*-C, Ph),.147.07 (CH-Ph).

Preparation of *cis*-alkyl substituted vinylsilanes





General procedure for preparation of 1-trimethylsilyl-1-alkyne [4]: All apparatus were thoroughly dried in a hot (>120°C) oven for at least 24 hours before use. A three-necked, round bottomed 250 ml flask was equipped with a magnetic stirrer, a double face condenser with a nitrogen inlet and bubbler, a dropping funnel, and a rubber septum. The flask was flushed with a slow stream of nitrogen, then charged with 0.15 mol of 1-alkyne and 80 ml of dry THF. 63 ml (0.1575 mol, 1.05 equivalent) of a 2.5M (in hexane) solution of n-Butyl lithium was quickly transferred using a syringe to the flask by puncturing the rubber septum on the flask. The solution was added dropwise to the stirring mixture at such a rate as to maintain a gentle reflux. The reaction mixture was kept at reflux for 30 minutes, then cooled to room temperature. 0.1725 mol (18.740 g, 21.893 ml) of chlorotrimethylsilane was placed in the addition funnel and added dropwise to the stirred reaction mixture against a slow nitrogen stream over a 20-minute period. the mixture was refluxed for 1 hour, then cooled to room temperature, followed by hydrolytic work up. The aqueous layer was extracted by diethyl ether (3x30 ml). The organic phase was dried over $MgSO_4$, filtered, concentrated, then the crude alkynyltrimethylsilane purified by distillation.

General procedure for the preparation of *cis*-alkyl substituted vinylsilanes [4]: All apparatus were thoroughly dried in a hot (>120 °C) oven for at least 24 hours before use. A three necked, round-bottomed 250 ml flask in a water bath was equipped with a magnetic stirrer, a double face condenser, a nitrogen inlet and bubbler, and a rubber septum. The flask was flushed with a slow stream of nitrogen for 10 minutes then 50 mmol of alkynyl trimethylsilane and 80ml of dry ether added. 554.6 ml of a 1 mol solution (in hexanes) of DIBALH was quickly transferred using a syringe to the flask by puncturing the rubber septum on the flask. The solution was added dropwise to the stirring mixture during a 40-minute period at room temperature. The reaction mixture was then refluxed for 4 hour, cooled to 0°C and cautiously treated with 646 ml of 3M sodium

hydroxide solution. The aqueous layer was extracted with hexane. The organic extracts were washed with 3M sodium hydroxide solution, brine, and then dried over $MgSO_4$. After removal of the solvent, the *cis*-alkyl substituted vinyltrimethylsilane was purified by distillation.

Preparation of 1-trimethylsilyl-1-heptyne [4]: See the general procedure using 0.15 mol, 14.426 g, 19.680 ml of 1-heptyne. The yield of the product is 77%. υ_{max}(neat film/cm^{-1}) 2960.0 (s, CH), 2935.0 (s, CH_3), 2176.1 (s, CC), 1249.5 (s, SiMe), 842.1 (s, $SiMe_3$), 759.7;

Preparation of *cis*-1-trimethysilyl-1-heptene[4]: See the general procedure using 50 mmol, 8.418 g of 1-trimethylsilyl-1-heptyne. The yield of the product is 81%. υ_{max}(neat film/cm^{-1}) 2958.8 (s, CH), 2927.5 (s, CH_3), 2874.5 (w, CH_3), 2858.4 (m, CH_2), 1607.4 (m, C=C), 1466.9 (w, CH), 1459.0 (w, CH_2), 1248.9 (SiMe), 857.6 (s, $SiMe_3$), 837.5 (s, $SiMe_3$), 762,7; NMR (ppm), δ_H($CDCl_3$) 0.12 (9H, s, $SiMe_3$), 0.90 (3H, t, J 7.1 Hz, CH_3), 1.28-1.42 (6H, m, CH_2), 2.09-2.14 (2H, m, CH_2-CH), 2.09-2.14 (2H, m, CH_2-CH), 6.31 (1H, tt, J 14.2 Hz, J 7.4 Hz, CH-CH_2), δ_C($CDCl_3$) 0.23 (1C, $SiMe_3$) 14. 03 (1C, CH_3), 22.63 (1C, CH_2), 29.46 (1C, CH_2), 31.59 (1C, CH_2), 33.53 (1C, CH_2-CH), 128.68 (CH-Si), 149.32 (CH); m/z(EI) 170 (7%, M^+), 155 (100, M-Me), 127 (9, $C_7H_{15}Si$), 114 (30, $C_6H_{14}Si$), 99 (34, $C_5H_{11}Si$), 95 (25, C_7H_{11}), 85 (23, C_4H_9Si), 73 (100, $SiMe_3$), 59 (76, $HSIMe_2$), 43 (15, C_3H_7); (Found: C 70.38, H 12.92, $C_{10}H_{22}Si$ requires C 70.50, H 13.02%).

Preparation of 1-trimethylsilyl-1-octyne [4]: See the general procedure using 0.15 mol, 16.530 g, 22.129 ml of 1-octyne. The yield of the product is 87%. υ_{max}(neat film/ cm^{-1}) 2959.1(s, CH), 2933.5 (s, CH_3), 2873.6 (m, CH_3), 2860.5 (m, CH_2), 2176.6 (s, CC), 1249.2 (s, SiMe), 841.7 (vs, $SiMe_3$); NMR (ppm), δ_H($CDCl_3$) 0.13 (9H, $SiMe_3$), 0.88 (3H, t, J 7.1 Hz, CH_3), 1.22-1.42 (6H, m, CH_2), 1.50 (2H, p, J 7.2 Hz, CH_2), 2.19 (2H, t, J 7.2 Hz, CH_2), δ_C($CDCl_3$) 0.64 (3C, $SiMe_3$), 14.48 (1C, CH_3),

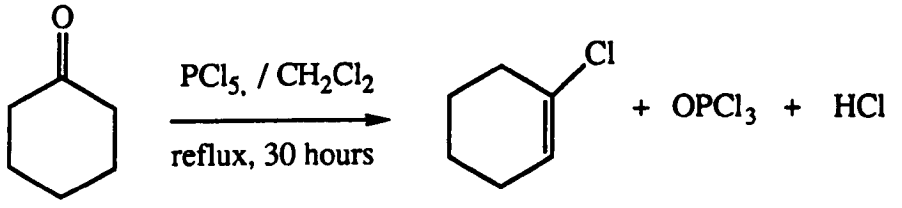
20.35 (1C, CH_2), 23.02 (1C, CH_2), 28.96 (1C, CH_2), 29.11 (1C, CH_2), 84.67 (1C, CC), 108.16 (1C, CC).

Preparation of *cis*-1-trimethylsilyl-1-octene [4]: See the general procedure using 50 mmol, 9.119 g of 1-trimethylsilyl-1-octyne. The yield of the product is 86%. υ_{max}(neat film /cm^{-1}) 2958.0 (s, CH), 2926.8 (s, CH_3), 2873.6 (w, CH_3), 2856.7 (m, CH_2), 1607.0 (m, C=C), 1466.8 (w, CH), 1458.9 (w, CH_2), 1248.7 (s, SiMe), 858.2 (s, $SiMe_3$), 837.6 (s, $SiMe_3$), 763.0, NMR (ppm) $\delta_H(CDCl_3)$ 0.13 (9H, s, $SiMe_3$), 0.91 (3H, t, J 5.3 Hz, CH_3), 1.27-1.38 (8H, m, CH_2), 2.03-2.20 (2H, m, CH_2), 5.48 (1H, dt, J 14.2 Hz, J 1.2 Hz, CH-Si), 6.33 (1H, dt, J 14.2 Hz, J 7.4 Hz, CH-CH_2); $\delta_C(CDCl_3)$ 0.85 (3C, $SiMe_3$), 14.70 (1C, CH_3), 23.26 (1C, CH_2), 29.69 (1C, CH_2), 30.38 (1C, CH_2), 32.45 (1C, CH_2), 34.17 (1C, CH_2-CH), 129.30 (1C, CH-Si), 149.93 (1C, CH); m/z(EI) 184(15%, M^+), 169 (100, M-Me), 141 (4, $C_8H_{17}Si$), 125 (6, $C_7H_{13}Si$), 114 (25, $C_6H_{14}Si$)), 109 (15, C_8H_{13}), 99 (23, $C_5H_{11}Si$)), 73 (80, $SiMe_3$), 59 (47, C_2H_7Si), 43 (12, C_3H_7); (Found: C 71.52, H 13.00, $C_{11}H_{24}Si$ requires C 71.65, H 13.12%).

6.2.3 Synthesis of trisubstituted vinylsilanes

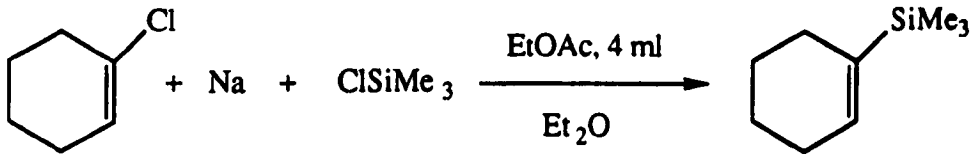
(1) Synthesis of 1-trimethylsilylcyclohexene

Preparation of 1-chlorocyclohexene [5],



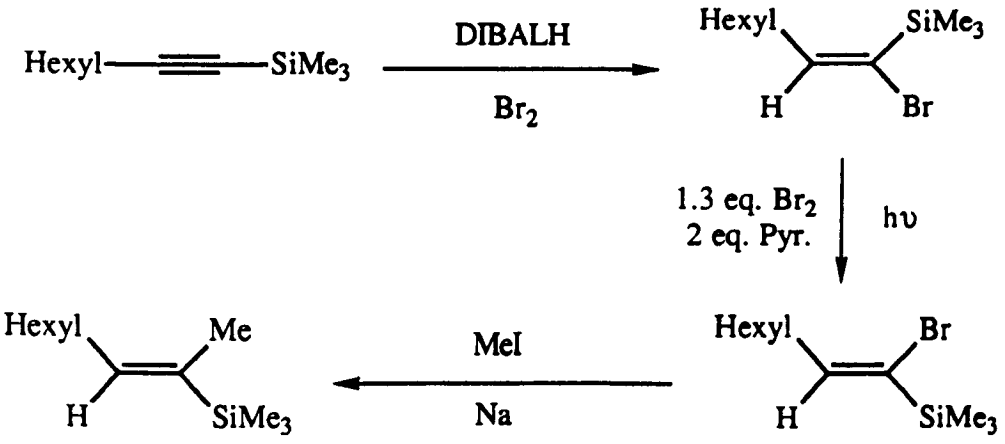
A solution of 99 g. (1 mol) of cyclohexanone in 500 ml of dichloromethane was added to a suspension of 230 g. (1.1 mol) of phosphorus pentachloride in 1000 ml of dry dichloromethane in a three neck round bottomed 3 L flask fitted with reflux condenser and

stirrer. The reaction mixture was held at reflux for 30 hours, cooled and treated with ice. The product was taken into benzene-ether and washed well with water, 10% sodium carbonate solution, water, and saturated sodium chloride solution. The organic layer was then filtered to remove the magnesium sulphate and the solvent removed under vacuum. Distillation in vacuo yielded 1-chlorocyclohexene 68%. NMR (ppm) $\delta_H(CDCl_3)$ 1.60-1.53 (2H, m, C^4H_2), 1.69-1.75 (2H, m, C^5H_2), 2.05-2.10 (2H, m, C^3H_2), 2.25-2.30 (2H, m, C^6H_2), 5.79 (1H, hep, C^2H), $\delta_H(CDCl_3)$ 21.22 (1C, C^4H_2), 23.64 (1C, C^5H_2), 26.01 (1C, C^3H_2), 32.73 (1C, C^6H_2), 124.49 (1C, C^2H), 131.86 (1C, *t*-C^1).



1-Trimethylsilylcyclohexene [6,7] : To 23g of sodium in a finely divided state under ether was added 66g of chlorotrimethylsilane, 5 ml of 1-chlorocyclohexene, and 2 ml of ethyl acetate. After reaction had commenced, 60 g of 1-chlorocyclohexene was added over 2 hours. The resulting solution was decanted into a 250 ml conical flask. The residue was washed with 50 ml of diethyl ether twice and also decanted into the conical flask. The ethereal solution was filtered through a pad of silica gel. After removal of the solvent under vacuum, the crude product was distilled to yield 68 g of 1-trimethylcyclohexene. υ_{max}(neat film/cm^{-1}) 2953.9 (s, CH), 2928.6 (s CH_3), 2857.8 (m, CH_2), 2832.1 (m, CH_2), 1616.7 (w, C=C), 1447.4 (w, CH), 1435.3 (w, CH_2), 1247.0 (s, SiMe), 1063.5, 939.1 (w, CH), 856.2 (s, $SiMe_3$), 836.4 (s, $SiMe_3$), 749.1; NMR (ppm) $\delta_H(CDCl_3)$ 0.03 (9H, s, $SiMe_3$), 1.58-1.62 (4H, m, CH_2), 2.03 (4H, b, CH_2), 5.99 (1H, m, CH), δ_C ($CDCl_3$) -1.64 (3C, $SiMe_3$), 23.07 (1C, C^4H_2), 23.34 (1C, C^5H_2), 27.09 (1C, C^3H_2), 27.35 (1C, C^6H_2), 136.10 (1C, C^2), 139.27 (1C, C^1); m/z(EI) 154 (7%, M^+), 139 (41, M-Me),111 (5, $C_6H_{11}Si$), 81 (17, C_6H_9), 80 (27, C_6H_8), 79 (42, C_6H_7), 73 (100, $SiMe_3$), 59 (55, $HSiMe_2$), 28 (27, C_2H_4).

(2). Synthesis of E-1-methyl-2-hexyl-vinylsilane



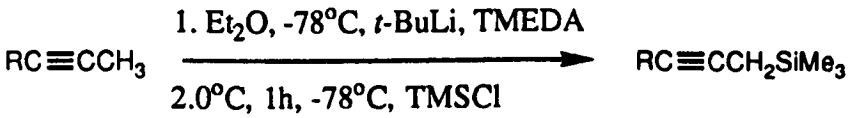
Procedure for the preparation of (*Z*-1-Bromo-1-Octenyl)trimethylsilane (Z-Br) [8]: Into a dry 100 ml three neck round-bottomed flask equipped with a nitrogen inlet and thermometer and kept under a static pressure of nitrogen was added (5.47 g, 30 mmol) of 1-octynyl trimethylsilane and anhydrous ether (15 ml). Diisobutylaluminium hydride (10% excess, 33 mmol, 6.12 ml) was added dropwise using a syringe while maintaining the temperature during the addition at 25-30°C by means of a water bath. The solution was stirred at room temperature for 15 min and then heated at 40°C for 1 hour. The hydroalumination product formed was diluted at 0°C with ether (30 ml) and pyridine (4.8 ml). To the resultant yellow reaction mixture was added at -70°C a solution of bromine (39 mmol, 1.5 M) in methylene chloride at such a rate as to maitain the temperature during the addition below -60°C. The yellow slurry that formed was kept for an additional 20 minutes at -70°C. The resulting solution containing the E bromide (E-Br) was poured slowly into a vigorously stirred, chilled 10% hydrochloric acid (100 ml) solution. After shaking the mixture until it become clear, the aqueous layer was extracted with three 10-ml portions of ether. The combined organic extracts were washed successively with 10% hydrochloric acid (10 ml), saturated aqueous sodium carbonate and brine. After drying over $MgSO_4$ and filtration, the ethereal solution containing (*E*-1-Bromo-1-Octenyl)trimethylsilane was stirred under a UV sunlamp and treated three times

at room temperature (water bath, cooled as needed) with 0.50 ml of pyridine followed by 1.0 ml of a 1.0 M solution of bromine in methylene chloride after 0, 30, and 60 minutes during a 90-min period. The reaction mixture was decanted from the gummy residue and washed with 10% hydrochloric acid (70 ml), 20% aqueous cadmium chloride (to remove trace pyridine), water, 1M sodium hydroxide, and brine. After drying and distillation from a small amount of calcium carbonate, 6.32 g (80% yield) of (Z-1-bromo-1-octenyl)trimethylsilane was obtained.

Procedure for the preparation of *E*-1-methyl-2-hexyl-vinyltrimethylsilane [9] ***(Wurtz-Fittig reaction)*:** To a stirred suspension of 50 mmol of freshly drawn sodium wire in 30 ml of anhydrous ether under N_2 was added 30 mmol of methyl iodide. The resulting mixture was stirred at room temperature for 15 min, and then a solution of 20 mmol of (Z-1-bromo-1-octenyl)trimethylsilane in 20 ml of anhydrous ether was added dropwise. The mixture become warm during the addition. The resulting mixture , which gradually turned blue, was stirred at room temperature for 24 hr and then quickly filtered using anhydrous ether. The filtrate was washed with a saturated aqueous solution of Na_2CO_3 followed by water, then dried over $MgSO_4$, concentrated and distilled to give the title compound 2.49 g (12.6 mmol, 63% yield). NMR (ppm) $\delta_H(CDCl_3)$ 0.12 (9H, s, $SiMe_3$), 0.89 (3H, t, J = 6.3 Hz, CH_3), 1.28-1.34 (8H, m, CH_2), 1.75 (3H, s, CH_3), 2.04-2.09 (2H, m, CH_2), 5.97 (1H, m, CH), δ_C ($CDCl_3$) -0.10 (3C, $SiMe_3$), 14.09 (1C, CH_3), 22.65 (1C, CH_2), 24.64 (1C, CH_3), 29.1 (1C, CH_2), 30.18 (1C, CH_2), 31.85 (1C, CH_2), 31.99 (1C, CH_2), 134.26 (1C, *t*-C), 142.84 (1C, CH).

6.2.4. Synthesis of *cis*-allylsilanes

$$RC{\equiv}CH \quad + \quad I{-}CH_3 \xrightarrow[n\text{-BuLi}]{N_2\,/\,\text{Hexanes}} RC{\equiv}CCH_3$$



6.2.4.1 General procedure for the preparation of 2-alkyne: All apparatus must be thoroughly dried in a hot (>120°C) oven before use. 0.135 mol of the 1-alkyne and 50 ml of dry THF were placed in a dry, three-necked flask under nitrogen. 1.1 equivalent, 0.149 mol, 59.4 ml of a 2.5M solution of *n*-BuLi in hexanes was added dropwise using a gas tight syringe at room temperature over a 20 min period. The resulting reaction mixture was refluxed for 20 min, and then cooled to room temperature. 1.15 equivalent, 0155 mol, 22.036 g, 9.665 ml of iodomethane was added via the addition funnel. The resulting solution was stirred for 3 h at room temperature. 20 ml of water was added carefully to the flask and the mixture was stirred for 10 minutes. The aqueous phase was extracted with hexanes (3x20ml). The organic layers were dried over $MgSO_4$, and then passed through a 3 cm column of silica gel, and concentrated. The crude 2-alkyne was purified by distillation.

6.2.4.2 General procedure for the preparation of propargylsilanes[10]: All apparatus must be thoroughly dried in a hot (>120°C) oven before use. To a solution of *t*-BuLi (105mmol, 61.765 ml, 1.7 M in pentane), cooled to -78°C, were added sequentially with stirring ether(100 ml), TMEDA (100 mmol, 11.621 g, 15.092 ml), and the 2-alkyne (100 mmol) under nitrogen. The yellow slurry thus produced was allowed to rise to 0°C, and was stirred at this temperature for a further hour. The yellow solution was then cooled to -78°C, and treated dropwise with TMSCl (120 mmol, 13.037 g, 15.230 ml). The mixture, on reaching ambient temperature, was poured onto ice-water (100 ml), and the layers were separated. The aqueous layer was extracted with ether (3X100 ml), and

the combined extracts were washed with aqueous HCl (100 ml, 3M) and brine,and then dried. Concentration and distillation gave the product.

6.2.4.3 General Procedure for the preparation of *cis* allylsilanes[11]: All apparatus must be thoroughly dried in a hot (>120°C) oven before use. To a solution of 1-trimethylsilyl-2-alkyne (60 mmol) in hexane (60 ml) was added DIBALH (120 mmol, 17.066 g, 21.386 ml, neat) using a syringe, maintaining the reaction temperature at 25-30°C by means of a water bath. The solution was stirred at ambient temperature for 30 min. and then heated at 70°C for 4 hours. On cooling to ambient temperature, the reaction mixture was transferred, using a double-ended needle, to a vigorously stirred mixture of aqueous HCl (120 ml, 3 M), ice (120g) and pentane (60 ml). The mixture was stirred for a further 15 minutes. After separation, the aqueous layer was extracted with pentane (3X60 ml). The combined organic extracts were washed with water (100 ml) and brine (100 ml), and dried. Concentration and distillation gave the product.

Preparation of 1-trimethylsilyl-2-hexyne: See the general procedure 6.2.4.2 using 100 mmol, 8.215 g, 11.238 ml of 2-hexyne. The yield of the product is 71%. NMR(ppm) δ_H ($CDCl_3$) -0.08 (9H, s, $SiMe_3$), 0.96 (3H, t, J 7.3 Hz, CH_3), 1.41 (2H, t, J 2.7 Hz, CH_2-Si), 1.46-1.51 (2H, m, CH_2-Me), 2.14-2.09 (2H, m, CH_2-C), δ_C($CDCl_3$) -1.41 (3C, $SiMe_3$), 7.60 (1C, CH_2-Si), 14.17 (1C, CH_3), 21.65 (1C, CH_2-Me), 23.51 (1C, CH_2-C), 78.12 (1C, CH-CH_2-Si), 79.47 (1C, CH-CH_2).

Preparation of *cis*-1-trimethylsilyl-2-hexene: See the general procedure 6.2.4.3 using 60 mmol, 9.259 g of 1-trimethylsilyl-2-hexyne. The yield of the product is 84%. NMR (ppm) δ_H($CDCl_3$) 0.00 (9H, s, $SiMe_3$), 0.90 (3H, t, J 7.3 Hz, CH_3), 1.32-1.41 (2H, m, CH_2-Me), 1.47 (2H, d, J 8.8 Hz, CH_2-Si), 1.93-1.99 (2H, m, CH_2-CH), 5.24-5.30 (1H, m, CH-CH_2-Si), 5.43-5.36 (1H, m, CH), δ_C($CDCl_3$) -1.09 (3C, $SiMe_3$), 14.62 (1C, CH_3), 19.11 (1C, CH_2-Si), 23.64 (1C, CH_2-Me), 29.86 (1C, CH_2-CH), 126.09 (1C, CH-CH_2-Si), 128.23 (1C, CH).

Preparation of 2-heptyne: See the general procedure 6.2.4.1 using 0.135 mol, 11.090 g 15.511 ml, of 1-hexyne. The yield of the product is 67%. υ_{max}(neat film/cm^{-1}) 2959.0 (s, CH),2932.0 (s, CH_3), 2873.5 (m, CH_3), 2862.6 (m, CH_2), 2053.0 (very weak, CC), 1466.0 (m, CH), 1458.0 (m, CH); NMR(ppm) δ_H($CDCl_3$) 0.88 (3H, t, CH_3), 1.47-1.32 (4H, m, CH_2), 1.75 (3H, t, CH_3-CC), 2.12-2.07 (2H, m, CH_2-CC), δ_C($CDCl_3$) 3.85 (1C, CH_3-CC), 14.06 (1C, CH_3), 18.87 (1C, CH_2), 22.42 (1C, CH_2), 31.67 (1C, CH_2), 75.71 (1C, *t*-C-Me), 79.77 (1C, *t*-C-C_4).

Preparation of 1-trimethylsilyl-2-heptyne [10]: See the general procedure 6.2.4.2 using 100 mmol, 9.617 g, of 2-heptyne. The yield of the product is 73%. υ_{max}(neat film/cm^{-1}) 2957.6 (s, CH), 2933.3 (m, CH_3), 2875.6 (w, CH_3), 2863.9 (w, CH_2), 2222.0 (very weak, CC), 1466.8 (w, CH), 1458.9 (w, CH_2), 1249.0 (s, SiMe) and 850.6 (s, $SiMe_3$); NMR(ppm) δ_H($CDCl_3$) 0.08 (9H, s, $SiMe_3$), 0.89 (3H, t, J 7.4 Hz, CH_3), 1.37-1.47 (6H, CH_2), 1.41 (2H, t, J 2.7 Hz, CH_2-Si), 2.11-2.15 (2H, m, CH_2), δ_C($CDCl_3$) -1.63 (3C, $SiMe_3$), 7.40 (1C, CH_2-Si), 1410 (1C, CH_3), 19.07 (1C, CH_2), 22.40 (1C, CH_2), 32.04 (1C, CH_2), 77.72 (1C, *t*-C-CH_2-Si) and 79.38 (1C, *t*-C).

Preparation of *cis*-1-trimethylsilyl-2-heptene [11]: See the general procedure 6.2.4.3 using 60 mmol, 10.101 g of 1-trimethylsilyl-2-heptyne. The yield of the product is 81%. υ_{max}(neat film/cm^{-1}) 3007.4 (m,), 2957.0 (s, CH), 2927.8 (s, CH_3), 2874.4 (m, CH_3), 2860.8 (m, CH_2), 1466.6(w, CH), 1458.6 (w, CH_2), 1248.7 (s, SiMe), 1151.3 (m,), 854.8 (vs, $SiMe_3$), 840.9 (vs, $SiMe_3$), 725.9 (m,), 699.7 (m,); NMR(ppm) δ_H($CDCl_3$) 0.04 (9H, s, $SiMe_3$), 0.90 (3H, t, J 6.4 Hz, CH_3), 130-1.36 (4H, m, CH_2), 1.47 (2H, d, J 8.3 Hz, CH_2-Si), 1.99 (2H, m, CH_2), 5.23-5.35 (1H, m, CH-CH_2-Si), 5.34-5.43 (1H, m, CH), δ_C($CDCl_3$) -1.29 (3C, $SiMe_3$), 14.55 (1C, CH_3), 18.89 (1C, CH_2-Si), 23.00 (1C, CH_2), 27.28 (1C, CH_2), 32.55 (1C, CH_2), 125.71 (1C, CH-C-Si), 128.23 (1C, CH);

Preparation of 2-octyne: See the general procedure 6.2.4.1 using 0.135 mol 12.983 g, 17.71 ml of 1-heptyne. The yield of product is 83%. NMR(ppm) δ_H($CDCl_3$)0.89 (3H,

t, 6.8 Hz, CH_3), 1.28-1.48 (6H, m, CH_2), 1.77 (3H, t, J 2.4 Hz, CH_3), 2.13-2.08 (2H, m, CH_2), $\delta_C(CDCl_3)$ 4.07 (1C, CH_3-CC) ,14.66 (1C, CH_3) ,19.38 (1C, CH_2), 22.95 (1C, CH_2), 29.49 (1C, CH_2), 31.80 (1C, CH_2-C), 75.96 (1C, C-CH_3), 80.10 (1C, C-CH_2).

Preparation of 1-trimethylsilyl-2-octyne [10]: See the general procedure 6.2.4.2 using 100 mmol, 11.020 g of 2-octyne. The yield of the product is 71%. NMR(ppm), $\delta_H(CDCl_3)$ 0.08 (9H,s, $SiMe_3$), 0.89 (3H, t, J 7.1 Hz, CH_3), 1.30-1.47 (10H, m, CH_2), 1.41 (2H, t, J 2.7 Hz, CH_2-Si), 2.11-2.15 (2H, m, CH_2-C), $\delta_C(CDCl_3)$ -2.11 (3C, $SiMe_3$), 6.92 (1C, CH_2-Si), 14.02 (1C, CH_3), 18.86 (1C, CH_2), 22.23 (1C, CH_2), 31.06 (1C, CH_2-C), 77.27 (1C, C-CH_2-Si), 78.96 (1C, C-CH_2).

Preparation of *cis*-1-trimethylsilyl-2-octene [11]: See the general procedure 6.2.4.3 using 60 mmol 10.943 g of 1-trimethylsilyl-2-octyne. The yield of the product is 71%.

Preparation of 2-nonyne: See the general procedure 6.2.4.1 using 0.135 mmol, 14.877 g 19.916 ml of 1-octyne. The yield of product is 83%. υ_{max}(neat film/cm^{-1}) 2958.0 (s, CH), 2931.0 (s, CH_3), 2872.0 (s, CH_3), 2859.3 (s, CH_2), 2052.7 (very weak, CC), 1466.7 (m, CH), 1458.7 (m, CH_2); NMR (ppm) $\delta_H(CDCl_3)$ 0.856 (3H, t, J 5.7 Hz, CH_3-CH_2), 1.73 (3H, t, J 2.5 Hz, CH_3-C), 2.03-2.09 (2H, m, CH_2-C), $\delta_C(CDCl_3)$ 3.84 (1C, CH_3-C), 14.52 (1C, CH_3-CH_2), 19.29 (1C, CH_2), 21.93 (1C, CH_2), 23.14 (1C, CH_2), 29.17 (1C, CH_2), 31.99 (1C, CH_2-C), 75.70 (1C, C-CH_3), 79.84 (1C, C-CH_2).

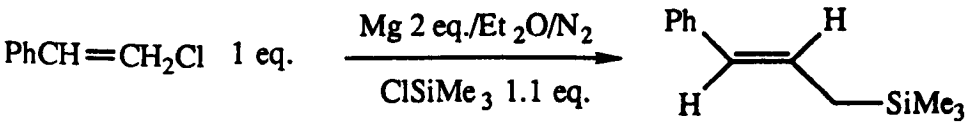
Preparation of 1-trimethylsilyl-2-nonyne [10]: See the general procedure 6.2.4.2 using 100 mmol, 12.423 g of 2-nonyne. The yield of the product is 83%. υ_{max}(neat film/cm^{-1}) 2957.0 (s, CH), 2931.0 (s, CH_2), 2874.4 (s, CH_3), 2859.1 (s, CH_2), 2222.3 (very weak, CC), 1467.0 (w, CH), 1458.9 (w, CH_2), 1249.2 (s, SiMe), 851.3 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ 0.08 (9H, s, $SiMe_3$), 0.89 (3H, t, J 8.6 Hz, CH_3), 1.41 (2H, t, J 2.7 Hz, CH_2-Si), 1.24-1.47 (8H, m, CH_2), 2.15-2.10 (2H, m, CH_2-C),

$\delta_C(CDCl_3)$-2.13 (3C, $SiMe_3$), 6.90 (1C, CH_2-Si), 14.03 (1C, CH_3), 18.90 (1C, CH_2), 22.61 (1C, CH_2), 28.54 (1C, CH_2), 29.42 (1C, CH_2), 31.41 (1C, CH_2-C), 77.24 (1C, C-CH_2-Si), 78.94 (1C, C-CH_2).

Preparation of *cis*-1trimethylsilyl-2-nonene [11]: See the general procedure 6.2.4.3 using 60 mmol, 11.784 g of 1-trimethylsilyl-2-nonyne. The yield of the product is 76%. υ_{max} (neat film/cm^{-1}) 3006.9 (m,), 2956.0 (s, CH), 2926.0 (s, CH_3), 2873.4 (m, CH_3), 2856.6 (m, CH_2), 1645.3 (vw, C=C), 1467.0 (w, CH), 1459.5 (w, CH_2), 1248.5 (s, SiMe), 1151.9 (m,), 854.7 (vs, $SiMe_3$), 720.2 (w,), 701.5 (w,), 662.4 (w); NMR (ppm) $\delta_H(CDCl_3)$ 0.01(9H, s, $SiMe_3$), 0 .89 (3H, t, J 6.3 Hz, CH_3), 5.42-5.34 (1H, m, CH), 1.23-1.35 (8H, m, CH_2), 1.46 (2H, d, J 8.3 Hz, CH_2-Si), 1.95-2.00 (2H, m, CH_2-CH), 5.31-5.23 (1H, m, CH-CH_2-Si), $\delta_C(CDCl_3)$ -1.09 (3C, $SiMe_3$), 14.81 (1C, CH_3), 19.11 (1C, CH_2-Si), 23.38 (1C, CH_2), 27.79 (1C, CH_2), 29.86 (1C, CH_2), 30.52 (1C, CH_2), 32.55 (1C, CH_2-CH), 125.89 (1C, CH-CH_2-Si), 128.50 (1C, CH).

6.2.5. Preparation of *trans*-allylsilanes

Preparation of *trans*-trimethyl-3-phenylallylsilane [12]



A Modified Procedure: All apparatus must be thoroughly dried in a hot (>120°C) oven before use. Oven dried magnesium turnings (2 equivalent, 12.2 g, 0.5 mol), a small crystal of iodine, chlorotrimethylsilane (1.2 equivalent, 0.3 mol, 33.3 g, 38.9 ml), and dry THF (350 ml) were placed in a 1000 ml three necked, round-bottomed flask fitted with a double face condenser, a nitrogen bubbler, a magnetic stirrer bar, and a 250 ml dropping funnel. A few drops of cinnamyl chloride were added and after reaction had commenced, a solution of cinnamyl chloride [1 equivalent, 0.25 mol, 38.8 g (95% purity)], and dry THF (100 ml) was added dropwise. The mixture was stirred overnight.

Distilled water was added dropwise with cooling (ice-water cooling bath) and the mixture was extracted with ether (3 X 200ml). The combined extracts were dried over magnesium sulphate, concentrated and distilled under reduced pressure (0.05 mmHg, bp 77-79°C) to give 42.2 g (88.7%) (literature yield less than 50%) of *trans*-trimethyl-3-phenylallylsilane. υ_{max}(neat film/cm^{-1}) 3081.5 (w, Ar CH), 3060.5 (w,Ar CH), 3024.1 (w, Ar CH), 2954.9 (m, CH), 2896.3 (w, CH_3), 1642.5 (w, C=C), 1598.7 (w, Ar C=C), 1495.9 (w, Ar C=C) 1447.9 (w, Ar C=C), 1405.6 (w), 1248.0 (s, SiMe), 1147.9 (m), 1021.5 (w, Ar CH), 961.5 (m, CH), 862.1 (s, $SiMe_3$), 844.5 (s, $SiMe_3$), 758.9(w, Ar CH), 740.2 (m, Ar CH), 693.7 (s, Ar CH); NMR(ppm) $\delta_H(CDCl_3)$ 0.09 (9H, s, $SiMe_3$) ,1.70-1.72 (2H, m, CH_2), 6.27-6.30 (2H, m, CH), 7.36-7.17 (5H, m, Ph), $\delta_C(CDCl_3)$ -1.86 (3C, $SiMe_3$), 23.93 (1C, CH_2), 125.48 (2C, Ar CH), 126.16 (1C, Ar CH), 127.80 (=CH-CH_2), 128.23 (1C, =CH-Ph), 128.41 (2C, Ar CH), 138.48 (1C, Ar *t*-C); m/z(EI) 190 (12%, M^+), 175 (3, M-Me), 77 (8, C_6H_5), 59 (13, $HSiMe_2$); (Found: C, 74.84, H, 9.37, $C_{12}H_{18}Si$ requires C, 75.71, H, 9.53%).

§ 6.3 Asymmetric dihydroxylation of allyl- and vinylsilanes

All silyldiols were prepared using the Sharpless asymmetric dihydroxlation [13] procedure. A typical procedure [14] involved: A 25mL round bottomed flask, equipped with magnetic stirrer, was charged with 5ml of *tert*-butyl alcohol, 5ml of water, and 1.4 g of AD-mix-α or AD-mix-β. Stirring at room temperature produced two clear phases; the lower aqueous phase appears bright yellow. [Methanesulfonamide(95 mg, 1 equivalent based on 1mmol of olefin) was added at this point only if the olefin is trisubstituted or 1,2-disubstituted. No $CH_3SO_2NH_2$ should be added for terminal olefins]. The mixture was cooled to 0°C when some of the dissoluted salts precipitated. One mmol of olefin was added at once, and the heterogeneous slurry was stirred vigorously at 0°C for 24 hours. While the mixture was stirred at 0°C, solid sodium sulphite (1.5 g) was added and the mixture was allowed to warm to room temperature and stirred for 30-60 min. Methylene chloride(10mL) was

added to the reaction mixture, and after separation of the layers, the aqueous phase was further extracted with the organic solvent (3X5 ml) (when methanesulfonamide was used, the combined organic layers were washed with 2M KOH). The combined organic extracts were dried over anhydrous magnesium sulphate and concentrated to give the diol and the ligand. This crude product was purified by flash chromatography (silica gel, CH_2Cl_2/Et_2O, 3 / 2, the ligand does not move in this solvent system) to afford the 1,2-silyldiol in 80% or more yield. 2-Trimethylsilyl-nonylene-2,3-diol was made using modified conditions, instead of the normal 0°C for about 24 hours the reaction mixture was left at room temperature for 7 days .

The following data refer to reaction with AD-mix-β. The physical properties of the products from reaction with AD-mix-α were identical apart from the e.e. which are given in Table 2-4.

3-Trimethylsilyl-1,2-diol [14] The title compound (122 mg, 83% yield, 34%e.e.) was prepared from allyltrimethylsilane (114mg) and AD-mix-β. The reaction mixture was kept at 0°C for 14 h and worked up in the usual way. The product was separated by preparative TLC (SiO_2, CH_2Cl_2/Et_2O, 3 / 2); Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.57; υ_{max}(neat film/cm^{-1}) 3399.8 (s, br, OH) 2953.7 (s, CH), 1248.8 (s, SiMe), 1117 0 (m, C-O), 1082.5 (m, C-O), 1032.7 (w, C-O), 863.6 (s $SiMe_3$), 839.9 (s, $SiMe_3$); NMR(ppm) $\delta_H(CDCl_3)$ 0.05 (9H, s, $SiMe_3$), 0.71($1H^a$, dd, J 14.0 Hz, J 8.0 Hz CH_2-Si), 2.35 ($1H^b$, dd, J 14.0 Hz, J 8.0 Hz, CH_2-Si), 2.35(2H, br, OH), 3.34 ($1H^a$, dd, J 11.0 Hz, J 8.0 Hz CH_2OH), 3.60 ($1H^b$, dd, J 11.0 Hz, J 3.0 Hz, CH_2OH), 3.87 (1H, m, CHOH), $\delta_C(CDCl_3)$ -0.85 (3C, $SiMe_3$), 21.64 (1C, CH_2), 68.97 (1C, CH_2), 70.25 (1C, CH); m/z(FAB) 147(13.5%, M-H), 115 (8, M-H_2O-CH_3), 102 (100, M-H_2O-CHOH), and 73 (44, $SiMe_3$).

***erythro*-1-Trimethylsilylhexane-2,3-diol** [14]. The title compound (158 mg, 83% yield, 54%e.e.) was prepared from 1-trimethylsilylhex-2-ene (156 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 24 h and work up in the usual way. Rf

(CH_2Cl_2/Et_2O, 3 / 2) 0.75; υ_{max} (neat film/cm^{-1}) 3382.0(s, br, OH), 2957.0 (s, CH), 2935.0 (s, CH), 1249.0 (s, SiMe), 1054.5 (w, C-O), 1029.0 (w, C-O), 863.0 (s, $SiMe_3$), 840.0 (s, $SiMe_3$); NMR(ppm) $\delta_H(CDCl_3)$ 0.06 (9H, s, $SiMe_3$), 0.66 ($1H^a$, dd, J 15 Hz, J 4 Hz, CH_2-Si), 0.81 ($1H^b$, dd, J 15.0 Hz, J 10.0 Hz, CH_2-Si), 0.95 (3H, t, J 6.8 Hz, CH_3), 1.34 ($1H^a$, m, CH_2-COH), 1.40 (2H, m, CH_2), 1.53 ($1H^b$, m, CH_2-COH), 1.81 (2H, br, OH), 3.56 (1H, m, CH-C-Si), and 3.79 (1H, m, CH-C_3H_7), $\delta_C(CDCl_3)$ -0.316 (3C, $SiMe_3$), 14.61 (1C, CH_3), 19.31 (1C, CH_2-Si), 19.67 (1C, CH_2), 33.88 (1C, CH_2), 73.13 (1C, CH) and 76.31 (1C, CH-C-Si); m/z (FAB) 189 (4%, M-H), 157 (20, M-H_2O-CH_3), 117 [20, M-$CH_3(CH_2)CHOH$], 73 (100, $SiMe_3$) (Found: C 56.49, H, 11.61. $C_9H_{22}O_2Si$ requires C, 56.79, H, 11.65%).

***erythro*-1-Trimethylsilylnonane-2,3-diol** [14] The title compound(186 mg, 81% yield, 43%e.e.) was prepared from 1-trimethylsilylnon-2-ene (198 mg) and AD-mix-β (1.4 g) then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2), 0.81; υ_{max}(neat film/cm^{-1}) 3399.4 (s, br, OH), 2955.0 (s, CH), 2928.0 (s, CH_2), 2873.5 (m, CH_3), 2858.5 (s, CH_2), 1248.2 (s, $SiMe_3$), 1058.0 (w, C-O), 1045.6 (w, C-O), 861.5 (s, $SiMe_3$), 840.0 (s, $SiMe_3$); NMR(ppm) $\delta_H(CDCl_3)$, 0.06 (9H, s, $SiMe_3$), 0.66 ($1H^a$, dd, J 15.0 Hz, J 4.0 Hz, CH_2-Si), 0.80 ($1H^b$, dd, J 15.0 Hz, J 10.0 Hz, CH_2-Si), 0.88 (3H, t, J 6.8 Hz, CH_3), 1.39 [10H, m, $(CH_2)_5$], 1.87 (2H, br, OH), 3.53 [1H,,m,C_6-CH(OH)] and 3.79 (1H, m, CH-C-Si), $\delta_C(CDCl_3)$ -0.01 (3C, $SiMe_3$), 14.86 (1C, CH_3), 19.60 (1C, CH_2-Si), 23.40 (1C, CH_2), 26.79 (1C, CH_2), 30.19 (1C, CH_2), 32.05 (1C, CH_2), 32.58 (1C, CH_2), 73.42 (1C, CH-C_6), 76.93 (1C, CH-C-Si); m/z (FAB) 231 (3%,M-H), 199 (37, M-H_2O-CH_3), 125 (26, M-H_2O-CH_2SiMe_3) and 73 (100, $SiMe_3$) (found: C, 63.79, H, 9.07, $C_{12}H_{28}O_2Si$ requires C, 64.24, H, 8.98%).

***threo*-1-Phenyl-3-trimethylsilylpropane-1,2-diol** [14] The title compound (193 mg, 86% yield, 95%e.e.) was prepared from 1-phenyl-3-trimethylsilylprop-ene (190 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 28 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3;2) 0.81; υ_{max}(film/cm^{-1}) 3382.6 (s, br, OH), 2952.6 (m, CH), 2919.8 (w, CH_3), 2895.5 (m, CH_3), 1494.3 (w, Ar C=C), 1454.2 (w,

Ar C=C), 1247.9 (s, SiMe), 1209.3 (w, OH), 1071.4 (m, C-O), 1052.7 (m, C-O), 951.2 (m, CH), 862.7 (s, $SiMe_3$), 839.9 (s, $SiMe_3$), 762.7 (s, Ar CH), 701.3 (s, Ar CH); NMR(ppm) $\delta_H(CDCl_3)$ 0.01 (9H, s, $SiMe_3$), 0.56 ($1H^a$, dd, J 15.0 Hz, J 3.0 Hz, CH_2-Si), 0.75 ($1H^b$, dd, J 14.0 Hz, J 11.0 Hz, CH_2-Si), 2.33 (1H, br, OH), 2.65 (1H, br, OH), 3.85 (1H, m, CH-C-Si), 4.37 (1H, d, J 6.0 Hz, CH-Ph) 7.33 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.39 (3C, $SiMe_3$), 21.23 (1C, CH_2-Si), 74.54 (1C, CH-C-Si), 80.87 (1C, CH-Ph), 127.41 (2C, Ph), 128.34 (1C, Ph), 128.87 (2C, Ph) and 141.91 (1C, *t*-C, Ph); m/z (FAB) 223 (2%, M-H), 207 (8, M-OH), 191 (10, M-H_2O-CH_3), 117 (87, M-PhCHOH) and 73 (80, $SiMe_3$) (Found: C, 64.51, H, 8.72, $C_{12}H_{20}O_2Si$ requires C, 64.24, H, 8.89%).

***erythro*-1-Trimethylsilyloctane-2,3-diol** [14]. The title compound (181 mg, 82% yield, 53%e.e.) was prepared from 1-trimethylsilyloct-2-ene (184 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 24 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.81; υ_{max}(neat film/cm^{-1}) 3407.2 (s, br, OH), 2956.0 (s, CH), 2931.8 (s, CH_3), 2873.7 (m, CH_3), 2861.1 (m, CH_2), 1248.6 (s, SiMe), 1052.3 (m, C-O), 1033.7 (m, C-O), 861.7 (s, $SiMe_3$), 840.6 (s, $SiMe_3$); NMR(ppm) $\delta_H(CDCl_3)$ 0.06 (9H, s, $SiMe_3$), 0.66 ($1H^a$, dd, J 15.0 Hz, J 4.0 Hz, CH_2-Si), 0.80 ($1H^b$, dd, J 15.0 Hz, J 11.0 Hz, CH_2-Si), 0.89 (3H, t, J 7.0 Hz, CH_3), 1.38 [8H, m, $(CH_2)_4$], 1.84 (2H, br, OH), 3.54 (1H, m, C_5-CH) and 3.79 (1H, m, CH-C-Si), $\delta_C(CDCl_3)$ -0.315 (3C, $SiMe_3$), 14.52 (1C, CH_3), 18.77 (1C, CH_2), 19.27 (1C, CH_2-Si), 23.08 (1C, CH_2), 26.20 (1C, CH_2), 31.69 (1C, CH_2), 32.40 (1C, CH_2); m/z (FAB) 217 (3%, M-H), 199 (14, M-H-H_2O), 185 (23, M-H_2O-CH_3), 147 (20, M-C_5H_{11}), 111 (28, $C_5H_{11}COC$) and 73 (100, $SiMe_3$) (Found: C, 60.65, H, 11.95, $C_{11}H_{26}O_2Si$ requires C, 60.49, H, 12.00%).

1-Trimethylsilylethane-1,2-diol [14]. The title compound (107 mg, 80% yield, 34%e.e.) was prepared from vinyltrimethylsilane (100 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 14 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.51; υ_{max}(neat film/cm^{-1}) 3368.4 (s, br, OH), 2956.0 (m, CH), 2902.3

(w, CH_3), 1249.9 (s, SiMe), 1065.5 (m, C-O), 995.2 (w, C-O), 881.9 (s, $SiMe_3$), 840.5 (s, $SiMe_3$); NMR(ppm) $\delta_H(CDCl_3)$ 0.07 (9H, s, $SiMe_3$), 2.26 (2H, br, OH), 3.46 (1H, m, CH-Si) and 3.73 (2H, m, CH_2), $\delta_C(CDCl_3)$ -2.89 (3C, $SiMe_3$), 65.52 (1C, CH_2) and 68.21 (1C, CH); m/z (FAB) 135 (12%, $M+H^+$), 117 (23, $M-H_2O$) and 73 (100, $SiMe_3$).

1-Dimethylphenylsilylethane-1,2-diol [14]. The title compound (163 mg, 83% yield, 27%e.e.) was prepared from vinyldimethylphenylsilane (162 mg and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 48 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.73; υ_{max}(neat film/cm^{-1}) 3367.2 (s, br,OH), 3069.9 (w, Ar CH), 3050.6 (w, Ar CH), 2959.3 (m, CH), 1428.2 (m, SiPh), 1250.8 (s, SiMe), 1112.9 (m, SiPh), 1068.0 (m, C-O), 1002.0 (w, C-O), 876.9 (s, $SiMe_3$), 833.8 (s, $SiMe_3$), 817.1 (s, Ar, CH), 785.1 (s, Ar, CH), 734.5 (s, Ar, CH), 700.1 (s, Ar, C=C); NMR(ppm) $\delta_H(CDCl_3)$0.37 [3H, s, $Si(Me)_A$], 0.38 [3H, s, $Si(Me)_B$], 2.07 (2H, br, OH), 3.63-3.76 (3H, m, $CHCH_2$), 7.37-7.62 (5H, m, Ph), $\delta_C(CDCl_3)$ -4.83 (1C, SiMe), -4.80 (1C, SiMe), 66.07 (1C, CH_2), 67.83 (1C, CH-Si), 128.47 (2C, Ph), 130.02 (1C, Ph), 134.50 (2C, Ph) and 136.46 (1C, t-C, Ph); m/z (FAB) 393 (2%, M_2H^+), 197 (3, MH^+), 195 (5, $M-H^+$), 135 (100, $SiMe_2Ph$) (Found: C, 61.35, H, 8.15. $C_{10}H_{16}Si$ requires C, 61.18, H, 8.21%).

1-Diphenylmethylsilylethane-1,2-diol [14]. The title compound (80mg, 30% yield, 0%e.e.) was prepared from vinyldiphenylmethylsilane (258 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 62 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.62; υ_{max}(film/cm^{-1}) 3375 (br, OH),1428.4 (m, SiPh), 1250.0 (s, SiMe), 1113.7 (s, SiPh), 791.3 (s, Ar CH), 731.3 (s, Ar CH), 699.1 and (s, Ar C=C); NMR(ppm) $\delta_H(CDCl_3)$ 0.64 (3H, s, SiMe), 2.11 (2H, br, OH), 3.79 (2H, dd, J 9.0 Hz, J 4.0 Hz, CH_2-C), 4.05 (1H, dd, J 8.0 Hz, J 4.0 Hz,CH-Si) and 36-7.45 (5H, m, Ph); m/z (FAB) 257 (4%, $M-H^+$), 255 (5, $M-2H^+$), 241 (2, M-OH) and 197 (82, $SiPh_2Me$).

1-Triphenylsilyl-1,2-diol [14]. The title compound (80 mg, 25% yield, 0%e.e.) was prepared from vinyltriphenylsilane (286 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 96 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.5; υ_{max}(nujol/cm-1) 3354.0 (br, OH), 1427.6 (s, SiPh), 1110.1 (s, $SiPh_3$) and 699.5 (s, Ar C=C); NMR(ppm) δ_H($CDCl_3$) 2.12 (2H, br, OH), 3.92 (2H, d, J 6.0 Hz,CH_2-C), 4.36 (1H, t, J 6.4 Hz, CH-Si) and 7.35-7.36 (15H, m, Ph), δ_C($CDCl_3$) 65.65 (1C, CH_2), 67.17 (1C, CH-Si), 128.58 (6C, Ph), 130.46 (3C, Ph), 132.80 (3C, *t*-C, Ph), 136.55 (6C, Ph); m/z (FAB) 319 (6%, M-H^+) and 259 [81, $Si(Ph)_3$] (Found: C, 74.85, H, 6.30. $C_{20}H_{20}Si$ requires C, 74.96, H, 6.29%).

***threo*-1-Trimethylsilylhexane-1,2-diol** [14] The title compound (160 mg, 76% yield, 96%e.e.) was prepared from *E*-1-trimethylsilylhex-1-ene (156 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 24 h and worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3;2) 0.74; υ_{max}(neat film/cm^{-1}) 3399.8 (br, OH), 1249.0 (s, SiMe), 858.4 (s, CH) and 839.5 (s, CH); NMR(ppm) δ_H($CDCl_3$) 0.09 (9H, s, $SiMe_3$), 0.91 (3H, t, J 6.8 Hz, CH_3), 1.31-1.59 [6H, m, $(CH_2)_3$], 1.85 1H, br, OH), 2.03 (1H, br, OH), 3.17 (1H, d, J 6.2 Hz, CH-Si) and 3.67 (1H, m, CH-C_4), δ_C($CDCl_3$) -2.92 (3C, $SiMe_3$), 14.00 (1C, CH_3), 22.63 (1C, CH_2), 27.99 (1C, CH_2), 33.80 (1C, CH_2), 69.36 (1C, CH-Si), 73.42 (1C, CH-C_4); m/z (FAB) 189 (3%, M-H^+), 173 (17, M-OH), 133 (28, M-C_4H_9) and 73 (100, $SiMe_3$) (Found: C, 55.25, H, 11.15. $C_9H_{22}O_2Si$ requires C, 56.79, H, 11.65%).

***threo*-1-Trimethylsilyl-2-Phenylethane-1,2-diol** [14]. The title compound (175 mg, 83% yield, 97%e.e.) was prepared from *E*-trimethylsilylstyrene (176 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 28 h and worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.82; υ_{max}(film/cm^{-1}) 3324.5 (br, OH), 1249.8 (s, SiMe), 842.7 (s, $SiMe_3$), 599.6 (s, Ar C=C); NMR(ppm) δ_H($CDCl_3$) 0.10 (9H, s, $SiMe_3$), 3.49 (1H, d, J 7.0 Hz, CH-Si), 4.73 (1H, d, J 7.0 Hz, CHPh) and 7.28-7.37 (5H, m, Ph), δ_C($CDCl_3$) -2.88 (3C, $SiMe_3$), 71.25 (1C, CH-Si), 76.99 (1C, CH-Ph), 127.43 (2C, Ph), 128.73 (1C, Ph), 129.05 (2C, Ph) and 141.91 (1C, t-C, Ph); m/z

(FAB) 209 (1%, M-H^+), 207 (2, M-3H^+), 193 (35, M-OH), 103[15, M-PhCH(OH)] and 73 (100, $SiMe_3$) (Found: C, 62.25, H, 8.65. $C_{11}H_{18}O_2Si$ requires C, 62.81, H, 8.62%).

***erythro*-1- Trimethylsilyloctane-1,2-diol [14].** The title compound (177 mg, 81% yield, 61%e.e.) was prepared from *Z*-1-trimethylsilyloct-1-ene (184 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 26 h and worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.80; υ_{max}(neat film/cm^{-1}) 3418.7 (br, OH), 2955.0 (s, CH), 2928.0 (s, CH_3), 2859.0 (m, CH_2), 1250.3 (s, SiMe) and 841.2 (s, $SiMe_3$); NMR(ppm) δ_H($CDCl_3$) 0.11 (9H, s, $SiMe_3$), 0.88 (3H, t, J 6.7 Hz, CH_3), 1.21-1.63 (10H, m, CH_2), 2.18 (2H, br, OH), 3.78-3.82 (1H, m, CH-C_6) and 4.32 (1H, d, J 4.0 Hz, CH-Si), δ_C($CDCl_3$) -2.02 (3C, $SiMe_3$), 14.57 (1C, CH_3), 23.09 (1C, CH_2), 26.79 (1C, CH_2), 29.73 (1C, CH_2), 32.29 (1C, CH_2), 33.63 (1C, CH_2), 71.43 (1C, CH-Si) and 75.51 (1C, CH); m/z (FAB-) 217 (15%, M-H^+), 199 (12, M-H_2O-H^+), 159 (32, M-H_2O-$C_3H_4^{+\cdot}$), 127 (42, $C_8H_{15}O$), 89 (79, $OSiMe_3$), and 73 (10, $SiMe_3$); (Found: C, 60.67, H, 11.95. $C_{11}H_{26}O_2Si$ requires C, 60.49, H, 12.00%).

2-Trimethylsilylnonane-2,3-diol [14]. The title compound (123 mg, 53% yield, 85%e.e.) was prepared from *E*-2-trimethylsilylnon-2-ene (198 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 20°C for 168 h and worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.83; υ_{max}(net film/cm^{-1}) 3439.0 (br, OH), 2956.2 (s, CH), 2927.8 (s, CH_3), 2858.6 (m, CH_2), 1249.0 (m, SiMe) and 839.4 (s, $SiMe_3$); NMR(ppm) δ_H($CDCl_3$) 0.10 (9H, $SiMe_3$), 0.88 (3H, t, J 6.8 Hz, CH_3), 1.18 (3H, s, CH_3), 1.22-1.56 (10H, m, CH_2), 2.06 (2H, br, OH), and 3.42 (1H, dd, J 10.0 Hz, J 2.0 Hz, CH), δ_C($CDCl_3$) -1.815 (3C, $SiMe_3$), 14.57 (1C, CH_3), 22.51 (1C, CH_3), 23.11 (1C, CH_2), 27.50 (1C, CH_2), 29.79 (1C, CH_2), 32.33 (1C, CH_2), 33.30 (1C, CH_2), 70.44 (1C, t-C), 80.85 (1C, CH); m/z (FAB) 231 (3%, M-H^+), 215 (64, M-OH), 199 (6, M-H_2O-CH_3), 143 (29, M-C_6H_{13}-4H^+), 91 (80, $SiMe_3$+H_2O) and 73 (100, $SiMe_3$) (Found: C, 62.91, H, 11.86. $C_{12}H_{26}O_2Si$ requires C, 62.90, H, 12.14%).

***threo*-1-Trimethylsilyloctane-1,2-diol.** The title compound (190 mg, 87% yield, 96%e.e.) was prepared from *E*-1-trimethylsilyloct-1-ene (182 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 26 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.60; υ_{max}(neat film/cm^{-1}) 3402.0 (br, OH), 2956.0 (s, CH), 2930.0 (s, CH_3), 2858.0 (s, CH_2), 1467.0 (w, CH), 1408.0 (w, CH_2), 1249.0 (s, SiMe), 1127.0 (w,), 1065.0 (w, C-O), 840.0 (s, $SiMe_3$), 753.0 (w,), 694.0 (w); NMR(ppm) δ_H($CDCl_3$) 0.09 (9H, s, $SiMe_3$), 0.88 (3H, t, J 7.0 Hz, CH_3), 1.28-1.50 (10H, m, CH_2), 1.92 (1H, br, OH), 2.09 (1H, br, OH), 3.17 (1H, d, J 5.6 Hz, CH-Si), 3.65-3.70 (1H, m, CH), δ_C($CDCl_3$) -2.47 (3C, $SiMe_3$), 14.55 (1C, CH_3), 23.08 (1C, CH_2), 26.29 (1C, CH_2), 29.75 (1C, CH_2), 32.29 (1C, CH_2), 34.65 (1C, CH_2), 69.87 (1C, CH-Si) and 73.99 (1C, CH); m/z (FAB-) 217 (9%, $M-H^+$), 198 (19, $M-2H^+-H_2O$), 127 (60, $C_6H_{15}OSi$), 89 (77, $OSiMe_3$), 73 (7, $SiMe_3$), 59 (9, $HSiMe_2$) (Found: C, 60.07, H, 12.04. $C_{11}H_{26}O_2Si$ requires C, 60.49, H, 12.00%).

***threo*-1-Trimethylsilylheptane-1,2-diol.** The title compound (182 mg, 89% yield, 96%e.e.) was prepared from *E*-1-trimethylsilyl-1-heptene (170 mg) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 24 h and then worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.63; υ_{max}(neat film/cm^{-1}) 3390.3 (br, OH), 2956.4 (s,CH), 2932.4 (s, CH_3), 2873.2 (m, CH_3), 2960.2 (m, CH_2), 1467.0 (w, CH), 1459.2 (w, CH_2), 1249.0 (s, SiMe), 1052.2 (w, C-O), 1001.9 (w, C-O), 859.8 (s, $SiMe_3$) and 839.4 (s, $SiMe_3$); NMR(ppm) δ_H($CDCl_3$) 0.10 (9H, s, $SiMe_3$), 0.89 (3H, t, J 6.8 Hz, CH_3), 1.25-1.80 (8H, m, CH_2), 1.79 (1H, br, OH), 1.96 (1H, br, OH), 3.17 (1H, d, J 6.4 Hz, CH-Si) and 3.66-3.70 (1H, m, CH), δ_C($CDCl_3$) -2.47 (3C, $SiMe_3$), 14.53 (1C, CH_3), 23.13 (1C, CH_2), 26.04 (1C, CH_2), 32.31 (1C, CH_2), 34.65 (1C, CH_2), 69.91 (1C, CH-Si) and 74.01 (1C, CH); m/z (FAB-) 408 (4%, dimer), 203 (12, $M-H^+$), 185 (22, $M-H^+-H_2O$), 113 (80, $C_7H_{13}O$), 89 (100, $OSiMe_3$), 73 (8, $SiMe_3$), 59 (15, $HSiMe_2$) (Found: C, 58.95, H, 11.80. $C_{10}H_{24}O_2Si$ requires C, 58.77, H, 11.84%).

***erythro*-1-Trimethylsilylheptane-1,2-diol.** The title compound (175 mg, 86%yield, 61%e.e.) was prepared from *Z*-1-trimethylsilyl-1-heptene (170 mg) and AD-

mix-β (1.4 g). The reaction mixture was kept at 0°C for 24 h and worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.63; υ_{max}(neat film/cm^{-1}) 3398.5 (br, OH), 2956.3 (s, CH), 2932.9 (s, CH_3), 2873.2 (m, CH_3), 2859.9 (m, CH_2), 1467.0 (w, CH), 1458.9 (w, CH_2), 1249.3 (s, SiMe), 1068.6 (w, C-O), 1034.6 (w, C-O) and 839.5 (s, $SiMe_3$); NMR(ppm) $\delta_H(CDCl_3)$ 0.10 (9H, s, $SiMe_3$), 0.89 (3H, t, J 7.0 Hz, CH_3), 1.26-1.57 (8H, m, CH_2), 1.90 (2H, br, OH), 3.42 (1H, d, J 3.6 Hz, CH-Si), 3.76-3.81 (1H, m, CH), $\delta_C(CDCl_3)$ -2.04 (3C, $SiMe_3$), 14.52 (1C, CH_3), 23.01 (1C, CH_2), 26.50 (1C, CH_2), 32.26 (1C, CH_2), 33.61 (1C, CH_2), 71.41 (1C, CH-Si) and 75.49 (1C, CH); m/z (FAB-) 407 (4%, MM^+-H^+), 203 (14, $M-H^+$), 185 (22, $M-H^+-H_2O$), 113 (75, $C_7H_{13}O$), 89 (94, $OSiMe_3$), 73 (8, $SiMe_3$), 59 (23, $HSiMe_2$) (Found: C, 58.43, H, 11.82. $C_{10}H_{24}O_2Si$ requires C, 58.77, H, 11.84%).

1-Trimethylsilylcyclohexane-1,2-diol. The title compound (160 mg, 85% yield, 82%e.e.) was prepared from 1-trimethylsilylcyclohexene (154 g) and AD-mix-β (1.4 g). The reaction mixture was kept at 0°C for 24 h and worked up in the usual way; Rf (CH_2Cl_2/Et_2O, 3 / 2) 0.76; υ_{max}(KBr film/cm^{-1}) 3370.0 (br, OH), 2940.1 (s, CH), 2931.4 (s, CH_3), 2899.5 (s, CH_3), 2858.6 (s, CH_2), 1445.8 (m, CH), 1399.9 (w, CHOH), 1388.4 (w, CHOH), 1244.7 (s, SiMe), 1075.0 (s, C-O), 1059.6 (s, C-O), 1045.0 (s, C-O), 997.5 (m,), 955.4 (m,), 924.9 (s,), 865.7 (s, CH), 837.0 (vs, $SiMe_3$), 824.2 (vs, $SiMe_3$), 755.0 (m,), 744.9 (m,), 687.9 (m,); NMR (ppm) $\delta_H(CDCl_3)$ 0.07 (9H, s, $SiMe_3$), 1.21-1.82 (10H, m, CH_2, OH), 3.58-3.63 [1H, CH(OH)], $\delta_C(CDCl_3)$ -2.68 (3C, $SiMe_3$), 19.42 (1C, CH_2), 24.56 (1C, 30.10), 32.46 (1C, CH_2), 69.11 (1C, t-C) and 73.82 (1C, CH-Si); m/z (FAB+) 170 (56%, M^+-H_2O), 155 (22, $M^+-H_2O-CH_3$), 81 (48, C_6H_8), 73 (100, $SiMe_3$) (Found: C, 57.30, H, 10.69. $C_9H_{20}O_2Si$ requires C, 57.40, H, 10.70%).

Preparation of *cis*-1-trimethylsilyloctane-1,2-epoxide

A solution of *m*-chloroperbenzoic acid (85%, 6.64 g, 38.5 mmol) in 65 ml of dichloromethane was added at room temperature to a mixture containing 28.3 mmol of *cis* -

1-trimethylsilyl-1-octene and anhydrous $NaHPO_4$ (6.21 g, 43.7 mmol) in 60 ml of dichloromethane. The mixture was stirred until GLC analysis showed complete reaction (12-22 hours), and then saturated $NaHSO_3$ solution (20 ml) was added. The mixture was stirred for 30 minutes. Saturated $NaHCO_3$ solution (80 ml) was added carefully, and stirring was continued for another 30 minutes. The organic layer was separated, washed with saturated $NaHSO_3$ solution and brine, dried and concentrated. The crude expoxide was distilled.

Preparation of *trans*-1-trimethylsilylhexane-1,2-epoxide

The title compound was prepared using the above procedure and with 28.3 mmol of *trans*-1-trimethylsilyl-1-hexene as starting material.

Preparation of *threo* 1-trimethylsilyloctane-1,2-diol

30 ml of water and 17.4 ml of 1M H_2SO_4 was added to a solution of 4.0 g (9.98 mmol) of *cis*-1-trimethylsilyloctane-1,2-epoxide in 30 ml of THF. The mixture was stirred for 3 hours at 0°C, then left at room temperature for 2 hours. After addition of an aqueous solution of $NaHCO_3$ (saturated, 50 ml), the solution was stirred for 30 minutes, and the combined ethereal extracts were washed with water, dried over $MgSO_4$, and concentrated. The crude product was purified by chromatography using 85g of Florisil. Elution with petroleum ether removed unreacted epoxide and a small amount of octanol. Elution with methylene chloride and with 10% diethyl ether in dichloromethane give the pure product.

Preparation of *erythro*-1-trimethylsilylhexane-1,2-diol [14]

The title compound was prepared using the above procedure and with 10 mmol of *trans*-1-trimethylsilylhexane-1,2-epoxide as starting material.

Decomposition of *threo*-1-trimethylsilyoctane-1,2-diol [14]

6 g of *threo*-1-Trimethylsilyloctane-1,2-diol from epoxide opening reaction was heated to 60-65°C for 30 minutes under vacuum (0.02 mmHg). The resulting product, 4.3 g (95%

yield) of 1-heptyl-3-trimethylsilyl-4-hexyl-cyclicacetal, was obtained and almost pure. υ_{max} (film/cm^{-1}) 2956.0 (s, CH), 2928.0 (s, CH_3), 1467.0 (w), 1459.0 (w), 1250.0 (SiMe), 1116.0 (m, C-O), 867.0 (s, $SiMe_3$), 841.0 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ isomer-1 (60%) 0.07 (9H, s, $SiMe_3$), 0.86 (6H, t, J 6.7 Hz, CH_3), 1.28-1.62(22H, m, $(CH_2)_5$, $(CH_2)_6$), 3.08 (1H, d, J 9.3 Hz, CH-Si), 3.79-3.83 (1H, m, CH-C_6), 4.75 (1H, t, CH-O_2); $\delta_H(CDCl_3)$ isomer-2 (40%) 0.05 (9H, s, $SiMe_3$), 0.86 (6H, t, J 6.7 Hz, CH_3), 1.28-1.62 [12H, m, $(CH_2)_5$, $(CH_2)_6$], 3.08 (1H, d, J 9.3 Hz, CH-Si), 3.79-3.83 (1H, m, CH-C_6), 4.86 (1H, t, J 6.2 Hz, CH-O_2); m/z (EI+) 328 (3%, M), 313 (8, M-CH_3), 229 (19, M-C_7H_{15}), 200 [12, M-(C_7H_{15}-CHO)], 185 [24, M-(C_7H_{15}-CHO-CH_3)], 157 (20, $C_8H_{17}OSi$), 129 (100, $C_6H_{13}OSi$), 73 (71, $SiMe_3$); Found: C, 68.88, H, 12.07, $C_{19}H_{40}O_2Si$ requires : C, 69.45, H, 12.27%.

Decomposition of *erythro*-1-trimethylsilylhexane-1,2-diol [14]

5 g of *erythro*-1-Trimethylsilylhexane-1,2-diol from epoxide ring opening reaction was heated to about 40°C for 30 minutes under vacuum (0.03 mmHg). The resulting product was purified using column chromatography with silica gel, and eluted with dichloromethane /hexane (1:1) Rf=0.95. 3.1 g (85% yield) of 1-pentyl-3-trimethylsilyl-4-butylcylicacetal was obtained. υ_{max}(film/cm^{-1}) 3645.0 (br, OH), 3583.0 (br, OH), 2957.0 (s, CH), 2860.0 (m,), 1467.0 (w,), 1408.0 (w,), 1251(SiMe), 1199.0 (m, C-O-C), 1114.0 (m, C-O-C), 842.0 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ 0.12 (9H, s, $SiMe_3$), 0.87-0.92 (6H, m, CH_3), 1.27-1.66 (20H, m, CH_2), 3.47 (1H, d, J 7.2 Hz, CHSi), 4.13 (1H, ddd, J_1 10.2 Hz, J_2 7.2 Hz, J_3 3.0 Hz, OCH-CH_2-), 4.78 (1H, t, J 6.5 Hz, O_2CH); $\delta_C(CDCl_3)$ -2.30 (3C, s, $SiMe_3$), 13.98 (1C, s, CH_3), 14.02 (1C, s, CH_3). 22.58 (2C, s, CH_2), 23.67 (1C, s, CH_2), 28.68 (1C, s, CH_2), 31.81 (1C, s, CH_2), 34.04 (1C, s, CH_2), 34.52 (1C,s, CH_2), 74.48 (1C, s, CH-Si), 78.87 (1C, s, OCH), 105.46 (1C, s, O_2CH); m/z (EI+) 271 (7%, M^+-H), 257 (6, M^+-CH_{13}), 201 (5, C_5H_{11}), 157 (41, $C_8H_{17}OSi$), 143 (17, $C_7H_{15}OSi$), 129 (100, $C_6H_{13}OSi$), 73 (75, $SiMe_3$); Found: C, 66.24, H, 11.82, $C_{15}H_{32}O_2Si$ requires: C, 66.11, H, 11.84%.

Preparation of optically active secondary allylic alcohols via the Peterson elimination reaction

Preparation of *S*-oct-1-en-3-ol [16]: All apparatus must be dried in a hot (>120°C) oven before use. A 100 ml 3-neck round-bottomed flask was set up with a nitrogen inlet with a bubbler, magnetic stirrer bar, and carbon dioxide-acetone cooling bath. To a THF (15 ml) suspension of potassium hydride (10 mmol, 400 mg) was added *erythro*-1-trimethyl-silyloctane-2,3-diol (2 mmol, 436.8 mg) at -78°C. This suspension was warmed to room temperature over 3 hours and stirred for 1 hour. 5 ml of water was added dropwise to the reaction mixture which was left stirring for 10 minutes. The mixture was extracted with ether (3x15ml). The ethereal extracts were dried over magnesium sulphate and concentrated using rotary evaporator of 60 mm Hg at 20°C. The crude oct-1-en-3-ol was purified by chromatography on silica gel (CH_2Cl_2 / ether = 3 /2). The optical rotation of the purified oct-1-en-3-ol was α_D = +44.7 ($CHCl_3$, concentration not available) which has the same positive rotation of authentic sample of *S*-oct-1-en-3-ol [17] (literature value α_D = +20.6 (c 5.3, C_2H_5OH)).

Preparation of racemic trimethylsilyl-1,2-diols

General procedure 1[18]: 30 mmol of vinyl- or allylsilane, 40 mmol of trimethylamine *N*-oxide, 15 ml of distilled water, 50 ml of *tert*-butyl alcohol, and 1.2 ml solution of osmiumtetroxide (2.5 wt/v %) in *tert*-butyl alcohol were placed in a 250 ml round-bottomed flask equipped with a magnetic stirrer, and refluxing condenser. The mixture was refluxed with stirring overnight and then cooled to room temperature. 21 ml of 20% aqueous sodium metabisulphite solution was added to this reaction mixture which was stirred for 20 minutes and then most of the *t*-butyl alcohol was removed using a rotary evaporator. The residue was saturated with sodium chloride and extracted with diethyl ether (40 ml x 3). The organic extract was washed with brine (40 ml), dried over magnesium sulphate, and concentrated to give the crude silyldiol which can be purified by column chromatography on silica gel (CH_2Cl_2 / Et_2O = 3 / 2).

General procedure 2 [13]: 3 equivalents of potassium ferricyanide, $K_3Fe(CN)_6$, (75 mmol, 24.7 g), 3 equivalents of potassium carbonate, K_2CO_3, (75 mmol, 10.47 g), 1 equivalent of methanesulphonamide $MeSO_2NH_2$, (25 mmol, 2.43 g) and 0.0002 equivalents of potassium osmate, $K_2OsO_2(OH)_4$, (0.05 mmol, 18.4 mg) were placed in a 250 ml round-bottomed flask equipped with a magnetic stirrer. 75 ml of *tert*-butyl alcohol and 75 ml of distilled water were added to the flask and the mixture was stirred for 10 minutes. 1 equivalent of allyl- or vinyl-silane (25 mmol) was then added into the flask. This reaction mixture was stirred at room temperature for about 12 hours and then 19 g of sodium sulphite, 120 ml of dichloromethane was added and stirred for another 20 minutes. After the mixture was separated, the aqueous slurry was extracted with dichloromethane (50 ml x 2), and the organic extracts dried over magnesium sulphate, filtered, concentrated to give the crude silyl diol which was purified by column chromatography on silica gel (CH_2Cl_2 / Et_2O = 3 / 2).

§ 6.4 Synthesis of optically active trimethylsilylated amino alcohols and aziridines

General procedure for preparation of trimethylsilyl cyclic sulphites[19]

All apparatus was thoroughly dried in a hot (>120°C) oven for at least 24 hours before use. A mixture of 8.0 mmol (1 equivalent) of the silane-1,2-diol, 20 ml of dried ether and 1.62 g, 16.0 mmol (2 equivalent) of dried triethylamine were cooled under nitrogen in an ice bath. 1.00 g, 8.4 mmol (1.05 equivalent) of distilled thionyl chloride was dissolved in 10 ml of dried ether and added to the mixture slowly with a syringe with rapid stirring. The mixture was stirred for about 30 minutes then filtered under nitrogen. The filtrate was washed with 5% sodium hydrogen carbonate to remove excess of $SOCl_2$, followed by saturated sodium chloride solution, dried using $MgSO_4$ and concentrated, and a corresponding cyclic sulphite was obtained.

1-Trimethylsilylethylene-1,2-sulfite (1.05 g, 5.84 mmol, 73% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphites was used. The title compound was made from 1.07 g, 8.0 mmol of 1-trimethylsilylethane-1,2-diol. υ_{max}(film/cm^{-1}) 2953.0 (m, CH), 1254.5 (s, SiMe), 1208.1 (vs, SO), 931.0 (C-O-S), 844.7 (vs, $SiMe_3$), 747.7 (C-O-S), 662.1; NMR (ppm) δ_H($CDCl_3$) isomer-a, 0.17 (9H, s, $SiMe_3$), 3.81 (1H, dd, J_{gem} 7.4 Hz, J_{trans} 12.7 Hz, CH_2), 4.39 (1H, dd, J_{cis} 6.8 Hz, J_{trans} 12.7 Hz, CH), 4.72 (1H, dd, J_{cis} 6.8 Hz, J_{gem} 7.4 Hz, CH_2), δ_C($CDCl_3$) -3.98 (3C, $SiMe_3$), 68.62 (1C, CH), 72.23 (1C, CH_2); isomer-b, δ_H($CDCl_3$) 0.15 (9H, s, $SiMe_3$), 3.79 (1H, dd, J_{trans} 13.2 Hz, J_{cis} 6.4 Hz, CH), 4.33 (1H, dd, J_{gem} 8.8 Hz, J_{trans} 13.2 Hz, CH_2), 4.56 (1H, dd, J_{cis} 6.4 Hz, J_{gem} 8.8 Hz, CH_2); δ_C($CDCl_3$) -3.98 (3C, $SiMe_3$), 68.51 (1C, CH_2), 76.43 (1C, CH). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

1-Dimethylphenylsilylethylene-1,2-sulfite (1.45 g, 6.0 mmol, 75% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphites was used. The title compound was made from 8.0 mmol, 1.57 g of 1-dimethylphenylsilyl-ethylene-1,2-diol. υ_{max}(film/cm^{-1}) 1253.3 (s, SiMe), 1209.5 (vs, SO), 1118.0 (s, SiPh), 929.51 (m, C-O-S), 838.1 (s, $SiMe_2$), 816.3 (m, C-O-S), 789.7 (m, C-O-S), 737.2 (m, CH, Ar), 700.9 (m, C=C, Ar); NMR (ppm) δ_H($CDCl_3$) isomer-a, 0.49 (3H, s, SiMe), 0.52 (3H, s, SiMe), 3.84 (1H, dd, J 7.2 Hz, J 12.0 Hz, CH_2), 4.64 (1H, dd, J 6.8 Hz, J 12.0 Hz, CH-Si), 6.69 (1H, t, J 6.8 Hz, CH_2), 7.36-7.46 (5H, m, Ph); isomer-b, 0.51 (3H, s, SiMe), 0.55 (3H, s, SiMe), 4.00 (1H, dd, J 6.4 Hz, J 13.2 Hz, CH-Si), 4.41 (1H, dd, J 13.2 Hz, J 8.8 Hz, CH_2), 4.52 (1H, dd, J 8.0 Hz, J 6.4 Hz, CH_2), 7.36-7.46 (5H, m, Ph); δ_C($CDCl_3$) isomer-a -6.52 (1C, $SiCH_3$), -5.25 (1C, $SiCH_3$), 72,98 (1C, CH_2), 76.59 (1C, CHSi), 128.16 (2C, Ph), 131.81 (1C, Ph), 134.27 (2C, Ph), 139.66 (1C, t-C, Ph); isomer-b -4.56 (1C, $SiCH_3$), -4.52 (1C, $SiCH_3$), 68.94 (1C, CHSi), 69.34 (1C, CH_2), 128.76 (2C, CH, Ph), 133.50 (1C, Ph), 134.34 (2C, CH, Ph), 140.26 (1C, *t*-C, Ph). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

1-Trimethylsilyl-3-phenylpropane-2,3-cyclic sulphite (1.64 g, 6.07 mmol, 76% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphites was used. The title compound was made from 8.0 mmol, 1.80 g of 1-trimethylsilyl-3-phenyl propane-2,3-diol. υ_{max}(KBr film/cm^{-1}) 3089.0 (vw,), 3052.0 (vw,), 2954.5 (m,), 2933.7 (w,), 1608.0 (vw,), 1494.4 (w,), 1456.8 (w,), 1250.7 (s, SiMe), 1210.2 (vs, S=O), 1042.1 (m,), 951.8 (s, S-O-C), 921.7 (s, C-O-S), 900.6 (s, S-O-C), 863.5 (s, S-O-C), 842.3 (s, $SiMe_3$), 805.5 (s, S-O-C), 759.2 (s,), 702.3 (s,); NMR (ppm) $\delta_H(CDCl_3)$ isomer-a (35%) 0.06 (9H, s, $SiMe_3$), 1.00-1.02 (2H, m, CH_2Si), 4.84-4.87 (2H, m, CH-CH), 7.38-7.49 (5H, m, Ph), isomer-b (65%) 0.07 (9H, s, $SiMe_3$), 1.00 (1H, dd, J 11 Hz, J 3.6 Hz, H_a, CH_2Si), 1.23 (1H, J 14.8 Hz, J 11.0 Hz, H_b, CH_2Si), 4.41 (1H, ddd, J 11.0 Hz, J 8.8 Hz, J 3.6 Hz, CH), 5.42 (1H, d, J 8.8 Hz, CH-Ph), 7.39-7.49 (5H, m, Ph), $\delta_C(CDCl_3)$ isomer-a -1.11 (3C, $SiMe_3$), 17.40 (1C, CH_2Si), 83.44 (1C, CH), 92.12 (1C, CHPh), 127.69 (2C, Ph), 128.96 (2C, Ph), 129.30 (1C, Ph), 133.67 (1C, t-C, Ph), isomer-b -1.07 (3C, $SiMe_3$), 19.70 (1C, CH_2Si), 86.45 (1C, CH), 88.65 (1C, CHPh), 127.31 (2C, Ph), 129.01 (2C, Ph), 129.62 (1C, Ph), 133.09 (1C, Ph); m/z (FB+) 255 (11%, M^+-CH_3), 191 (13, MH^+-SO_3), 117 (100, C_9H_9), 73 (76, $SiMe_3$), 59 (8, $HSiMe_2$) (Found: C, 53.50, H, 6.74, $C_{12}H_{18}O_3SSi$ requires C, 53.30, H, 6.71%).

1-Trimethylsilyloctane-2,3-cyclic sulphite (1.63 g, 6.16 mmol, 77% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphites was used. The title compound was made from 8.0 mmol, 1.75 g of 1-trimethylsilyloctane-2,3-diol. υ_{max}(film/cm^{-1}) 2956.0 (s, CH), 2932.0 (s, CH_3), 2862.0 (m, CH_2), 1250.0 (s, SiMe), 1211.0 (vs, S=O), 979.0 (m, C-O-S), 950.5 (s, C-S-O), 900.1 (C-S-O), 862.9 (vs, C-S-O), 840.5 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ isomer-a (33%) 0.10 (9H, s, $SiMe_3$), 0.82 -0.91 (2H, m, CH_2Si), 0.90 (3H, t, CH_3), 1.22-1.40 (6H, m, CH_2), 1.48-1.63 (2H, m, CH_2), 4.36-4.40 (1H, m, CH-Pentyl), 4.61-4.66 (1H, m, CH), isomer-b (67%) 0.097 (9H, s, $SiMe_3$), 0.72 (1H, dd, J 14 .0 Hz, J 4.4 Hz, H_a, CH_2Si), 0.96 (1H, dd, J 14.0 Hz, J 11.2 Hz, H_b, CH_2Si), 1.22-1.40 (6H, m, CH_2), 1.50-1.60 (2H, m, CH_2),

4.75-4.79 (1H, m, CH-Pentyl), 5.00-5.05 (1H, m, CH), $\delta_C(CDCl_3)$ isomer-a (33%) -1.02 (3C, $SiMe_3$), 13.91 (1C, CH_3), 18.06 (1C, CH_2Si), 22.41 (1C, CH_2), 25.61 (1C, CH_2), 30.26 (1C, CH_2), 31.46 (1C, CH_2), 83.69 (1C, CH), 85.28 (1C, CH-Pentyl), isomer-b (67%) -1.02 (3C, $SiMe_3$), 13.91 (1C, CH_3), 16.43 (1C, CH_2-Si), 22.41 (1C, CH_2), 25.39 (1C, CH_2), 28.78 (1C, CH_2), 31.46 (1C, CH_2), 81.43 (1C, CH), 82.87 (1C, CH-Pentyl). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

1-Trimethylsilylpropane-2,3-cyclic sulphite (1.12 g, 5.76 mmol, 72% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphites was used. The title compound was made from 8.0 mmol, 1.19 g of 1-trimethylsilylpropane-2,3-diol. υ_{max}(film/cm^{-1}) 2956.0 (m, CH), 2899.3 (w, CH_3), 1252.2 (s, SiMe), 1209.1 (vs, S=O), 980.2 (s, C-O-S), 958.2 (s, C-O-S), 858.1 (vs, C-O-S), 845.8 (vs, $SiMe_3$), 787.3 (s, C-O-S), 747.5 ; NMR (ppm) $\delta_H(CDCl_3)$ isomer-a (42%) 0.086 (9H, s, $SiMe_3$), 0.98 (1H, dd, J 14 Hz, J 7.2 Hz, H_a, CH_2Si), 1.20 (1H, dd, J 14 Hz, J 7.2 Hz, H_b, CH_2Si), 3.72 (1H, t, J 8.0 Hz, H_a, CH_2), 4.65 (1H, dd, J 8.0 Hz, J 5.6 Hz, H_b, CH_2), 5.09-5.16 (1H, m, CH), isomer-b (58%) 0.088 (9H, s, $SiMe_3$), 1.12 (1H, dd, J 14.0 Hz, J 7.2 Hz, H_a, CH_2Si), 1.40 (1H, dd, J 14 Hz, J 7.2 Hz, H_b, CH_2Si), 4.20 (1H, dd, J 8.8 Hz, J 10.0 Hz, H_a, CH_2), 4.44 (1H, dd, J 8.8 Hz, J 5.6 Hz, H_b, CH_2), 4.57-4.61 (1H, m, CH), $\delta_C(CDCl_3)$ isomer-a -1.18 (3C, $SiMe_3$), 20.18 (1C, CH_2Si), 73.75 (1C, CH_2), 79.07 (1C, CH), isomer-b, -1.18 (3C, $SiMe_3$), 21.75 (1C, CH_2Si), 71.15 (1C, CH_2), 83.58 (1C, CH). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

General procedure for the preparation of the trimethylsilyl cyclic sulphates[20]

5.5 mmol (equivalent) of the silyl cyclic sulphite, 16ml of carbon tetrachloride, 6 ml of acetonitrile, 9 ml of water, 1.76 g, 8.23 mmol (1.5 equivalent) of sodium periodate and 0.88 mg, 0.0034 mmol (0.06% equivalent.) of $RuCl_3$ $3H_2O$ were placed in a 100 ml

flask. The mixture was stirred vigorously for 1 hour at 0°C and then allowed to rise to room temperature and the stirring continued for another hour. The mixture was then diluted with ether (45 ml) and the two phases were separated. The organic layer was washed with water (2 ml), saturated aqueous $NaHCO_3$ (1 ml) and brine (2 ml). After drying over $MgSO_4$, the solution was filtered through a pad of silica gel. The filtrate was concentrated.

1-Trimethylsilylethylene-1,2-sulphate (0.76 g, 3.90 mmol, 70.8% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphates was used. The title compound was made from 5.5 mmol of 1-trimethylsilylethylene-1,2-sulphite. υ_{max}(film/cm^{-1}) 1381.2 (vs, SO_2), 1257.4 (s, SiMe), 1206.0 (vs, SO_2), 957.5 (C-O-S), 849.0 (s, $SiMe_3$), 823.0 (C-O-S), 790.1 (C-O-S); NMR (ppm) $\delta_H(CDCl_3)$ 0.10 (9H, s, $SiMe_3$), 4.48 (1H, m, CH), 4.62 (2H, m, CH_2); $\delta_C(CDCl_3)$ -4.31 ($SiMe_3$), 72.57 (CH_2), 77.84 (CH). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

1-Dimethylphenylsilylethylene-1,2-sulphate (1.00 g, 3.88 mmol, 70.6% yield): The general procedure for the preparation of the trimethylsilyl cyclic sulphates was used. The title compound was made from 5.5 mmol, 1.33 g of 1-dimethylphenylsilyl ethylene-1,2-cyclicsulphite. υ_{max}(in nujol/cm^{-1}) 1375.1 (vs, SO_2), 1254.3(s, SiMe), 1200.3 (vs, SO_2), 1119.4 (s, SiPh), 935.6 (m, C-O-S), 852.1 (s, $SiMe_3$), 832.3 (s, $SiMe_3$), 813.7 (m, C-O-S); NMR (ppm) $\delta_H(CDCl_3)$ 0.52 (3H, s, SiMe), 0.53 (3H, s, SiMe), 4.52 (1H, dd, J 12 Hz, J 8.8 Hz, CH_2), 4.56 (1H, dd, J 8.8 Hz, J 6.4 Hz, CH_2), 4.86 (1H, dd, J 6.4 Hz, J 12 Hz, CH), 7.35 -7.56 (5H, m, Ph); $\delta_C(CDCl_3)$ -6.49 (1C, SiMe), -5.48 (1C, SiMe), 72.37 (1C, CH_2), 77.48 (1C, CH-Si), 128.70 (2C, Ph), 130.99 (1C,Ph), 131.75 (1C, Ph), 134.00 (2C, Ph); M/z(FAB-) 259 (23%, MH^+), 258 (51, M^+), 257 (30, $M\text{-}H^+$), 123 (51, M^+ - $SiMe_2Ph$), 96 (94, SO_4), 80 (100, SO_3), 64 (22, SO_2). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

Preparation of 2-trimethylsilyl-1-benzylaziridine[21]

All apparatus must be completely dried in a hot (>120°C, >24 hours) oven before use. 0.55 g (5.1 mmol) of benzylamine was added slowly under nitrogen to 0.5 g (2.548 mmol) of 1-trimethylsilylethylene-1,2-cyclic sulphate in 25ml of dried THF and the mixture stirred for 24 hours at room temperature. The solution was cooled to -78°C and 1.24 ml (3.1 mmol) of 2.5 M n-BuLi solution in hexane was added and stirring continued for another 2 hours. The resulting solution was diluted with dried ether(50 ml), filtered on a pad of silica gel and concentrated. The product was purified by chromatography on silica gel to give 110 mg of pure product (20% yield). υ_{max}(film/cm^{-1}) 3031.0 (CH, Ar), 2956.0 (s, CH), 2924.0 (s, CH_3), 1496.0 (w, C=C, Ar), 1454.0 (w, C=C, Ar), 1247 (s, SiMe), 1027.0 (m, CN), 1012.0 (m, CN), 854 (s, CH), 839.0 (s, $SiMe_3$), 752.0 (m, CH, Ar), 730.0 (m, C=C, Ar), 698.0 (m, C=C, Ar); NMR (ppm) δ_H($CDCl_3$) -0.12 (9H, s, $SiMe_3$), 0.50 (1H, dd, J 4.6 Hz, J 7.4 Hz, CH), 1.46 (1H, d, J 8 Hz, CH_2), 1.72 (1H, d, J 4.8 Hz, CH_2), 2.89 (1H, d, J 13.2 Hz, CH_2-Ph), 3.86 (1H, d, J 13.2 Hz, CH_2-Ph), 7.21-7.32 (5H, m, Ph); δ_C($CDCl_3$) -3.19 (3C, $SiMe_3$), 28.57 (1C, CH), 31.83 (1C, CH_2), 67.56 (1C, CH_2-Ph), 126.87 (1C, CH, Ph), 128.12 (2C, CH, Ph), 128.21 (2C, CH, Ph), 139.71 (1C, *t*-C, Ph); m/z(EI+) 205 (3%, M), 204 (8, M-H$^+$), 190 (11, M-CH_3), 114 (100, M-CH_2-Ph), 91 (58, CH_2-Ph), 86 (46, $HCSiMe_3$), 73 (70, $SiMe_3$). The title compound was too unstable to be kept at room temperature, so it was not possible to obtain a micro analysis.

The general procedure for the preparation of trimethylsilylated azido alcohols [22]

All apparatus must be completely dried in a hot (>120°C, >24 hours) oven before use. A 100 ml of 3-neck round-bottomed flask was set up with a reflux condenser, nitrogen inlet with a bubbler, magnetic stirrer bar, and oil bath. The flask was flushed with a slow stream of nitrogen for 10 minutes, then 5 mmol (1 equivalent) of the trimethylsilylated cyclic sulphite, 6 mmol, 0.39 g (1.2 equivalent.) of sodium azide, and 15 ml of dried,

fresh distilled dimethylformamide (DMF) were added. The mixture was heated to 80-90°C for 15 hours, and cooled to room temperature, and the DMF removed under vacuum. 3 ml of water was added to the solid residue, and the mixture stirred for 20 minutes. The resulting mixture was extracted with Et_2O (25ml X 3). The ethereal extracts were dried over magnesium sulphate, concentrated and purified by column chromatography on silica gel (EtOAc / Hexane = 20 / 80), to give the pure trimethylsilyl azido alcohol.

3-Azido-3-phenyl-1-trimethylsilylpropan-2-ol (1001.2 mg, 4.02 mmol, 80.3% yield): The general procedure for the preparation of the trimethylsilylated azido alcohols was used. The title compound was made from 5 mmol, 1.35 g (1 equivalent) of 1-trimethylsilyl-3-phenylpropane-2,3-cyclic sulphite. υ_{max}(film/cm^{-1}) 3463.5 (br, OH), 3084.0 (vw,), 3062.0 (vw, CH, Ar), 3025.0 (vw, CH, Ar), 2953.7 (w, CH), 2923.1 (w, CH_3), 2895.6 (w, CH_2), 2104.2 (vs, N_3), 1248.2 (s, SiMe), 862.2 (s, CH), 841.8 (s, $SiMe_3$), 701.3 (m, C=C, Ar); NMR (ppm) $\delta_H(CDCl_3)$ 0.04 (9H, s, $SiMe_3$), 0.71 (1H, dd, J 14.8 Hz, J 10.8 Hz, H_a, CH_2Si), 0.85 (1H, dd, J 14.8 Hz, J 2.8 Hz, H_b, CH_2Si), 1.64 (1H, br, OH), 3.91-3.94 (1H, m, CH), 4.42 (1H, d, J 6.0 Hz, CHPh), 7.31-7.44 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.85 (3C, $SiMe_3$), 20.76 (1C, CH_2Si), 72.61 (1C, CH), 74.59 (1C, CHPh), 128.01 (2C, CH, Ph), 128.52 (1C, CH, Ph), 128.76 (2C, CH, Ph), 136.35 (1C, *t*-C, Ph); (Found: C, 57.68, H, 7.70, $C_{12}H_{19}N_3OSi$ requires C, 57.79, H, 7.68%). A by-product 1-trimethylsilyl-2-trimethylsiloxy-3-azido-3-phenyl-propane (10%) 2955.2 (s, CH), 2104.5 (vs, N_3), 1251.1 (s, SiMe), 1101.9 (m,), 1089.0 (m,) 1052.3 (m,), 1038.7 (m,), 1030.7 (m,) 839.1 (s,), 757.1 (s,), 699.2 (m,); NMR (ppm) $\delta_H(CDCl_3)$ 0.03 (9H, s, $SiMe_3$), 0.11 (9H, s, $OSiMe_3$), 0.66 (1H, dd, J 14.8 Hz, J 5.2 Hz, H_a, CH_2Si), 1.01 (1H, dd, J 14.8 Hz, H_a, CH_2Si), 4.10-4.14 (1H, m, CH), 4.53 (1H, d, J 4.8 Hz, CH-Ph), 7.29-7.39 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.41 (3C, $SiMe_3$), 0.47 (3C, $OSiMe_3$), 20.75 ((1C, CH_2Si), 71.50 (1C, CH-Ph), 74.60 (1H, CH), 127.89 (2C, CH, Ph), 127.95 (1C, CH, Ph), 128.35 (2C, CH, Ph), 137.17 (1C, *t*-C, Ph), $\delta_{Si}(CDCl_3)$ 1.15 (1Si, $SiMe_3$), 17.28 (1Si, $OSiMe_3$); m/z (EI+) 320 (1%, M^+), 306 (3%,

M^+-N), 279 (23, M^+-N_3), 263 (7, M^+-N_3-CH_3), 189 (64, $C_8H_{21}OSi_2$), 147 (13, $C_8H_9N_3$), 117 (100, $C_5H_{13}OSi$), 73 (43%, $SiMe_3$)

Azido-1-trimethylsilylpropanol (537.2 mg, 3.1 mmol, 62% yield): The general procedure for the preparation of the trimethylsilylated azido alcohols was used. The title compound was made from 5 mmol, 972 mg of 1-trimethylsilylpropane-2,3-cyclic sulphite. υ_{max}(film/cm^{-1}) 3364.5 (br, OH), 2954.7 (m, CH), 2104.1 (vs, N_3), 1250.9 (s, SiMe), 1048.1 (m, C-O), 860.0 (s, CH), 841.2 (s, $SiMe_3$); NMR (ppm) δ_H($CDCl_3$) 2-azido-3-trimethylsilylpropan-1-ol (25%) 0.06 (9H, s, $SiMe_3$), 0.77 (1H, dd, J 14.4 Hz, J 5.2 Hz, H_a, CH_2Si), 0.86 (1H, dd, J 14.4 Hz, J 8.8 Hz, H_b, CH_2Si), 3.20 [1H, dd, J 12.4 Hz, J 8.0 Hz, H_a, $CH_2(N_3)$], 3.35 [1H, dd, J 12.4 Hz, J 3.2 Hz, H_b, $CH_2(N_3)$], 3.92 (1H, m, CH), δ_C($CDCl_3$) -0.91 (3C, $SiMe_3$), 22.90 (1C, CH_2Si), 59.76 (1C, CH_2), 68.97 (1C, CH); δ_H($CDCl_3$) 3-azido-1-trimethylsilylpropan-2-ol 0.08 (9H, $SiMe_3$), 0.80 (1H, dd, J 14.8 Hz, J 7.2Hz, H_a, CH_2Si), 0.89 (1H, dd, J 14.8 Hz, J 8.0 Hz, H_b, CH_2Si), 3.50 (1H, dd, J 10.8 Hz, J 8.0 Hz, H_b, CH_2), 3.55 (1H, m, CH), 3.66 (1H, dd, J 10.8 Hz, J 2.4 Hz, H_b, CH_2Si), δ_C($CDCl_3$) -1.11 (3C, $SiMe_3$), 18.02 (1C, CH_2Si), 62.11 (1C, CH), 67.25 (1C, CH_2). by-product thought to be 1-trimethylsilyl-2-trimethylsiloxy-3-azido-3-phenyl-propane (10%)

The general procedure for the preparation of trimethylsilylated amino alcohols [22]

All apparatus were thoroughly dried in a hot (>120°C) oven before use. A 3 neck round-bottomed flask was set up with a reflux condenser, nitrogen inlet bubbler and a magnetic stirrer. 3 mmol of trimethylsilyl azido alcohol in 20 ml of dry diethyl ether was placed in the flask under nitrogen. 6 mmol, 228 mg of lithium aluminium hydride (2 equivalent.) was added to the mixture was stirred at room temperature for 2 h. 6 ml of 20% aqueous solution of sodium hydroxide was then added gradually. The mixture solution was separated and the aqueous phase was extracted with ether (20ml X 3). The

ethereal extracts were dried over $MgSO_4$ and concentrated to give the trimethylsilyl amino alcohol.

3-Amino-3-phenyl-1-trimethylsilylpropan-2-ol (623.3 mg, 2.79 mmol, 93% yield): The general procedure for the preparation of the trimethylsilylated amino alcohols was used. The title compound was made from 3 mmol, 748.1 mg (1 equivalent) of 3-azido-3-phenyl-1-trimethylsilylpropan-2-ol. υ_{max}(film/cm^{-1}) 3416.0 (br, OH), 3363.3 (w, NH), 3293.3 (m, NH), 3616.6, 3086.8 (w, CH, Ar), 3062.5 (w, CH, Ar), 3031.1 (w, CH, Ar), 2952.0 (s, CH), 2916.3 (m, CH_3), 2897.3 (m, CH_3), 2851.8 (w, CH_2), 1594.6 (m, C=C, Ar), 1494.0 (w, C=C, Ar), 1448.1 (w, C=C, Ar), 1240.9 (s, SiMe), 1071.6 (m, C-O), 1021.5 (s, C-N), 962.6 (m), 877.3 (m), 864.0 (vs, $SiMe_3$), 839.5 (s, $SiMe_3$), 700.6 (s, CH, Ar); NMR (ppm) $\delta_H(CDCl_3)$ 0.02 (9H, s, $SiMe_3$), 0.55 (1H, dd, J 14.8 Hz, J 10.8 Hz, H_a, CH_2Si), 0.67 (1H, dd, J 14.8 Hz, J 3.2 Hz, H_b, CH_2Si), 1.89 (3H, br, OH, NH_2), 3.84-3.90 (2H, m, CH), 7.27-7.35 (5H, m,Ph), $\delta_C(CDCl_3)$ -0.80 (3C, $SiMe_3$), 20.49 (1C, CH_2), 62.46 (1C, CH), 73.40 (1C, CHPh), 127.31 (1C, Ph), 127.48 (2C, Ph), 128.33 (2C, Ph), 142.04 (1C, *t*-C, Ph); m/z (FB+) 224 (40.3%, MH^+), 206 (33, MH^+-H_2O), 117 (100, $C_5H_{13}OSi$), 106 (20, C_7H_8N), 91 (19, C_7H_7), 73 (96, $SiMe_3$) (Found: C, 63.52, H, 9.26, $C_{12}H_{21}NOSi$ requires C, 64.52, H, 9.47%).

1-Trimethylsilyl-3-phenylpropane-2-hydroxy-3-p-toluenesulphonamide [23] (95%e.e., 62% yield): A solution of 3-amino-3-phenyl-1-trimethylsilylpropan-2-ol (1 equivalent, 0.787 g, 3.523 mmol) in triethylamine was slowly added to a solution of *p*-toluenesulfonyl chloride (2 equivalent, 1.343 g, 7.046 mmol) in triethylamine at 0°C. After 1 hour at 0°C, the reaction was allowed to warm to room temperature and was maintained there for 18 hours. Removal of the solvent under reduced pressure gave a brown oil which was partioned between ether and water. The aqueous layer was further extracted with ether. The combined organic extracts was washed with 5% H_2SO_4, saturated $CuSO_4$, water, saturated $NaHCO_3$, brine and dried using $MgSO_4$. Concentration afford a solid which was purified by flash chromatography (silica gel, hexane/EtOAc = 80/20) to give the title compound. υ_{max}(film/cm^{-1}) 3582.5 (w,), 3505.5

(s, OH), 3417.2 (w), 3304.6 (m, NH), 3086.6 (w, CH, Ar), 3064.8 9 (w, CH, Ar), 3030.4 (w, CH, Ar), 2952.8 (w, CH), 2920.6 (w, CH_3), 2899.6 (w, CH_3), 1598.6 (w, C=C, Ar), 1495.3 (w, C=C, Ar), 1455.5 (wm, C=C, Ar), 1415.6 (m, OH), 1352.7 (wm, OH), 1323.7 (vs, SO_2-N), 1305.1 (wm), 1252.7 (s, SiMe), 1245.6 (s, C-N), 1216.3 (w), 1183.4 (w, C-N), 1159.3 (vs, SO_2-N), 1089.1 (s, C-O), 1065.6 (m), 1052.1 (s), 1010.4 (w), 929.7 (w, SO_2-N), 864.9 (s, CH), 843.8 (s, $SiMe_3$), 806.0 (s,), 700.5 (s, SO_2-N), 658.7 (m,), 566.3 (s,), 541.0 (s,); NMR (ppm) $\delta_H(CDCl_3)$ -0.04 (9H, s, $SiMe_3$), 0.41 (1H, dd, J 14.8 Hz, J 10.8 Hz, H_a, CH_2Si), 0.63 (1H, dd, J 14.8 Hz, J 3.2Hz, H_b, CH_2Si), 1.60 (1H, d, J 7.3 Hz, OH), 2.33 (3H, s, CH_3), 3.95 (1H, m, CH), 4.23 (1H, dd, J 8.4 Hz, J 3.6 Hz, CH-Ph), 5.67 (1H, d, J 8.0 Hz, NH), 7.02-7.17 (7H, m, Ph), 7.54 (2H, d, J 8.4 Hz, Ph), $\delta_C(CDCl_3)$ -1.12 (3C, $SiMe_3$), 21.35 (1C, CH_3), 21.53 (1C, CH_2Si), 64.03 (1C, CH-Ph), 72.44 (1C, CH), 126.98 (2C, Ph), 127.44 (1C, Ph), 127.93 (2C, CH, Ph), 128.03 (2C, CH, Ph), 129.21 (2C, CH, Ph), 136.40 (1C, *t*-C, Ph), 137.26 (1C, *t*-C, Ph), 142.97 (1C, *t*-C, Ph); m/z (FAB) 376 (17%, M-H^+), 288 (14, M^+-$OSiMe_3$), 286 (28, M^+-$OSiMe_3$-$2H^+$), 197 (6, M-OH-$SiMe_3$-Ph+H^+), 183 (8, M^+-Ph-$PhCH_3$-OH), 155 (66, Me-Ph-SO_2), 89 (17, $OSiMe_3$)), 59 (19, $HSiMe_2$) (found: C, 60.54, H, 7.19, N, 3.70, $C_{19}H_{27}NO_3SSi$ requires C, 60.44, H, 7.21, N, 3.71%).

1-Trimethylsilyl-3-phenylpropane-2-hydroxy-3-*N*-diphenylphosphinoyl-amide [24] To a solution of 3-amino-3-phenyl-1-trimethylsilylpropan-2-ol (162 mg, 0.725 mmol) in THF (20 ml), under nitrogen at 0°C, was added 2 equivalents of diphenylphosphinic chloride (98%, 1.45 mmol, 350 mg, 282 µl), and 3 equivalents of triethylamine (2.18 mmol, 302 µl). A white precipitate of triethylammonium hydrochloride was formed immediately. The resulting suspension was stirred for 20 hours at room temperature. The solvent was then removed in vacuo to leave a solid. The crude solid product was purified by chromatography on silica gel (dichloromethane / ether = 3 / 2) giving 163 mg (0.384 mmol, 53% yield) of title compound. υ_{max}(film/cm^{-1}) 3357.2 (br, OH), 3222.3 (s, NH), 3058.5 (w, P-Ar), 3027.6 (w, C-H, Ar), 2950.3 (w, CH), 2929.4 (w, CH_3), 2892.6 (w, CH_3), 2870.7 (vw, CH_2), 1605.0 (w, C=C, Ar), 1495.0 (w,

C=C, Ar), 1495.0 (w, C=C, Ar), 1243.9 (m, SiMe), 1167.5 (vs, N-P=O), 1125.8 (s, P-Ph), 1080.1 (s, C-O), 860.3 (s, $SiMe_3$), 835.1 (s, $SiMe_3$), 748.6 (m,), 728.3 (s,), 693.9 (s, P-Ph); NMR (ppm) $\delta_H(CDCl_3)$ -0.38 (9H, $SiMe_3$), 0.40 (1H, dd, J = 14.0 Hz, J = 2.4 Hz, H_a, CH_2Si), 0.56 (1H, dd, J 14.0 Hz, J 11.2 Hz, H_b, CH_2Si), 3.95 (1H, dd, J 10.8 Hz, J 4.8 Hz, CH-Ph), 4.11 (1H, m, CH), 3.50-4.50 (1H, br, OH), 4.25 (1H, NH), 7.24-7.51 (11H, m, Ph), 7.78 (2H, dd, J 12.4 Hz, J 8.0 Hz, Ph), 7.93 (2H, J 12.0 Hz, J 8.0 Hz, Ph), $\delta_C(CDCl_3)$ -0.06 (3C, $SiMe_3$), 19.39 (1C, CH_2Si), 63.50 (1C, CH), 72.89 (1C, CH-Ph), 127.07 (1C, P-Ph), 127.13 (2C, CH, Ph), 128.28 (2C, P-Ph), 128.41 (1C, CH, Ph), 128.52 (1C, P-Ph), 128.63 (2C, CH, Ph), 130.59 (1C, d, J 526.8 Hz, *t*-C, P-C, P-Ph), 131.76 (2C, d, J 36.4 Hz, P-Ph), 131.88 (1C, P-Ph), 132.05 (1C, P-Ph), 132.57 (2C, d, J 36.8 Hz, P-Ph), 136.50 (1C, d, J 2655.2 Hz, *t*-C, P-C, P-Ph), 139.89 (1C, *t*-C, Ph).

The general procedure for the preparation of trimethylsilylated aziridines[25]

All apparatus were thoroughly dried in a hot (>120°C) oven for at least 24 hours before use. 3 mmol of the silylazidoalcohol and 3 mmol of triphenylphosphine in 30 ml of dry diethyl ether were placed under nitrogen in a 3 neck round-bottomed flask equipped with reflux condenser, nitrogen inlet bubbler and a magnetic stirrer. The mixture was refluxed for 3 hours, cooled to room temperature, and filtered through a 2 cm pad of silica gel. The pad was eluted with another 80 ml of ether. The organic extracts were concentrated, and the silylated aziridine purified using column chromatography on silica gel, eluting with ether.

1-Trimethylsilyl-3-phenylpropane-2,3-aziridine (412.8 mg, 2.01 mmol, 67% yield): The general procedure for the preparation of the silylated aziridine was used. The title compound was made from 3 mmol, 748.1 mg (1 equivalent) of 3-azido-3-phenyl-1-trimethylsilylpropan-2-ol. υ_{max}(film/cm^{-1}) 3291.5 (w, NH), 3247.4 (w, NH), 3084.3 (w, CH, Ar), 3063.4 (w, CH, Ar), 3030.7 (w, CH, Ar), 2953.9 (s, CH), 2896.4 (m, CH_3), 2877.5 (w, CH_3), 1605.7 (w, C=C, Ar), 1496.0 (m, C=C, Ar), 1456.7 (w, C=C,

Ar), 1419.4 (w), 1403.9 (w), 1347.2 (w), 1249.0 (s, SiMe), 1218.0 (w, C-N-C), 1183.8 (w, C-N), 1136.5 (w, C-N) 1112.4 (w), 973.8 (w), 913.8 (w), 860.1 (vs, SiM_3), 835.7 (vs, $SiMe_3$), 745.8 (s, NH), 697.9 (s, C=C, Ar), 610.3 (w,), 527.6 (w,); NMR (ppm) *cis*-isomer (95%e.e.) $\delta_H(CDCl_3)$ -0.04 (9H, s, $SiMe_3$), 0.42 (1H, dd, J 14.8 Hz, J 6.4 Hz, H_a, CH_2Si), 0.52 (1H, dd, J 14.8 Hz, J 6.4 Hz, H_b, CH_2Si), 1.00 (1H, NH), 2.40 (1H, q, J 6.8 Hz, CH), 3.23 (1H, d, J 6.8 Hz, CHPh), 7.21-7.32 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.75 (3C, $SiMe_3$), 15.49 (1C, CH_2Si), 35.26 (1C, CH), 38.11 (1C, CH-Ph), 126.99 (1C, Ph), 128.23 (2C, Ph), 128.32 (2C, Ph), 138.79 (1C, *t*-C, Ph); *trans*-isomer (95%e.e.) $\delta_H(CDCl_3)$ 0.07 (9H, s, $SiMe_3$), 0.64 (1H, dd, J 14.8 Hz, J 8.4 Hz, H_a, CH_2Si), 0.79 (1H, NH), 1.12 (1H, dd, J 14.8 Hz, J 5.6 Hz, H_b, CH_2Si), 2.00 (1H, m, CH), 2.64 (1H, d, J 2.9 Hz, CH-Ph), 7.19-7.32 (5H, m, Ph), $\delta_C(CDCl_3)$ -1.31 (3C, $SiMe_3$), 23.38 (1C, CH_2Si), 39.29 (1C, CH), 40.81 (1C, CH-Ph), 125.48 (2C, CH, Ph), 126.78 (1C, CH, Ph), 128.39 (2C, CH, Ph), 140.61 (1C, *t*-C, Ph); *cis*-isomer, m/z (EI+) 205 (22%, M^+), 190 (21, M^+-CH_3), 178 (22, $C_{10}H_{16}NSi$), 132 (100, $C_9H_{10}N$), 105 (69, PhCH=NH), 73 (87, $SiMe_3$), 58 (17, $SiMe_2$), 45 (29, H_2SiMe) (*cis*-isomer, Found: C, 69.56, H, 9.24, N, 6.72, $C_{12}H_{19}NSi$ requires C, 70.18, H, 9.32, N, 6.82%).

Procedure for ring opening of trimethylsilyl cyclic sulphites with benzylamine (amines)[22]: All apparatus must be completely dried in a hot (>120°C, >24 hours) oven before use. A 100 ml 3-neck round-bottomed flask was set up with a reflux condenser, nitrogen inlet with a bubbler, magnetic stirrer bar, and oil bath. The flask was flushed with a slow stream of nitrogen for 10 minutes. 5 mmol (1 equivalent) of trimethylsilylated cyclic sulphite, 25 mmol, (5 equivalent) of benzylamine, and 15 ml of dried, freshly distilled dimethylformamide (DMF) were added. The mixture was heated to 80-90°C overnight, and cooled to room temperature. DMF was removed under vacuum and 5 ml of 20% NaOH solution was added to the residue, and stirred for 30 minutes. The resulting mixture was extracted with Et_2O (25ml X 3). The ethereal extracts was dried over magnesium sulphate, concentrated, and the title compound purified by column chromatography on silica gel ($CHCl_3$ / MeOH = 10 / 1).

Ring opening of 1-trimethylsilylpropane-2,3-cyclic sulphite with benzylamine[22]: The above procedure was used with 25 mmol (5 equivalent.) of benzylamine. A mixture of regioisomer (1-trimethylsilylpropane-2-(*N*-benzyl)amino-3-alcohol : 1-trimethylsilylpropane-3-(*N*-benzyl)amino-2-alcohol = 45 : 55) of ring opening product 379 mg (1.6 mmol, 32% yield) was obtained. NMR(ppm)1-trimethylsilylpropane-2-(*N*-benzyl)amino-3-alcohol, $\delta_H(CDCl_3)$ -0.02 (9H, s $SiMe_3$), 0.64 (1H, dd, J 14.6 Hz, J 5.4 Hz, H_a, CH_2Si), 0.82 (1H, dd, J 14.6 Hz, J 8.8 Hz, H_b, CH_2Si), 2.70 (1H, dd, J 12.7 Hz, J 10.2 Hz, H_a, CH_2), 2.79 (1H, dd, J 12.7 Hz, J 2.9 Hz, H_b, CH_2), 4.09 (2H, s, CH_2-Ph), 4.15 (1H, m, CH), 6.50 (2H, br, OH, NH), 7.23-7.55 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.87 (3C, $SiMe_3$), 23.62 (1C, CH_2Si), 51.54 (1C, CH_2-Ph), 54.65 (1C, CH_2), 65.41 (1C, CH), 128.41 (1C, Ph), 129.03 (2C, Ph), 129.91 (2C, Ph), 131.83 (1C, *t*-C, Ph); 1-trimethylsilylpropane-3-(*N*-benzyl)amino-2-alcohol $\delta_H(CDCl_3)$ -0.02 (9H, s $SiMe_3$), 0.99-1.25 (2H, m, CH_2Si), 3.07 (1H, m, CH), 3.58 (1H, dd, J 12.4 Hz, J 7.8 Hz, H_a, CH_2), 3.77 (1H, dd, J 12.4 Hz, J 3.4 Hz, H_b, CH_2), 3.99 (1H, d, J 13.2 Hz, H_a, CH_2-Ph), 4.23 (1H, d, J 13.2 Hz, H_b, CH_2-Ph), 7.23-7.55 (5H, m, Ph), $\delta_C(CDCl_3)$ -1.04 (3C, $SiMe_3$), 15.75 (1C, CH_2Si), 47.92 (1C, CH_2-Ph), 57.18 (1C, CH), 62.50 (1C, CH_2), 128.23 (1C, CH, Ph), 129.03 (2C, CH, Ph), 129.91 (2C, CH, Ph), 131.61 (1C, *t*-C, Ph).

Procedure for ring opening of trimethylsilyl cyclic sulphites with hard nucleophiles BuLi, MeLi, RMgX: All apparatus must be completely dried in a hot (>120°C, >24 hours) oven before use. A 100 ml three-neck round-bottomed flask was set up with a reflux condenser, nitrogen inlet with a bubbler, magnetic stirrer bar, and a septum. The flask was flushed with a slow stream of nitrogen for 10 minutes. 5 mmol (1 equivalent) of trimethylsilylated cyclic sulphite and 25 ml of dried, freshly distilled THF were placed in the flask. 2 ml (5 mmol, 1 equivalent) of a 2.5 mol solution in hexanes of n-BuLi (MeLi, RMgX), was added slowly, using a gas tight syringe, to the flask at 0°C, and the mixture stirred for 3 hours at room temperature. 10 ml of water was added dropwise to the reaction mixture, which was then extracted with ether (20 ml x 3). The

ethereal extracts were dried over magnesium sulphate, filtered and concentrated to give the corresponding trimethylsilyldiol.

Procedure for ring opening of trimethylsilyl cyclic sulphite with the hard nucleophile RNHLi: The lithium benzylamide was prepared from benzylamine by reaction with 1 equivalent of n-BuLi in dried THF and refluxing for 30 min. To this red solution was added 1 equivalent of 1-trimethylsilyl-3-phenylpropane-2,3-cyclic sulphite at 0°C. This reaction mixture was kept at room temperature with stirring for 3 hours. 2 equivalents of water were then added dropwise and the resulting solution extracted with ether three times. The organic extracts were dried over magnesium sulphate and concentrated. Pure 1-trimethylsilyl-3-phenylpropane -2,3-diol was obtained in high yield using column chromatography.

§ 6.5 Synthesis of optically active trimethylsilylepoxides and trimethylsilyl amino alcohols

General procedure for the preparation of trimethylsilylepoxides[26,27]: All apparatus was thoroughly dried in a hot (>120°C) oven before use. Chlorotrimethylsilane (6 mmol, 0.76 ml) was added to a solution of trimethylsilyl-1,2-diol (5 mmol), trimethyl orthoacetate (5.95 mmol, 0.76 ml) and PPTS (Pyridinium *p*-toluenesulphonate) (0.05mmol, 12.5 mg) in dichloromethane (15 ml) at 0°C under nitrogen. The solution was stirred for 60 minutes, then evaporated to obtain the crude trmethylsilyl acetoxy halide. The crude product was dissolved in dry methanol (10 ml) and K_2CO_3 (12.5 mmol, 1.73 g)was added. The suspension was stirred vigorously for 100 min, then filtered and the residue washed with CH_2Cl_2. The filtrate was evaporated in a rotary evaporator at room temperature under vacuum (water aspirator) and the residue purified by flash chromatography on silica gel (Hexane : EtOAc : Et_2O = 75 / 20 / 5). The purity of the silylepoxide was checked on a GC BP-5 column (70-170°C), since the epoxysilanes are invisible on TLC plates under UV light.

General procedure for the preparation of trimethylsilyl azido alcohols [27,28,29]: To a 100 ml round-bottomed flask equipped with a condenser and a magnetic stirrer bar was added 3 mmol of the trimethylsilyl epoxide, 6 mmol, 321 mg of ammonium chloride, 15 mmol, 975 mg, of sodium azide in 16 ml of methanol and 2 ml of water. The mixture was refluxed for 6 hours and then cooled to room temperature. The methanol was removed under vacuum and the residue was extracted with ether (15ml X 3). The extracts were dried over $MgSO_4$ and concentrated in a rotary evaporator to obtain the crude trimethylsilyl azido alcohol. The crude product was purified by flash chromatography on silica gel [petrol (45-60°C) : EtOAc : Et_2O = 75 / 20 / 5].

General procedure for the preparation of trimethylsilyl amino alcohols[27]: All apparatus was thoroughly dried in a hot (>120°C) oven before use. To a round-bottomed flask equipped with reflux condenser, nitrogen inlet bubbler and a magnetic stirrer bar was added 2 mmol of trimethylsilyl azido alcohol in 15 ml of dry diethyl ether. To this was added carefully and slowly 4 mmol, 152 mg of lithium aluminium hydride. The reaction mixture was stirred at room temperature for 2 hours, and then 5 ml of 20% sodium hydroxide was added gradually. The mixture was separated and the aqueous phase was extracted with ether (15ml X 3). The ethereal extracts were dried over magnesium sulphate and concentrated to give the trimethylsilyl amino alcohol.

The following data refer to reactions of derivatives of trimethylsilyl-1,2-diols made from AD-mix -β. The physical properties of the corresponding derivatives of trimethylsilyl-1,2-diols made from AD-mix-α were identical apart from the configurations and the e.e.s which are given in the Tables 4.1 and 4.3.

***trans*-1-Trimethylsilylhexane-1,2-epoxide** (4aA) (95%e.e., 534.3 mg, 62% yield). The general procedure for the preparation of the trimethylsilylepoxides was used and the title compound was made from 5 mmol, 952 mg of *1R,2R-threo*-1-trimethylsilylhexane-1,2-diol. Intermediate (shown in Scheme 4.1) **2a** (86%) 1-trimethylsilyl-2-chloro-1-acetoxyhexane NMR(ppm) $\delta_H(CDCl_3)$ 0.16 (9H, s, $SiMe_3$),

0.88 (3H, t, J = 6.8 Hz, CH_3), 1.24- 1.33 (4H, m, CH_2), 1.50-1.85 (1H, m, CH_2), 2.07 (3H, s, Me), 3.51 (1H, d, J 3.9 Hz, CHSi), 5.13 (1H, dt, J 9.8 Hz, J 3.7 Hz, CH), $\delta_C(CDCl_3)$ -0.65 (3C, $SiMe_3$), 13.93 (1C, CH_3), 21.17 (1C, CH_3), 22.37 (1C, CH_2), 27.66 (1C, CH_2), 31.35 (1C, CH_2), 52.95 (1C, CHSi), 75.35 (1C, CH), 170.62 (1C, CO). Intermediate (shown in Scheme 4.1) **3a** (14%) 1-trimethylsilyl-1-chloro-2-acetoxyhexane $\delta_H(CDCl_3)$ 0.15 (9H, $SiMe_3$), 0.88 (3H, t, J 6.8 Hz, CH_3), 1.24- 1.33 (4H, m, CH_2), 1.50-1.85 (1H, m, CH_2), 2.07 (3H, s, Me), 3.45 (1H, d, J 3.9 Hz, CHSi), 4.67 (1H, m, CH), $\delta_C(CDCl_3)$ -0.37 (3C, $SiMe_3$), 14.00 (1C, CH_3), 21.17 (1C, CH_3), 22.52 (1C, CH_2), 28.18 (1C, CH_2), 33.95 (1C, CH_2), 57.67 (1C, CHSi), 74.04 (1C, CH), 170.62 (1C, CO). The title compound **4aA** υ_{max} (neat film/cm^{-1}) 2958.0 (vs, CH), 2931.0 (s, CH_3), 2874.4 (m, CH_3), 2861.1 (m, CH_2), 1467.3 (w, CH), 1418.1 (w), 1249.3 (s, SiMe), 865.1 (vs, $SiMe_3$), 841.2 (vs, $SiMe_3$), 765.5 (w), 748.7 (w), 699.9 (w); NMR(ppm) $\delta_H(CDCl_3)$ 0.05 (9H, $SiMe_3$), 0.91 (3H, CH_3), 1.32-1.61 (6H, m, CH_2), 1.96 (1H, d, J 3.6 Hz, CH-Si), 2.73-2.77 (1H, m, CH); $\delta_C(CDCl_3)$ -3.67 (3C, $SiMe_3$), 14.03 (1C, CH_3), 22.54 (1C, CH_2), 28.50 (1C, CH_2), 33.75 (1C, CH_2), 51.71 (1C, CH-Si), 56.17 (1C, CH); m/z (EI+) 172 (1%, M^+), 157 (5, $C_8H_{17}Si$), 143 (3, $C_7H_{15}OSi$), 129 (30, $C_6H_{13}OSi$), 101 (4, C_4H_9OSi), 99 (4, $C_6H_{11}O$), 85 (7, C_5H_9O), 73 (100. $SiMe_3$), 59 (20, $HSiMe_2$), 45 (20, C_2H_5O), 43 (15, C_3H_7) (Found: C, 62.78, H, 11.55, $C_9H_{20}OSi$ requires C, 62.72, H, 11.55%).

1-Azido-1-trimethylsilylhexan-2-ol (5aA) (523.3 mg, 81% yield). The general procedure for the preparation of the trimethylsilyl azido alcohls was used and the title compound was made from 3 mmol, 517 mg of 4aA. Rf (petrol : EtOAc : Et_2O = 75 : 20 : 5) 0.80. υ_{max}(neat film/cm^{-1}) 3399.7 (br, OH), 2958.2 (s, CH), 2933.4 (s, CH_3), 2873.3 (m, CH_3), 2861.6 (m, CH_2), 2092.3 (vs, N_3), 1466.8 (w, CH), 1458.8 (w, CH_2), 1251.3 (s, SiMe), 1012.7 (w, C-O), 841.5 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ 0.16 (9H, s, $SiMe_3$), 0.90 (3H, t, J 7.8 Hz, CH_3), 1.28-1.55 (6H, m, CH_2), 1.72 (1H, d, J 6.0 Hz, OH), 2.96 [1H, d. J 4.8 Hz, $CH(N_3)$-Si], 3.77-3.81 (1H, m, CH), $\delta_C(CDCl_3)$ -1.55 (3C, $SiMe_3$), 14.33 (1C, CH_3), 22.87 (1C, CH_2), 28.41 (1C, CH_2),

34.99 (1C, CH_2), 61.18 [1C, $CH(N_3)$-Si], 73.75 (1C, CH); ^1H-^1H COSY 2-D and ^1H-^{13}C clearly show the proton OH is coupled with the butyl-CH.

1-Azido-1-trimethylsilylhexan-2-ol (6aA) (95%e.e., 329.5 mg, 87% yield). The general procedure for the preparation of the trimethylsilyl amino alcohols was used and the title compound was made from 2 mmol, 430.7 mg of 5aA. υ_{max}(neat film/cm^{-1}) 3349.0 (s, CH), 2936.7 (s, CH_3), 2874.0 (m, CH_3), 2859.0 (m, CH_2), 1466.0 (w, CH), 1250.0 (s, $SiMe_3$), 838.0 (vs, $SiMe_3$); NMR (ppm) δ_H($CDCl_3$) 0.07 (9H, s, $SiMe_3$), 0.90 (3H, t, J 7 Hz, CH_3), 1.22-1.53 (6H, m, CH_2), 1.73 (2H, br, OH, NH_2), 2.36 [1H, d, $CH(NH_2)$], 3.63-3.67 (1H, m, CH); δ_C($CDCl_3$) -2.82 (3C, $SiMe_3$), 14.07 (1C, CH_3), 22.70 (1C, CH_2), 28.61 (1C, CH_2), 33.55 (1C, CH_2), 48.20 (1C, CH-Si), 74.29 (1C, CH); m/z (FAB+) 190 (45%, MH^+), 172 (48, M-H_2O), 156 (4, $C_9H_{17}Si$) 128 (8, $C_6H_{14}NSi$), 98 (19, $C_6H_{12}N$), 73 (100, $SiMe_3$), 56 (20, C_3H_6N), 45 (16, H_2SiMe), 43 (15, C_3H_7).

***trans*-1-Trimethylsilylheptane-1,2-epoxide (4bA)** (95%e.e., 605.7 mg, 65%yield). The general procedure for the preparation of the trimethylsilylepoxides was used and the title compound was made from 5 mmol, 1022 mg of *1R,2R*-1-*threo*-1-trimethylsilylheptane-1,2-diol. υ_{max}(neat film/cm^{-1}) 2958.0 (s, CH), 2931.0 (s, CH_3), 2859.0 (m, CH_2), 1467.0 (w, CH), 1250.0 (s, SiMe), 875.0 (s, $SiMe_3$), 842.0 (vs, $SiMe_3$), 749.0 (w), 700.0 (w), 611.0 (w); NMR (ppm) δ_H($CDCl_3$) 0.05 (9H, s, $SiMe_3$), 0.89 (3H, t, J 7.1 Hz, CH_3), 1.29-1.61 (8H, m, CH_2), 1.96 (1C, d, J 4.0 Hz, CH-Si), 2.73-2.77 (1H, m, CH), δ_C($CDCl_3$) -3.67 (3C, $SiMe_3$), 13.98 (1C, CH_3), 22.59 (1C, CH_2), 26.01 (1C, CH_2), 31.65 (1C, CH_2), 34.01 (1C, CH_2), 51.72 (1C, CH-Si), 56.19 (1C, CH); m/z (EI+) 186 (1%, M^+), 171 (3, M^+-CH_3), 157 (5, $C_8H_{17}OSi$), 143 (6, $C_7H_{15}OSi$), 129 (44, $C_6H_{13}OSi$), 115 (12, $C_5H_{11}OSi$), 101 (10, C_4H_9OSi), 99 (9, $C_6H_{11}O$), 85 (8, C_5H_9O), 75 (54, C_2H_7OSi), 73 (100, $SiMe_3$), 59 (23, $HSiMe_2$), 45 (22, CH_5Si), 43 (20, C_3H_7) (Found: C, 65.08, H, 11.81, $C_{10}H_{22}OSi$ requires C, 64.45, H, 11.90%). A by product, 1,1-dimethoxyheptane was obtained, υ_{max}(neat film/cm^{-1}) 2953.0 (s, CH), 2930.2 (s, CH_3), 2859.8 (m, CH_2), 1134.7 (s,), 1125.3 (s,), 1061.7 (s

); NMR(ppm) $\delta_H(CDCl_3)$ 0.87 (3H, t, J 6.8 Hz, CH_3), 1.20-1.32 (10H, m, CH_2), 1.55-1.61 (2H, m, CH_2), 3.30 (6H, s, OMe), 4.35 (1H, t, J 6.0 Hz, CH), $\delta_C(CDCl_3)$ 14.03 (1C, CH_3), 22.56 (1C, CH_2), 24.55 (1C, CH_2), 29.12 (1C, CH_2), 31.76 (1C, CH_2), 32.47 (1C, CH_2), 52.53 (2C, OMe), 104.54 (1C, CH).

1-Azido-1-trimethylsilylheptan-2-ol (5bA) (578 mg, 84% yield, 100% G-2). The general procedure for the preparation of the trmethylsilyl azido alcohols was used and the title compound was made from 3 mmol, 559 mg of 4bA. Rf (petrol : EtOAc : Et_2O = 75 : 20 : 5) 0.81. υ_{max}(neat film/cm^{-1}) 3444.3 (s, CH), 2932.6 (s, CH_3), 2873.1 (m, CH_3), 2860.2 (m, CH_2), 2092.4 (vs, N_3), 1467.0 (w, CH), 1459.5 (w, CH_2), 1252.1 (s, SiMe), 841.5 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ 0.15 (9H, $SiMe_3$), 0.90 (3H, CH_3), 1.25-1.34 (6H, m, CH_2), 1.48-1.53 (2H, m, CH_2),1.72 (1H, br, OH), 2.96 [1H, d, J 5.2 Hz, $CH(N_3)$-Si], 3.78-3.81 (1H, m, CH), $\delta_C(CDCl_3)$ -1.86 (3C, $SiMe_3$), 14.00 (1C, CH_3), 22.59 (1C, CH_2), 25.63 (1C, CH_2), 31.66 (1C, CH_2), 34.96 (1C, CH_2), 60.87 [1C, $CH(N_3)$-Si], 73.45 (1C, CH); ^1H-^1H COSY 2-D and ^1H-^{13}C COSY 2-D clearly show the proton O<u>H</u> is coupled with the pentyl-C<u>H</u>.

1-Amino-1-trimethylsilylheptan-2-ol (6bA) (95%e.e., 362.1 mg, 89% yield). The general procedure for the preparation of the trimethylsilyl amino alcohols was used and the title compound was made from 2 mmol, 458.8 mg of 5bA. υ_{max}(neat film/cm^{-1}) 3357.2 (br,), 3311.0 (br,), 3287.3 (br,), 2955.7 (s, CH), 2930.9 (s, CH_3), 2872.3 (m, CH_3), 2859.2 (m, CH_2), 1466.7 (w, CH), 1456.9 (w, CH_2), 1249.6 (s, SiMe), 837.8 (vs, $SiMe_3$), 752.2 (w,); NMR (ppm) $\delta_H(CDCl_3)$ 0.07 (9H, s, $SiMe_3$), 0.88 (3H, t, J 6.8 Hz, CH_3), 1.24-1.53 (8H, m, CH_2), 1.78 (3H, br, OH, NH_2), 2.36 (1H, d, CH-Si), 3.64-3.68 (1H, m, CH), $\delta_C(CDCl_3)$ -2.33 (3C, $SiMe_3$), 14.05 (1C, CH_3), 22.67 (1C, CH_2), 26.12 (1C, CH_2), 31.87 (1C, CH_2), 33.80 (1C, CH_2), 48.22 [1C, $CH(NH_2)$-Si], 74.26 (1C, CH); m/z (FAB+) 204 (84%, MH^+), 186 (96, MH^+-H_2O), 112 (20, $C_7H_{14}N$), 73 (100, $SiMe_3$) (Found: C, 58.95, H, 12.29, $C_{10}H_{25}NOSi$ requires C, 59.05, H, 12.23%).

***cis*-1-Trimethylsilylheptane-1,2-epoxide (4dA)** (61%e.e., 368.4 mg, 61% yield). The general procedure for the preparation of the trimethylsilylepoxides was used and the title compound was made from 5 mmol, 1022 mg of *1S,2R-erthro*-1-trimethylsilyl-heptane-1,2-diol. υ_{max}(neat film/cm^{-1}) 2957.0 (s, CH), 2928.4 (s, CH_3), 2860.0 (m, CH_2), 1467.2 (w, CH), 1459.2 (w, CH_2), 1250.3 (s, SiMe), 885.1 (m, $SiMe_3$), 841.3 (vs, $SiMe_3$); NMR (ppm) δ_H($CDCl_3$) 0.12 (9H, s, $SiMe_3$), 0.90 (3H, t, J 6.8 Hz, CH_3), 1.30-1.54 (8H, m, CH_2), 2.19 (1H, d, J 5.2 Hz, CH-Si), 3.08-3.11 (1H, m, CH), δ_C($CDCl_3$) -1.73 (3C, $SiMe_3$), 14.00 (1C, CH_3), 22.61 (1C, CH_2), 26.75 (1C, CH_2), 31.54 (1C, CH_2), 31.74 (1C,CH_2), 50.63 (1C, CH-Si), 57.71 (1C, CH); m/z (EI+) 186 (1%, M^+), 171 (2%, M^+-Me), 157 (2, $C_8H_{17}OSi$), 155 (7, $C_9H_{19}Si$), 143 (3, $C_7H_{15}OSi$), 129 (23, $C_6H_{13}OSi$), 115 (4, $C_5H_{11}OSi$), 101 (4, C_4H_9OSi), 99 (3, $C_6H_{11}O$), 85 (4, C_5H_9O), 75 (27, C_2H_7OSi), 73 (100, $SiMe_3$), 59 (21, $HSiMe_2$), 45 (8, CH_5Si), 43 (6, C_3H_7)(Found: C, 64.65, H, 11.67, $C_{10}H_{22}OSi$ requires C, 64.45, H, 11.90%).

1-Azido-1-trimethylsilylheptan-2-ol (5dA) (585 mg, 85% yield). The general procedure for preparation of trimetylsilyl azido alcohols was used and the title compound was made from 3 mmol, 559 mg of 4dA. Rf (petrol : EtOAc : Et_2O = 75 : 20 : 5) 0.81. υ_{max}(neat film/cm^{-1}) 3448.1 (br, OH), 2957.0 (s, CH), 2932.3 (s, CH_3), 2872.8 (m, CH_3), 2860.0 (m, CH_2), 2090.3 (vs, N_3), 1467.0 (w, CH), 1459.1 (w, CH_2), 1379.6 (w, N_3), 1251.3 (s, SiMe), 1121.3 (w, N_3), 1044.2 (w, C-O), 841.2 (s, $SiMe_3$), 752.0 (w); NMR (ppm) δ_H($CDCl_3$) 0.17 (9H, s, $SiMe_3$), 0.90 (3H, t, J 6.8 Hz, CH_3), 1.25-1.21 (8H, m, CH_2), 1.71 (1H, d, J 6.8Hz, OH), 2.81 [1H, d, J 4 Hz, CH(N_3)-Si], 3.72 (1H, m, CH); δ_C($CDCl_3$) -2.08 (3C, $SiMe_3$), 14.02 (1C, CH_3), 22.59 (1C, CH_2), 25.63 (1C, CH_2), 31.70 (1C, CH_2), 35.76 (1C, CH_2), 59.97 [1C, CH(N_3)-Si], 72.59 (1C, CH); ^{1}H-^{1}H COSY 2-D and ^{1}H-^{13}C COSY 2-D clearly show the proton O<u>H</u> is coupled with the pentyl-C<u>H</u>.

1-Amino-1-trimethylsilylheptan-2-ol (6dA) (61%e.e., 345.8 mg, 85% yield). The general procedure for the preparation of the trimethylsilyl amino alcohols was used and

the title compound was made from 2 mmol, 458.8 mg of 5dA. υ_{max}(neat film/cm^{-1}) 3359.7 (br), 3291.1 (br), 3190.0 (br), 2955.7 (s, CH), 2929.4 (s, CH_3), 2872.6 (m, CH_3), 2859.2 (m, CH_2), 1466.7 (w, CH), 1459.0 (w, CH_2), 1249.1 (s, SiMe), 1121.9 (w, C-N) 1066.5 (w, O-C), 1050.4 (w,), 1021.8 (w, C-N), 838.3 (vs, $SiMe_3$), 751.3; NMR (ppm) δ_H($CDCl_3$) 0.07 (9H, s, $SiMe_3$), 0.89 (3H, t, J 6.8 Hz, CH_3), 1.25-1.44 (8H, m, CH_2), 2.13 [1H, d, J 4.8 Hz, CH(NH_2)-Si], 3.51-3.56 (1H, m, CH), δ_C($CDCl_3$) -2.79 (3C, $SiMe_3$), 14.05 (1C, CH_3), 22.69 (1C, CH_2), 25.78 (1C, CH_2), 31.94 (1C, CH_2), 35.61 (1C, CH_2), 45.95 [1C, CH(NH_2)-Si], 71.75 (1C, CH); m/z (FAB+) 204 (40%, MH^+), 186 (57, MH^+-HO), 112 (14, $C_7H_{14}N$), 73 (100, $SiMe_3$).

***trans*-1-Trimethylsilyloctane-1,2-epoxide (4cA)** (95%e.e., 631.3 mg, 63% yield). The general procedure for the preparation of the trimethylsilylepoxides was used and the title compound was made from 5 mmol, 1092 mg of *1R,2R-threo*-1-trimethylsilyloctane-1,2-diol. Intermediate (shown in Scheme 4.1) **2c** (93%) 1-trimethylsilyl-2-chloro-1-acetoxyoctane: υ_{max}(neat film/cm^{-1}) 2957.0 (s, CH), 2929.0 (s, CH_3), 2859.0 (m, CH_2), 1741.0 (vs, C=O), 1467.0 (w), 1372.0 (w), 1251.0 (s, SiMe), 1235.0 (s), 1143.0 (m), 1102.0 (m), 1022.0 (w), 934.0 (m), 843.0 (s, $SiMe_3$), 757.0 (m), 698.0 (m), NMR (ppm) δ_H($CDCl_3$) -0.17 (9H, $SiMe_3$), 0.88 (3H, t, J 7.1 Hz, CH_3), 1.27- 1.42 (8H, m, CH_2), 1.48-1.86 (1H, m, CH_2), 2.07 (3H, s, Me), 3.52 (1H, d, J 3.9 Hz, CHSi), 5.13 (1H, dt, J 9.8 Hz, J 3.4 Hz, CH), δ_C($CDCl_3$) -0.67 (3C, $SiMe_3$), 11.40 (1C, CH_3), 21.17 (1C, CH_3), 22.37 (1C, CH_2), 22.52 (1C, CH_2), 25.48 (1C, CH_2), 28.96 (1C, CH_2), 31.66 (2C, CH_2), 52.97 (1C, CHSi), 75.43 (1C, CH), 170.62 (1C, CO). The title compound **4cA** υ_{max}(neat film/cm^{-1}) 2958.0 (s, CH), 2929.0 (s, CH_3), 2858.0 (m, CH_2), 1467.0 (w, CH), 1419.0 (w), 1379.0 (w), 1290.0 (w), 1250.0 (s, SiMe), 1133.0 (w), 842.0 (vs, $SiMe_3$), 750.0 (w),700.0 (w); NMR (ppm) δ_H($CDCl_3$) 0.05 (9H, s, $SiMe_3$), 0.88 (3H, t, J 6.8 Hz, CH_3), 1.22-1.64 (10H, m, CH_2), 1.96 (1H, d, J 3.2 Hz, CH-Si), 2.73-2.77 (1H, m, CH), δ_C($CDCl_3$) -3.67 (3C, $SiMe_3$), 14.05 (1C, CH_3), 22.56 (1C, CH_2), 26.32 (1C, CH_2), 29.14 (1C, CH_2), 31.79 (1C, CH_2), 34.06 (1C, CH_2), 51.71 (1C, CH-Si), 56.17 (1C, CH); m/z (EI+) 200 (2%,

M^+), 185 (4, M^+-CH_3), 171 (4, $C_9H_{19}OSi$), 169 (6, $C_{10}H_{21}Si$), 157 (9, $C_8H_{17}OSi$), 143 (3, $C_7H_{15}OSi$), 129 (28, $C_6H_{13}OSi$), 115 (7, $C_5H_{11}OSi$), 101 (6, C_4H_9OSi), 99 (5, $C_6H_{11}O$), 85 (5, C_5H_9O), 75 (27, C_2H_7OSi), 73 (100, $SiMe_3$), 59 (20, $HSiMe_2$), 45 (8, CH_5Si), 43 (7, C_3H_7) (Found: C, 65.63, H, 11.91, $C_{11}H_{24}OSi$ requires C, 65.93, H, 12.07%). A by product, 1,1-dimethoxyoctane was obtained, υ_{max}(neat film/cm^{-1}) 2927.0 (s, CH_3), 2858.0 (m, CH_2), 1192.0 (w), 1134.0 (m), 1056.0 (m), $\delta_H(CDCl_3)$ 0.86 (3H, t, J 6.8 Hz, CH_3), 1.26-1.29 (10H, m, CH_2), 1.55-160 (2H, m, CH_2), 3.30 (6H, s, OMe), 4.34 (1H, t, J 5.6 Hz, CH), $\delta_C(CDCl_3)$ 13.82 (1C, CH_3), 22.39 (1C, CH_2), 24.37 (1C, CH_2), 28.99 (1C, CH_2), 29.20 (1C, CH_2), 31.76 (1C, CH_2), 32.45 (1C, CH_2), 52.51 (1C, OMe), 104.52 (1C, CH).

1-Azido-1-trimethylsilyloctan-2-ol (5cA) (635.3 mg, 87% yield). The general procedure for the preparation of the trimethylsilyl azido alcohls was used and the title compound was made from 3 mmol, 601.2 mg of 4cA. Rf (petro : EtOAc : Et_2O = 75 : 20 : 5) 0.82. υ_{max} (neat film/cm^{-1}) 3433.1 (br, OH), 2957.0 (s, CH), 2930.1 (s, CH_3), 2858.3 (m, CH_2), 2092.4 (vs, N_3), 1252.2 (s, SiMe), 841.2 (s, $SiMe_3$); NMR (ppm) $\delta_H(CDCl_3)$ 0.15 (9H, s, $SiMe_3$), 0.89 (3H, t, J 6.6 Hz, 1.22-1.42 (8H, m, CH_2), 1.52 (2H, m, CH_2), 1.73 (1H, d, J 6.0 Hz, OH), 2.95 [1H, d, J 5.2 Hz, CH(N_3)-Si], 3.80 (1H, m, CH), $\delta_C(CDCl_3)$ -1.88 (3C, $SiMe_3$), 14.03 (1C, CH_3), 22.56 (1C, CH_2), 25.89 (1C, CH_3), 29.14 (1C, CH_2), 31.76 (1C, CH_2), 60.85 (1C, CH(N_3)-Si), 73.44 (1C, CH); ^1H-^1H COSY 2-D and ^1H-^{13}C COSY 2-D clearly show the proton O<u>H</u> is coupled with the hexyl-C<u>H</u>.

1-Amino-1-trimethylsilyloctan-2-ol (6cA) (95%e.e., 374.1 mg, 86% yield). The general procedure for the preparation of the trimethylsilyl amino alcohols was used and the title compound was made from 2 mmol, 486.8 mg of 5cA. υ_{max}(neat film/cm^{-1}) 3361.0 (br, OH), 2956.0 (s, CH), 2928.0 (s, CH_3), 2957.0 (m, CH_2), 1466.0 (w, CH), 1379.0 (w), 1250.0 (s, SiMe), 1032.0(w, C-O), 839.0 (s, $SiMe_3$), 753.0 (w) 692.0 (w); NMR (ppm) $\delta_H(CDCl_3)$ 0.07 (9H, s, $SiMe_3$), 0.88 (3H, t, J 6.8 Hz, CH_3),1.24-1.70 (13H, m, CH_2, OH, NH_2), 2.36 (1H, d, J 4.4 Hz, CH(NH_2)-Si), 3.64-3.67 (1H, m, CH),

$\delta_C(CDCl_3)$ -2.33 (3C, $SiMe_3$), 14.07 (1C, CH_3), 22.61 (1C, CH_2), 26.42 (1C, CH_2), 29.34 (1C, CH_2), 31.85 (1C, CH_2), 33.86 (1C, CH_2), 48.20 (1C, $CH(NH_2)$-Si), 74.29 (1C, CH); m/z (FAB+) 218 (55%, MH^+), 200 (74, M-H_2O), 126 (21), 102 (12), 73 (100, $SiMe_3$), 56 (21, $HSiMe_2$) (Found: C, 60.94, H, 12.45, $C_{11}H_{27}NOSi$ requires C, 60.77, H, 12.52%).

***cis*-1-Trimethylsilyloctane-1,2-epoxide (4eA)** (61%e.e., 611.2 mg, 61% yield). The general procedure for the preparation of the trimethylsilylepoxides was used and the title compound was made from 5 mmol, 1092 mg of *1R,2S-erythro*-1-trimethylsilyloctane-1,2-diol. υ_{max}(neat film/cm^{-1}) 2957.0 (s, CH), 2927.5 (s, CH_3), 2872.9 (m, CH_3), 2858.1 (m, CH_2), 1466.9 (w, CH), 1459.1 (w, CH_2), 1418.2 (w), 1250.1 (s, SiMe), 841.4 (vs, $SiMe_3$), 754.4 (m), 695.1 (w), 651.7 (w); NMR (ppm) $\delta_H(CDCl_3)$ 0.12 (9H, s, $SiMe_3$), 0.88 (3H, t, J 6.8 Hz, CH_3), 1.26-1.52 (10H, m, CH_2), 2.18 (1H, d, J 5.2 Hz, CH-Si), 3.08 (1H, m, CH), $\delta_C(CDCl_3)$ -1.73 (3C, $SiMe_3$), 14.05 (1C, CH_3), 19.56 (1C, CH_2), 27.02 (1C, CH_2), 29.21 (1C, CH_2), 31.57 (1C, CH_2), 31.77 (1C, CH_2), 50.63 (1C, CH-Si), 57.69 (1C, CH); m/z (EI+) 200 (10%, M^+), 185 (18, M-CH_3), 171 (6, $C_9H_{19}OSi$), 169 (4, $C_{10}H21Si$), 157 (20, $C_8H_{17}OSi$), 143 (2, $C_7H_{15}OSi$), 129 (12, $C_6H_{13}OSi$), 115 (7, $C_5H_{11}OSi$), 101 (3, C_4H_9OSi), 99 (3, $C_6H_{11}O$), 85 (4, C_5H_9O), 75 (25, C_2H_5Si), 73 (100, $SiMe_3$), 58 (13, $SiMe_2$), 45 (12, CH_5Si), 43 (11, C_3H_7) (Found: C, 66.08, H, 11.81, $C_{11}H_{24}OSi$ requires C, 65.93, H, 12.07%).

***trans*-1-Trimethylsilylstyrene**[3,27] (589.6 mg, 67% yield). The general procedure for the preparation of the trimethylsilyl acetoxy halide was used to make the title compound. The title compound was made from 5 mmol, 1052 mg of *threo*-1-phenyl-3-trimethylsilylpropane-1,2-diol. m/z (EI+) 176 (30%, M^+), 161 (100, M^+-Me), 145 (51, M^+-2Me-H), 135 (25, $C_8H_{12}Si$), 105 (10, C_8H_9), 77 (5, C_6H_5), 73 (12, $SiMe_3$), 59 (34, $HSiMe_2$); NMR (ppm) $\delta_H(CDCl_3)$ 0.17 (9H, s, $SiMe_3$), 6.50 (1H, d, J 19.6 Hz, CH-Si), 6.89 (1H, d, J 19.6 Hz, CH-Ph), 7.24-7.47 (5H, m, Ph), $\delta_C(CDCl_3)$ -0.75 (3C,

$SiMe_3$), 126.82 (2C, CH, Ph), 128.51 (1C, CH, Ph), 129.00 (2C, CH, Ph), 130.01 (1C, CH-Si), 138.82 (1C, *t*-C, Ph), 144.05 (CH-Ph).

§ 6.6 Asymmetric epoxidation of allyl- and vinylsilanes catalyzed by manganese (III) salen complexes

6.6.1 Synthesis of chiral ligands and manganese(III) salen complexes

Procedure for the preparation of 4,6-di-*tert*-butyl-salicylaldehydes[30,31]: To a 3 liter three-necked round-bottomed flask equipped with a reflux condenser, magnetic stirrer, thermometer, and a nitrogen source was added 100 ml of anhydrous toluene, 0.5 mol, 103.2 g of 2,4-di-*tert*-butylphenol, 0.05 mol, 13 g of Tin(IV) chloride and 0.2 mol, 21.4 g of 2,6-lutidine. The mixture was stirred for 20 min at room temperature, then 1.1 mol, 33 g of paraformaldehyde was added. The resulting yellowish solution was heated at 100 °C for 8 hours. After cooling, the reaction mixture was poured into 2.5 liter of water, acidified to pH 2 with 2M hydrochloric acid, and extracted with ether. The ether extract was washed with a saturated sodium chloride solution, dried over Na_2SO_4, and concentrated to leave the crude 4,6-di-*tert*-butylsalicylaldehyde. The crude product was recrystalized from light petroleum (45-60 °C). υ_{max}(KBr film/cm^{-1}) 3800-2230 (br, OH-O), 2958.0 (vs, CH), 2911.0 (s), 2870.0 (s, CH_3), 1659.5 (vs, C=O), 1611.9 (m, Ar, C=C), 1494.0 (w, Ar, C=C), 1465.8 (m, Ar, C=C), 1455.9 (ms), 1439.0 (s), 1390.9 (m,), 1381.5 (ms), 1361.6 (s), 1322.8 (m), 1270.0 (s), 1249.4 (s), 1227.7 (s), 1200.4 (m), 1159.9 (s), 737.1 (ms), 712.8 (m); NMR (ppm) δ_H($CDCl_3$) 1.35 (9H, s, *t*-Bu), 1.45 (9H, s, *t*-Bu), 7.37 (1H, d, J 2.4 Hz, Ar, CH), 7.62 (1H, d, J 2.4 Hz, Ar, CH), 9.88 (1H, s, CHO), 11.68 (1H, s, OH), δ_C ($CDCl_3$) 29.23 (3C, s, CH_3), 31.28 (3C, s, CH_3), 34.2 (1C, s, *t*-C), 34.97 (1C, s, *t*-C), 119.9 (1C, s, Ar, *t*-C), 127.8 (1C, s, Ar, CH), 131.9 (1C, s, Ar, CH), 141.6 (1C, s, Ar, *t*-C), 159.1 (1C, s, Ar, *t*-C), 197.3 (1C, s, CHO); m/z (EI+) 235 (25%, M^+), 234 (30, M^+-H), 219 (100, M^+-H-Me).

Resolution of *trans*-1,2-cyclohexanediamine[32]: 50 ml (0.83 mol) of the crude *trans*-1,2-cyclohexanediamine mixture (4 equivalent of base) was dissolved in 80 ml of water in a 250 ml beaker. The solution was heated to 90 °C and first 30 g (0.21 mol) of (+)-tartaric acid, then 20 ml (0.36 mol) of glacial acetic acid was added in small portions with stirring (pH approx. 6). The mixture was cooled in ice with continued stirring. The precipitate was filtered, washed, first with 20 ml of ice cold water and then with 50 ml of ethanol and dried in air to give 23 g (0.088 mol, 42% yield) of white crystalline [(-)chxnH_2] [(+)tart].

The mother liquor was heated to 80°C, then 75 g (0.525 mol) of (+)-tartaric acid was added with stirring and the solution allowed to stand overnight at room temperature with continued stirring. The precipitate was filtered, washed, first with 9 ml of ice cold water, then with 42 ml of ethanol, and dried in air. Yield: 37 g (0.086 mol, 41%) of white crystalline [(+)chxnH_2] [H(+)tart]$_2$.H_2O.

Liberation of (-)chxn. [(-)chxnH_2] [(+)tart],47 g (0.18 mol) was placed in a 500 ml separating funnel. A solution of 40 g (mol) of KOH in 28 ml of water was added and the mixture shaken carefully. The amine layer was separated as rapidly as possible (before K_2(+)tart stared to precipitate), placed in a 500 ml flask provided with a reflux condenser fitted with a KOH drying tube, and diluted with 100 ml of ether. Sodium was added in excess, and the mixture was left overnight. The amine phase was then decanted, fresh sodium was added, and the mixture left overnight. The amine phase was decanted, treated with active carbon, and filtered under nitrogen. The yellowish solution was placed in a 500 ml flat flange flask, which was placed in a water bath of room temperature and the ether was evaporated by suction until the amine precipitated. The mixture was then cooled to -20°C before the precipitate was filtered, washed with ether (-20°C), and dried over potassium hydroxide. Yield: 16.8g, 82%.

Liberation of (+)chxn was performed in the same way using 93 g (0.215 mol) of [(+)chxnH_2] [H(+)tart]$_2$.H_2O, 40 g (1.8 mol) of KOH in 20 ml water and 102 ml ether. Yield: 20g, 84%.

Procedure for the preparation of *(S,S)*- or *(R,R)*-(-)-*N,N'*-bis(3,5-di-*tert*-butylsalicylidene-1,2-diaminocyclohexane [31, 33, 34]: 2.0 equivalent of 4,6-di-tert-butylsalicylaldehyde was added as a solid to a 0.2 M solution of *(R,R)*- or *(S,S)-trans*-1,2-cyclohexanediamine (1.0 equivalent) in absolute ethanol. The mixture was heated to reflux for 1 hour and then cooled to room temperature, and the yellow crystalline solid is collected by filtration and washed with small portion of 95% ethanol. υ_{max}(KBr film/cm^{-1}) 3500-2200 (br, O-H-N), 2962.3 (vs, CH), 2952.3 (vs, CH), 2936.1 (vs, CH_3), 2907.5 (s, CH_3), 2863.9 (s, CH_2), 1630.0 (vs, -N=C-), 1594.4 (m, Ar, C=C), 1495.0 (m, Ar, C=C), 1468.0 (s, Ar, C=C), 1449.0 (s), 1439.0 (s), 1391.0 (m) 1361.0 (s), 1270.0 (s), 1252.0 (s), 1241.1 (ms), 1202.8 (m), 1174.0 (s), 1135.2 (w), 1085.3 (w), 1038.0 (w), 878.7 (m), 826.6 (w), 828.3 (s), 772.6 (m); NMR (ppm) δ_H($CDCl_3$) 1.24 (9H, s, *t*-Bu), 1.42 (9H, s, *t*-Bu), 1.47-1.97 (8H, m, CH_2), 3.33 (2H, m, CH), 7.69 (2H, d, J 2.4 Hz, Ar, CH), 7.31 (2H, d, J 2.4 Hz, Ar, CH), 8.31 (2H, s, HC=N-), 13.72 (2H, br, O-H-N), δ_C($CDCl_3$) 24.35 (2C, s, CH_2), 29.43 (3C, s, CH_3), 31.41 (3C, s, CH_3), 33.27 (2C, s, CH_2), 34.02 (2C, s, *t*-C), 34.94 (2C, s, *t*-C), 72.43 (2C, s, N-CH), 117.86 (2C, s, Ar, *t*-C), 126.03 (2C, s, Ar, CH), 126.73 (2C, s, Ar, CH), 136.33 (2C, s, Ar, *t*-C), 139.87 (2C, s, Ar, *t*-C), 158.00 (2C, s, Ar, *t*-C), 165.81 (2C, s, -C=N); m/z (FB+, DCM/Thiodiethanol) 548 (3%, M^++2H), 281[29, M^+-(C_6H_2+2*t*-Butyl+OH)-*t*-butyl-OH+3H^+], 223 [25, (C_6H_2) (CHN) (C_6H_{10}) (NCH) + 2H^+], 207 (35, C_6H_2+2*t*-Butyl+OH + 2H^+), 191 (18, C_6H_2+2*t*-Butyl+OH - CH_3 + H^+), 133 (28, C_6H_2+*t*-Butyl +2H^+), 73 (100, C_6H); m/z (FB-) 546 (2%, M^+), 223 [25, (C_6H_2) (CHN) (C_6H_{10}) (NCH) + 2H^+].

Procedure for the preparation of *(S,S)*- or *(R,R)*-(-)-*N,N'*-bis(3,5-di-*tert*-butylsalicylidene -1,2- cyclohexane diamino manganese (III) chloride

31,33,34: 9.0 mmol, 4.92 g of ligand *(S,S)-* or *(R,R)-(-)-N,N'*-Bis(3,5-di-*tert*-butylsalicylidene-1,2-diaminocyclohexane was dissolved in 30 ml of chloroform in a 500 ml three-necked round-bottomed flask in a water bath, and 27 mmol (3 equivalent), 6.62 g of manganese acetate tetrahydrate dissolved in 250 ml of methanol was added to the flask with stirring. The mixture was heated to reflux for 3 hours, and then after cooling down for ten min, 27 mmol, 1.14 g of solid LiCl was added to the flask. The mixture was heated to reflux for 30 min with the top of the condenser opene to the atmospher. The solvent was removed under vacuum, and a dark brown crude solid product was obtained. The crude product was dissolved in 150 ml of methanol (or ethanol), and water was added gradually with a washing bottle, in 2 ml a portions, with shaking from time to time until the black crystals appearred. The mixture was filtered, and the black fine crystals washed with 20 ml of water, then dried in the open air. υ_{max}(KBr film/cm^{-1}) 2952.5 (vs), 2906.1 (m), 2866.5 (m), 1612.0 (vs), 1535.3 (s), 1462.8 (w), 1433.1 (s),1390.4 (m), 1361.1 (m), 1340.0 (m), 1312.3 (s), 1271.5 (m), 1252.6 (s), 1200,2 (w), 1175.4 (m), 837.43 (m), 781.0 (w), 749.1 (w), 570.1 (w), 543.4 (w), 485.3 (vw), 414.3 (vw), 357.3 (vw), 334.0 (vw); m/z 635 (2%, M^+), 600 (38, M^+-Cl), 547 (25, M^+ - Cl - Mn + $2H^+$), 314 [93, (C_6H_2+2*t*-Butyl+OH) + CHN + C_6H_{10}].

Procedure for the preparation of *(S,S)-* or *(R,R)-(-)-N,N'*-bis(3,5-di-*tert*-butylsalicylidene-1,2-cyclohexanediaminoiron (III) chloride: 5.0 mmol, 2.734 g of ligand *(S,S)-* or *(R,R)-(-)-N,N'*-Bis(3,5-di-*tert*-butylsilicylidene-1,2-diamino cyclohexane was dissolved in 20 ml of diethyl ether in a 100 ml 3-necked round-bottomed flask in a water bath, and 10 mmol (2 equivalent), 1.62 g of iron trichloride was added to the flask with stirring. The mixture was heated to reflux for 1 hours. The title compound precipitated out rapidly while refluxing. The reaction mixture was cooled to room temperature and filtered to give the title compound as fine black crystals. υ_{max}(KBr film/cm^{-1}) 2945.3 (vs), 2908.5 (m), 2865.7 (m), 1621.3 (s), 1598.8 (vs), 1534.5 (s), 1465.3 (w), 1428.1 (s), 1385.2 (m), 1362.4 (m), 1340.2 (m), 1312.6 (s), 1270.3 (m),

1253.1 (s), 1173.5 (m), 840.1 (m), 782.2 (w), 750.2 (w), 554.1 (w), 543.5 (w), 482.7 (vw), 355.2 (vw); m/z 600 (77%, M^+-Cl), 585 (14, M^+-Cl-Me).

6.6.2 Synthesis of optically active trimethylsilylepoxides using manganese (III) salen complexes

Procedure for the preparation of trimethylsilylepoxides using a salen manganese (III) catalyst [35]

A general Procedure: A solution of sodium hypochlorate was diluted to a final concentration of approximately 0.6 M in NaOCl using 0.05 M Na_2HPO_4. The pH of the resulting buffered solution was adjusted to pH=11.3 by the addition of 1M NaOH solution. To this solution (18.5 ml) in a 100 ml round-bottomed flask was added a solution of *(R,R)*-(-)-*N,N'*-bis(3,5-di-*tert*-butylsalicylidene-1,2-cyclohexanediamino manganese (III) chloride (0.2 mmol, 4% equivalent, 128 mg) and vinyl- or allyl-silanes (5 mmol) in 5 ml of dichloromethane (if necessary, an axial ligand was added). The two phase mixture was stirred at room temperature and the reaction progress monitored by GC (BP5). Samples were prepared by taking about 0.5 ml of the organic phase, drying it over magnesium sulphate and then passing it through a 3 cm pad of Florasil (60-100 U.S. mesh) packed in a pipet with ether / hexane (1:1) to get rid of the catalyst, followed by removal of most of the solvent. After 12 hours, 10 ml of dichloromethane was added to the mixture and the brown organic phase was separated, washed twice with 25 ml of water and once with 25 ml of saturated NaCl solution, and than dried over magnesium sulphate. After removal of the solvent, the residue was purified by flash chromatography on silica gel (hexane / ethyl acetate / ether = 75 / 20 / 5), and the collections were checked by GC (BP5) to give the silylated epoxide.

Preparation of *cis*-trimethylsilyloctane-1,2-epoxide under different conditions:

(1) Using the general procedure, the title compound was made from *cis*-octenyltrimethylsilane (5 mmol, 0.92 g) in the presence of *N*-methylimidazol (0.15 equivalent / olefin, 0.75 mmol, 62 mg) and tetra-*tert*-butylammonium bromide (0.005 equivalent / olefin, 0.025 mmol, 8.1 mg).

(2) Using the general procedure, the title compound was made from *cis*-heptenyltrimethylsilane (5 mmol, 0.85 g) in the presence of pyridine (0.15 equivalent / olefin, 0.75 mmol, 59 mg) and tetra-*tert*-butylammonium bromide (0.005 equivalent / olefin, 0.025 mmol, 8.1 mg).

(3) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g) in the presence of tetra-*tert*-butylammonium bromide (0.005 equivalent / olefin, 0.025 mmol, 8.1 mg).

(4) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g) in the presence of *N*-methylimidazol (0.15 equivalent / olefin, 0.75 mmol, 62 mg).

(5) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g) in the presence of pyridine (0.15 equivalent / olefin, 0.75 mmol, 59 mg).

(6) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g) in the presence of 4-dimethylaminopyridine (0.15 equivalent / olefin, 0.75 mmol, 93 mg).

(7) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g) in the presence of imidazole (0.15 equivalent / olefin, 0.75 mmol, 52 mg).

(8) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g).

The following experiments were performed using the manganese(III) salen catalyst purchased from Aldrich Chemical Limited.

(9) Using the general procedure, the title compound was made from *cis*-octenyl-trimethylsilane (5 mmol, 0.92 g).

(10) Using the general procedure, the title compound was made from *cis*-heptenyl-trimethylsilane (5 mmol, 0.85 g) in the presence of *N*-benzylquininium chloride (0.2 equivalent / olefin, 1.0 mmol, 451 mg).

(11) Using the general procedure, the title compound was made from *cis*-heptenyl-trimethylsilane (5 mmol, 0.85 g) in the presence of 1-benzyl-3-hydroxypyridinium chloride (0.2 equivalent / olefin, 1.0 mmol, 222 mg).

(12) Using the general procedure, the title compound was made from *cis*-heptenyl-trimethylsilane (5 mmol, 0.85 g) in the presence of 4-phenyl pyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg).

The results from (1) to (12) were shown in Table 5.2 in Chapter 5.

The manganese (III) salen complex catalyzed epoxidation of several types of allyl- and vinylsilanes and olefins

1) Formation of ***trans*-3-phenyl-2,3-epoxy-1-trimethylsilane**: Using the general procedure, the title compound was made from *trans*-3-phenyl-1-trimethylsilyl-2-propene (5 mmol, 0.95 g) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg) and internal standard: 200 mg undecane.

2) Formation of ***trans*-3-phenyl-2,3-epoxy-1-trimethylsilane**: Using the general procedure, the title compound was made from *trans*-3-phenyl-1-trimethylsilyl-2-propene (5 mmol, 0.95 g) in the presence of internal standard: 200 mg undecane.

3) Formation of ***trans*-2-hexyl-1-trimethylsilyl-1,2-epoxide**: Using the general procedure, the title compound was made from *trans*-heptenyltrimethylsilane (5 mmol, 0.92 g) in the presence of 4-phenyl pyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg) internal standard: 200 mg undecane.

4) Formation of ***cis*-2-hexyl-1-trimethylsilyl-1,2-epoxide**: Using the general procedure, the title compound was made from *cis*-heptenyltrimethylsilane (5 mmol, 0.92 g) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg) internal standard: 200 mg undecane.

5) Formation of ***cis*-3-hexyl-1-trimethylsilyl-2,3-epoxide**: Using the general procedure, the title compound was made from *cis*-1-trimethylsilyl-2-nonene (5 mmol, 0.99 g) in the presence of 4-phenyl pyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg) internal standard: 200 mg undecane.

6) Formation of ***cis*-5,6-epoxydecane**: Using the general procedure, the title compound was made from *cis*-5-decene (5 mmol, 0.77 g) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg) internal standard: 200 mg undecane.

The results from 1) to 6) were shown in Table 5.3 in Chapter 5.

Preparation of *cis* and *trans*-trimethylsilylheptane-1,2-epoxides from *cis*-1-trimethylsilyl-1-heptene:

Using the general procedure, the title compound (280 mg, 28% yield, *cis* / *trans* = 2.52) was made from *cis*-1-trimethylsilyl-1-heptene (5 mmol, 0.85 g) and 10% *(R,R)-(-)-N,N'-*

bis(3,5-di-*tert*-butylsalicylidene-1,2-cyclohexane diamino manganese (III) chloride (342 mg) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg).

***cis*-Trimethylsilylheptane-1,2-epoxide[27]:** (58%e.e.). IR, NMR, and MS data of the title compound prepared from above procedure were indentical with the one prepared in section § 6.5. Absolute configuration of the title compound was *1S, 2R* in comparison with one made from trimethylsilyl-1,2-diol (AD-mix-α) using chromatogram on Chiraldex G-PN 20m X 0.25mm chiral GC column

***trans*-1-Trimethylsilylheptane-1,2-epoxide[27]:** (95% e.e.). IR, NMR, and MS data of the title compound prepared from above procedure were indentical with the one prepared in section § 6.5. Absolute configuration of the title compound was *1S, 2S* in comparison with one made from trimethylsilyl-1,2-diol (AD-mix-α) using chromatogram on Chiraldex G-PN 20m X 0.25mm chiral GC column

Preparation of *cis* and *trans*-trimethylsilyloctane-1,2-epoxide from *cis*-1-trimethylsilyl-1-octene:

Using the general procedure, the title compound (427 mg, 43% yield, *cis* / *trans* = 2.54) was made from *cis*-1-trimethylsilyl-1-octene (5 mmol, 0.92 g) and 10% *(R,R)-(-)-N,N'*-bis(3,5-di-*tert*-butylsalicylidene-1,2-cyclohexane diamino manganese (III) chloride (342 mg) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg).

***cis*-1-Trimethylsilyloctane-1,2-epoxide[27]:** (58% e.e.). IR, NMR, and MS data of the title compound prepared from above procedure were indentical with the one prepared in section § 6.5. Absolute configuration of the title compound was *1S, 2R* in comparison with one made from trimethylsilyl-1,2-diol (AD-mix-α) using chromatogram on Chiraldex G-PN 20m X 0.25mm chiral GC column

***trans*-1-Trimethylsilyloctane-1,2-epoxide[27]:** (95% e.e.). IR, NMR, and MS data of the title compound prepared from above procedure were indentical with the one prepared in section § 6.5. Absolute configuration of the title compound was *1S, 2S* in

comparison with one made from trimethylsilyl-1,2-diol (AD-mix-α) using chromatogram on Chiraldex G-PN 20m X 0.25mm chiral GC column

Preparation of trimethylsilylpropane-2,3-epoxide:

Using the general procedure, the title compound (0.54 g, 83% yield) was made from allyltrimethylsilane (5 mmol, 0.57 g) in the presence of pyridine (0.15 equivalent / olefin, 0.75 mmol, 59 mg) and tetra-*tert*-butylammonium bromide (0.005 equivalent / olefin, 0.025 mmol, 8.1 mg). Trimethylsilylpropane-2,3-epoxide was unstable on a silica column. The crude trimethylsilylpropane-2,3-epoxide was obtained by passing it quickly through a 3 cm a pad of florasil (60-100 U.S. mesh) using 40-60°C petroleum / ether (1 / 1) to get rid of the catalyst. The solvent was removed by rotary evaporation followed by further purification by vacuum distillation. υ_{max}(film/cm^{-1}) 3040.0 (vw,), 2966.0 (s, C-H), 2898.0 (w, CH_3), 1418.0 (w), 1392.0 (w, CH_3), 1251.0 (s, SiMe), 1187.0 (w, C-O-C), 1079.0 (w, C-O-C), 1014.0 (w), 944.0 (w), 932.0 (w), 848.0 (vs, $SiMe_3$), 754.0 (w), 697.0 (m); NMR (ppm) $\delta_H(CDCl_3)$ 0.08 (9H, s, $SiMe_3$), 0.58 (1H^a, dd, J 8 Hz, J 14 Hz, CH_2-Si), 1.17 (1H^b, dd, J 5 Hz, J 14 Hz, CH_2-Si), 2.41 (1H^a, dd, J 3 Hz, J 5Hz, CH_2-O), 2.78 (1H^b, dd, J 4 Hz, J 5 Hz, CH_2-O), 2.95-3.00 (1H. m, CH-O), $\delta_C(CDCl_3)$ -1.25 (3C, s, $SiMe_3$), 21.08 (1C, s, CH_2-Si), 48.56 (1C, s, CH_2-O), 50.52 (1C, s, CH-O).

Preparation of *trans*-1-trimethylsilyl-3-phenylpropane-2,3-epoxide:

Using the general procedure, the title compound (937 mg, 91% yield) was made from *trans*-1-trimethylsilyl-3-phenyl-2-propene (5 mmol, 0.95 g) in the presence of pyridine (0.15 equivalent / olefin, 0.75 mmol, 59 mg) and tetra-*tert*-butylammonium bromide (0.005 equivalent / olefin, 0.025 mmol, 8.1 mg). υ_{max}(film/cm^{-1}) 3087.3 (vw, C-H, Ar), 3065.0 (vw, C-H, Ar), 3032.2 (vw, C-H, Ar), 2955.0 (s, C-H, CH_2-Si), 2894.6 (w, C-H, CH_2-Si), 1496.2 (w, C=C, Ar), 1459.2 (w, C=C, Ar), 1250.2 (s, SiMe), 1177.8 (w, C-O-C), 1012.2 (w), 884.6 (s), 859.8 (vs, $SiMe_3$), 838.8 (vs, $SiMe_3$), 750.6 (s,), 697.8 (s,); NMR (ppm) $\delta_H(CDCl_3)$ 0.10 (9H, s, $SiMe_3$), 0.81 (1H^a, dd, J 8 Hz,

J 14 Hz, CH_2-Si), 1.28 ($1H^b$, dd, J 5 Hz, J 14 Hz, CH_2-Si), 2.97 (1H, m, CH-C-Si), 3.54 (1H, d, J 2 Hz, CH-Ph), 7.25-7.36 (5H, m, Ph); $\delta_C(CDCl_3)$ -1.20 (3C, s, $SiMe_3$), 21.30 (1C, s, CH_2-Si), 60.03 (1C, s, CH-Ph), 61.42 (1C, s, CH-C-Si), 125.37 (2C, s, Ph), 127.86 (1C, s, Ph), 128.43 (2C, s, Ph), 138.08 (1C, s, t-C, Ph); m/z (EI) 206 (5.85%, M^+), 205 (8.1, M^+-H), 191 (36.4, M^+-CH_3), 179 (19), 135 (13.5, M^+-$SiMe_3$+2H), 117 (50, M^+-$OSiMe_3$), 115 (13.6, $C_5H_{12}OSi$), 105 (14.5), 85 (26.4,), 77 (12.6, C_6H_5), 75 (17.1, C_2H_7OSi), 74 (12.5), 73 (100, $SiMe_3$), 59 (12.5, C_2H_7Si), 45 (14, CH_5Si) (Found: C, 69.70, H, 8.70, $C_{12}H_{18}OSi$ requires C, 69.85, H, 8.79%).

Preparation of 3-hexyl-1-trimethylsilylpropane-2,3-epoxide:

Using the general procedure, the title compound (66.3 g, 62% yield) was made from *cis*-1-trimethylsilyl-2-nonene (5 mmol, 0.99 g) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg). υ_{max}(neat film/cm^{-1}) 2956.0 (s, CH), 2928.0 (s, CH_3), 2872.9 (m, CH_2), 2858.7 (m, CH_2), 1467.8 (w, CH), 1456.8 (w,), 1260.2, 1249.8 (s, SiMe), 859.1 (vs, $SiMe_3$); NMR (ppm) *cis*-isomer $\delta_H(CDCl_3)$ 0.08 (9H, $SiMe_3$), 0.88 (3H, CH_3), 0.71 ($1H^a$, dd, J 15 Hz, J 7.2 Hz, CH_2-Si), 0.94 ($1H^b$, dd, J 15.0 Hz, J 6.4 Hz, CH_2-Si), 1.24-1.52 (10H, m, CH_2), 2.90 (1H, m, CH), 3.03 (1H, m, CH-C-Si), $\delta_C(CDCl_3)$ -1.15 (3C, $SiMe_3$), 14.03 (1C, CH_3), 15.55 (1C, CH_2-Si), 22.56 (1C, CH_2), 26.53 (1C, CH_2), 27.81 (1C, CH_2), 29.23 (1C, CH_2), 31.77 (1C, CH_2), 55.07 (1C, CH-C-Si), 57.62 (1C, CH); m/z (EI) 199 (40%, M^+-CH_3), 157 (42, M^+-C_4H_9), 144 (46, M^+-C_5H_{11}+H^+), 129 (45, $C_6H_{13}OSi$), 115 (15, $C_5H_{12}OSi$), 73 (100, $SiMe_3$), 59 (12.5, C_2H_7Si).

Preparation of 5,6-epoxydecane:

Using the general procedure, the title compound (32 g, 41% yield) was made from *cis*-5-decene (5 mmol, 0.77 g) in the presence of 4-phenylpyridine (0.2 equivalent / olefin, 1.0 mmol, 171 mg). υ_{max}(neat film/cm^{-1}) 2958.0 (vs, CH), 2930.8 (vs, CH_3), 2873.1 (vs, CH_2), 2861.4 (vm, CH_2), 1467.0 (s, CH), 1436.0 (s), 1379.0 (m), 969.4 (m); NMR (ppm) *cis*-isomer $\delta_H(CDCl_3)$ 0.81 (6H, t, CH_3), 1.12-1.44 (12H, m, CH_2), 2.80 (2H,

m, CH): $\delta_C(CDCl_3)$ 13.92 (2C, s, Me), 22.60 (2C, s, CH_2), 27.48 (2C, s, CH_2), 28.69 (2C, s, CH_2), 57.12 (2C, s, CH, Ph); m/z (EI) 157 (10%, $M+H^+$), 127 (5, $M^+-C_2H_5$), 99 (38, $C_6H_{11}O$), 83 (100, C_5H_7O), 69 (40, C_4H_5O), 57 (48, C_4H_9), 41 (45, C_3H_5).

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