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<p>(21) International Application Number: PCT/EP95/00370</p> <p>(22) International Filing Date: 1 February 1995 (01.02.95)</p> <p>(30) Priority Data:</p> <table border="0"> <tr><td>9402213.4</td><td>4 February 1994 (04.02.94)</td><td>GB</td></tr> <tr><td>9402194.6</td><td>4 February 1994 (04.02.94)</td><td>GB</td></tr> <tr><td>9402200.1</td><td>4 February 1994 (04.02.94)</td><td>GB</td></tr> <tr><td>9411937.7</td><td>15 June 1994 (15.06.94)</td><td>GB</td></tr> <tr><td>9411936.9</td><td>15 June 1994 (15.06.94)</td><td>GB</td></tr> <tr><td>9411957.5</td><td>15 June 1994 (15.06.94)</td><td>GB</td></tr> </table> <p>(71) Applicant (for all designated States except US): SMITHKLINE BEECHAM P.L.C. [GB/GB]; New Horizons Court, Brentford, Middlesex TW8 9EP (GB).</p> <p>(72) Inventors; and</p> <p>(75) Inventors/Applicants (for US only): BELL, David [GB/GB]; SmithKline Beecham Pharmaceuticals, The Pinnacles, Coldharbour Road, Harlow, Essex CM19 5AD (GB). FINNEY, Frances [GB/GB]; SmithKline Beecham Pharmaceuticals, The Pinnacles, Coldharbour Road, Harlow, Essex CM19 5AD (GB). ATTRILL, Robin, Patrick [GB/GB]; SmithKline Beecham Pharmaceuticals, The Pinnacles, Coldharbour Road, Harlow, Essex CM19 5AD (GB). MILLER, David [GB/GB]; SmithKline Beecham Pharmaceuticals, The Pin-</p>		9402213.4	4 February 1994 (04.02.94)	GB	9402194.6	4 February 1994 (04.02.94)	GB	9402200.1	4 February 1994 (04.02.94)	GB	9411937.7	15 June 1994 (15.06.94)	GB	9411936.9	15 June 1994 (15.06.94)	GB	9411957.5	15 June 1994 (15.06.94)	GB	<p>nacles, Coldharbour Road, Harlow, Essex CM19 5AD (GB). TURNER, Gillian [GB/GB]; SmithKline Beecham Pharmaceuticals, The Pinnacles, Coldharbour Road, Harlow, Essex CM19 5AD (GB).</p> <p>(74) Agent: RUTTER, Keith; SmithKline Beecham, Corporate Intellectual Property, SB House, Great West Road, Brentford, Middlesex TW8 9BD (GB).</p> <p>(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ).</p> <p>Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>
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<p>(54) Title: PROCESS FOR EPOXIDISING PROCHIRAL OLEFINS AND A CATALYST THEREFOR AND INTERMEDIATES FOR MAKING THE CATALYST</p>																				
<p>(57) Abstract</p>																				
<p>A process for enantioselectively epoxidising a prochiral olefin, which process comprises reacting the prochiral olefin with a source of oxygen in the presence of a salen catalyst and a source of an electron donating ligand, characterised in that the donor ligand is isoquinoline N-oxide or a compound having donor ligand activity and having substantially the same solubility characteristics as isoquinoline N-oxide; and compounds used in such process. The catalyst (III) and intermediates for its preparation are also claimed in which M is a transition metal ion; A is a counter-ion if required; B, B', E and E' are independently selected from the group consisting of hydrogen aryl, C₁₋₆ alkyl, silyl or aryl-C₁₋₆ alkyl in which any aryl or alkyl moiety is optionally substituted or B' and B or E' and E together form a C₂₋₆ polymethylene link; with the proviso that only one of the carbons marked with an asterisk is a chiral centre; R₁, R₂, R₃, R₄, R₅, R₆, R₇, R₈, R₉ and R₁₀ are independently hydrogen, alkyl or alkoxy.</p>	<p>(III)</p>																			

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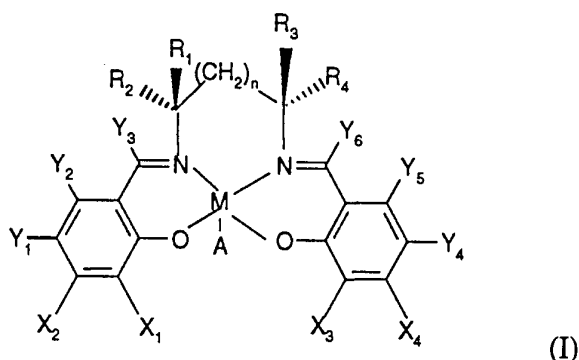
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PROCESS FOR EPOXIDISING PROCHIRAL OLEFINS AND A CATALYST THEREFOR AND INTERMEDIATES FOR MAKING THE CATALYST

This invention relates to a novel process for preparing epoxides from olefins and in particular chirally enriched epoxides, certain novel catalysts used in such process and compounds associated with the process.

WO 91/14694 describes certain catalysts of the following formula (I):



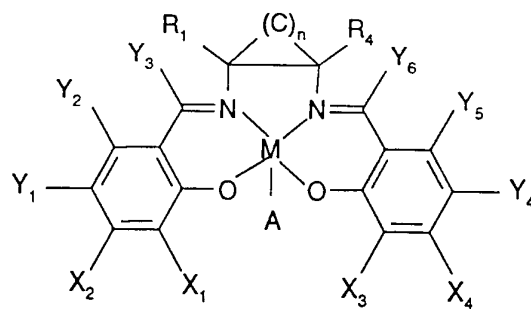
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in which

M is a transition metal ion, A is an anion, and n is either 0, 1 or 2. At least one of X₁ or X₂ is selected from the group consisting of silyls, aryls, secondary alkyls and tertiary alkyls; and at least one of X₃ or X₄ is selected from the same group. Y₁, Y₂, Y₃, Y₄, Y₅ and Y₆ are independently selected from the group consisting of hydrogen, halides, alkyls, aryl groups, silyl groups, and alkyl groups bearing heteroatoms such as alkoxy and halide. Also, at least one of R₁, R₂, R₃ and R₄ is selected from a first group consisting of H, CH₃, C₂H₅ and primary alkyls. Furthermore, if R₁ is selected from said first group, then R₂ and R₃ are selected from a second group consisting of aryl groups, heteroatom-bearing aromatic groups, secondary alkyls and tertiary alkyls. If R₂ is selected from said first group, then R₁ and R₄ are selected from said second group. If R₃ is selected from said first group, then R₁ and R₄ are selected from said second group. If R₄ is selected from said first group, then R₂ and R₃ are selected from said second group. Such catalysts are described as being useful in enantioselectively epoxidising a prochiral olefin.

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In addition WO 91/14694 describes certain catalysts of the formula shown below, herein referred to as formula (IA):

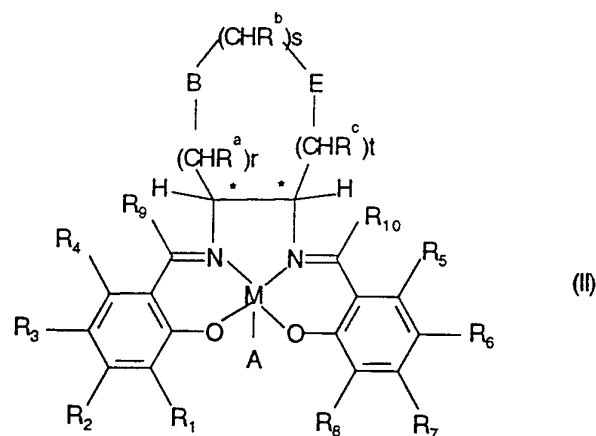


(IA)

where M is defined as a transition metal ion and A is an anion; where n is either 3,4,5 or 6; where at least one of X₁ or X₂ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where at least one of X₃ or X₄ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where at least one of Y₁ or Y₂ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where at least one of Y₄ or Y₅ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where Y₃, and Y₆ are independently selected from the group consisting of hydrogen and primary alkyl groups; where R₁ and R₄ are trans to each other and at least one of R₁ and R₄ is selected from the group consisting of primary alkyls and hydrogen; and where the carbons in the (C)_n portion have substituents selected from the group consisting of hydrogen, alkyl, aryl, and heteroatoms.

Such catalysts are described as being useful in enantioselectively epoxidising a prochiral olefin. These catalysts belong to the class of catalysts known in the art as 'salen catalysts'.

Co-pending International Patent Application Number PCT/GB93/01666 (now International Patent Application, Publication Number WO 94/03271) also discloses a series of salen catalysts, structurally distinct from the catalysts of formula (I) and having the general formula (II):



in which M is a transition metal ion;

A is a counter-ion if required;

5 r, s and t are independently 0 to 3 such that r+s+t is in the range of 1 to 3;

R^a, R^b, R^c are each independently hydrogen or CH₂OR' where R' is hydrogen or an organic group;

B and E are independently oxygen, CH₂, NR^d in which R^d is alkyl, hydrogen, alkylcarbonyl, or arylcarbonyl or SO_n where n is 0 or an integer 1 or 2, with the
10 proviso that B and E are not simultaneously CH₂ and that when B is oxygen, NR^d or SO_n, then r cannot be 0, and when E is oxygen, NR^d or SO_n, then t cannot be 0;

R₁, R₂, R₃, R₄, R₅, R₆, R₇, R₈, R₉ and R₁₀ are independently hydrogen, alkyl or alkoxy.

15 The compounds of formula (II) also catalyse the enantioselective expoxidation of certain prochiral olefins.

It has been suggested in the art that the use of compounds such as pyridine oxide and 2-methyl imidazole in combination with certain chiral (salen) manganese (III) complex catalysts improves the chemical yield such reactions (Syn. Lett. April 1991, 265-266), although the effect upon the enantioselectivity of the catalysed
20 reactions is currently not clear (Tetrahedron Vol. 50, No 15, p. 4323 -4334, 1994). In this context pyridine oxide and 2-methyl imidazole are referred to as 'donor ligands' as they are considered to donor-bond to the metallic ion of the salen catalyst.

One particular problem associated with the use of such donor ligands is the complete removal of the donor ligand from the final epoxide product, especially in
25 large scale reactions and most especially when two phase reaction systems are used.

It has now been discovered that one particular compound, isoquinoline N-oxide, previously unreported as a donor ligand, is particularly efficient as a donor ligand in that it advantageously enhances catalyst turnover and in addition it possesses very good solubility characteristics for use as a donor ligand, enabling it to be used in
30 the metal salen complex catalysed epoxidation reactions and subsequently to be readily removed from the epoxide products of the reaction. It has also been

discovered that a particular group of salen catalysts are especially suited to use with donor ligands in that the presence of the donor ligands consistently produces not only an increase in reaction rate but also an increase in the enantioselective specificity of the epoxidation reactions.

5 In addition a further series of salen catalysts which are structurally distinct from those of formulae (I), (IA) and (II) has now been prepared which surprisingly are also able to catalyse the enantioselective epoxidation of certain prochiral olefins.

Accordingly, in a first aspect, the invention provides a process for enantioselectively epoxidising a prochiral olefin, which process comprises reacting
10 the prochiral olefin with a source of oxygen in the presence of a salen catalyst and a source of an electron donating ligand, characterised in that the donor ligand is isoquinoline N-oxide or a compound having donor ligand activity and having substantially the same solubility characteristics as isoquinoline N-oxide.

A suitable salen catalyst is a compound of formula (I), (IA), (II) or a
15 compound of formula (III) (which compound of formula (III) is defined hereinafter).

The invention also provides isoquinoline N-oxide or a compound having donor ligand activity and having substantially the same solubility characteristics as isoquinoline N-oxide, for use as a donor ligand.

In a further aspect the invention provides a process for enantioselectively
20 epoxidising a prochiral olefin, which process comprises reacting the prochiral olefin with a source of oxygen in the presence of a salen catalyst and a source of an electron donating ligand, characterised in that the salen catalyst is a compound of formula (II).

A source of an electron donating ligand is suitably provided by a compound which is capable of forming a donor bond with the transition metal M of the said
25 salen catalyst, such that in use the rate of the epoxidation reaction is increased and the enantioselective specificity of the resulting product may also be increased.

A source of electron donating ligand is suitably provided by a compound which is capable of forming a donor bond with the transition metal M of the salen catalyst such that in use the enantioselective specificity of the compound of formula
30 (I) is increased.

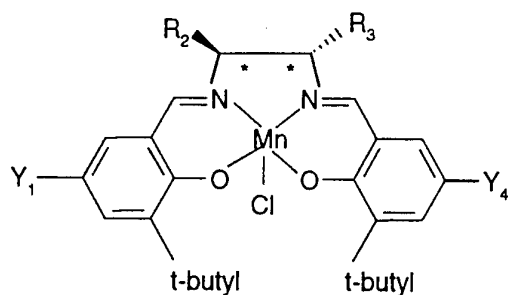
A suitable source of an electron donating ligand may be selected from the list consisting of: pyridine N-oxide, 2-methyl pyridine N-oxide, 4-methyl pyridine N-oxide, 4-phenyl pyridine N-oxide or isoquinoline N-oxide, especially isoquinoline N-oxide.

35 **In the compounds of formula (I) and (IA):**

Preferred values for M, A, n, X₁, X₂, X₃, X₄, Y₁, Y₂, Y₃, Y₄, Y₅, Y₆, R₁, R₂, R₃ and R₄ are as defined in WO 91/14694.

Suitable catalysts are those of formula (IA) as defined above.

A preferred sub-group of catalysts are those of formula (IB) as defined below:



(IB)

in which Y_1 and Y_4 are the same and are selected from the group consisting of methyl
 5 t -butyl or methoxy and R_2 and R_3 are either both phenyl or together with the carbon
 atoms to which they are attached form a hexyl ring.

Most preferably, in catalysts of formula (IB), Y_1 and Y_4 are both t -butyl and
 R_2 and R_3 together with the carbon atoms to which they are attached form a hexyl
 ring.

In the compounds of formula (II):

10 The suitable, favoured and preferred values of the variables A, B, E, R^a , R^b ,
 R^c , R^d , R' , R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 , R_8 , R_9 , R_{10} , n, r, s and t are as described in
 WO 94/03271 unless otherwise stated herein.

Suitable organic groups R' include alkyl, alkylcarbonyl, arylcarbonyl or aryl
 derivatives.

15 Particular examples of R' include substituted alkyl groups.

One example of R' is a triphenylmethyl group.

20 Preferably s and t are zero, r is 1 and R^a is hydrogen, B is oxygen and E is
 CH_2 ; or r, s and t are 1, R^a , R^b and R^c are hydrogen and B and E are both oxygen; or
 s is zero, r and t are both 1, R^a is hydrogen or triphenylmethyloxymethylene and R^c
 is hydrogen, B is oxygen and E is $-CH_2-$; or r and t are both 1, s is zero, R^a and R^c
 are hydrogen, B is NR^d where R^d is phenyl carbonyl and E is CH_2 .

Suitably, R_2 , R_4 , R_5 and R_7 each independently represent hydrogen.

Suitably R_1 , R_3 , R_6 and R_8 each independently represent C_{1-6} alkyl.

25 Favourably R_1 and R_8 represent branched alkyl groups such as tertiary alkyl
 groups.

R_3 and R_6 also advantageously represent branched alkyl groups.

One preferred example for each of R_1 and R_8 is tertiary butyl.

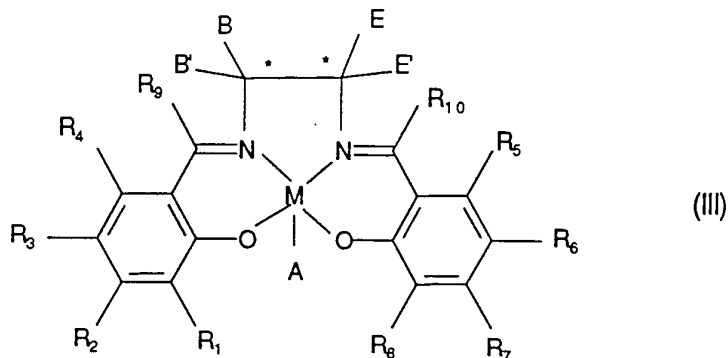
Particular examples of R_3 and R_6 are tertiary butyl and methyl.

Examples of R_2 , R_4 , R_5 and R_7 are hydrogen.

30 Examples of the compounds of formula (II) include those exemplified in WO
 94/03271 and particularly include those compounds referred to herein.

As stated above a further aspect of the invention is the discovery of a novel
 series of salen catalysts:

Accordingly, in a further aspect the present invention provides a compound of formula (III):



- 5 in which M is a transition metal ion;
 A is a counter-ion if required;
 B, B', E and E' are independently selected from the group consisting of hydrogen aryl, C₁₋₆ alkyl, silyl or aryl-C₁₋₆ alkyl in which any aryl or alkyl moiety is optionally substituted or B' and B or E' and E together form a C₂₋₆ polymethylene
 10 link; with the proviso that only one of the carbons marked with an asterisk is a chiral centre;

R₁, R₂, R₃, R₄, R₅, R₆, R₇, R₈, R₉ and R₁₀ are independently hydrogen, alkyl or alkoxy.

In the compounds of formula (III):

- 15 Suitably, R₂, R₄, R₅ and R₇ each independently represent hydrogen.
 Suitably R₁, R₃, R₆ and R₈ each independently represent C₁₋₆ alkyl.
 Favourably R₁ and R₈ represent branched alkyl groups such as tertiary alkyl groups.

R₃ and R₆ also advantageously represent branched alkyl groups.

- 20 One preferred example for each of R₁ and R₈ is tertiary butyl.
 Particular examples of R₃ and R₆ are tertiary butyl and methyl.
 Examples of R₂, R₄, R₅ and R₇ are hydrogen.

Preferably one of B and E is phenyl, methyl or isopropyl and the other is hydrogen. Most preferably one of B and E is phenyl and the other is hydrogen.

- 25 The compounds of formula (III) are also suitable salen catalysts for use in the process of the invention.

In the compounds of formula (I), (IA), (IB), (II) and (III):

The bond between M and A has varying degrees of ionic character depending on the anion used.

- 30 Suitable transition metal ions, M, include Mn, Cr, Fe, Ni, Co, Ti, V, Ru and Os in an appropriate oxidation state.

Preferably the transition metal ion, M, is Mn in oxidation state (II) or (III).

It should be appreciated that in some cases for example when M is Mn (II), a counter-ion is not required.

Suitable counter-ions, A, include those anions mentioned in WO 91/14694 and WO 94/03271.

5 Preferably, A is chloride.

In the process of the invention:

Suitable prochiral olefins include compounds which comprise the following groups as part of their structure, cyclohexene, 5,6-dihydro-2H-pyran, 1,2,5,6-tetrahydropyridine, 1,2,3,4-tetrahydropyridine and 5,6-dihydro-2H-thiopyran.

10 Favoured prochiral olefins include those compounds which comprise the following groups as part of their structure form: 1,2-dihydronaphthalene, 2H-chromene, 1,2-dihydroquinoline, 1,2-dihydroisoquinoline and 2H-thiochromene. Such compounds are well known in the potassium channel activator field.

15 Preferred prochiral olefins include those mentioned in EP-A-0 376 524, such as the compounds of formula (XIV) therein, and in particular 2,2-dimethyl-6-pentafluoroethyl-2H-1-benzopyran.

Preferred prochiral olefins include 6-acetyl-2,2-dimethyl-2H-1-benzopyran.

Suitable oxygen sources include oxidising agents such as sodium hypochlorite.

20 The epoxidation reaction may be carried out using any suitable procedure wherein the prochiral olefin, the source of oxygen, the compound of formula (I) and the source of the electron donating ligand are allowed to react to provide the required epoxide.

25 Suitably, the reaction is carried out in a two phase system, especially when the source of oxygen and/or one of the reaction components is soluble in water, and especially when the source of oxygen is sodium hypochlorite.

Suitable two phase systems are those used conventionally in the art taking into account the nature of the particular reactants, an example is methylene chloride and water.

30 The salen catalyst such as a compound of formula (I), (IA), (II) or (III), the prochiral olefin and the source of the electron donating ligand in an inert, water immiscible solvent such as dichloromethane may be reacted with the source of oxygen in water.

35 Generally the reaction takes place at a pH in the range of between 10 and 13, preferably between 10.5 and 12, most preferably between 11 and 11.5, conveniently the pH is controlled by the presence of a buffer such as sodium dihydrogen phosphate.

The reaction may be carried out at any suitable temperature providing a convenient rate of formation of the required product. Because of the increase in rate

of the reaction caused by the presence of the source of the electron donating ligand the reaction may be carried out at a lower temperature than without the said ligand, such as in the range of between 0°C and 40°C.

5 Generally it is carried out at ambient or at a slightly elevated temperature but preferably at ambient temperature.

Suitably the mole percentage ratio of the compound of formula (I) to the prochiral olefin is in the range of 0.01 to 10, preferably in the range of 0.1 to 0.5, 0.5 to 5, 1 to 5, 1 to 3, 0.5 to 2 most preferably in the range of 0.2 to 2.

10 Suitably the mole ratio of the source of the electron donating ligand to prochiral olefin is in the range of 0.05 to 3, such as 0.1 to 2.0 or 1 to 2, preferably in the range of 0.1 to 2. For example a suitable mole ratio range for N-pyridine oxide is 0.5 to 2. An example of a suitable mole ratio range for isoquinoline N-oxide is 0.1 to 0.5.

15 The present invention also extends to the preparation of all epoxides which are precursors to those compounds of formula (I) in EP-A-0376524, especially the specific examples thereof.

The present invention also extends to the preparation of all epoxides which are precursors to those compounds of formula (I) in WO 92/22293, especially the specific examples thereof.

20 The present invention also extends to the subsequent conversion of each of the said epoxides into the respective compounds of formula (I) of EP-A-0 376 524, in particular to the conversion of the relevant precursor epoxide into the respective specific example of EP-A-0 376 524, and especially to the conversion of 2,2-dimethyl-6-pentafluoroethyl-3,4-epoxy-2H-1-benzopyran into (-)trans-3,4-dihydro-2,2-dimethyl-4-(2-oxopiperidin-1-yl)-6-pentafluoroethyl-2H-1-benzopyran-3-ol or
25 the (+) trans isomer thereof.

The present invention also extends to the subsequent conversion of each of the said epoxides into the respective compounds of formula (I) of WO 92/22293, in particular to the conversion of the relevant precursor epoxide into the respective
30 specific example of WO 92/22293 and in particular to the conversion of (3R,4R) 6-acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran into trans-6-acetyl-4S-(4-fluorobenzoylamino)-3,4-dihydro-2,2-dimethyl-2H-1-benzopyran-3R-ol or the 3S, 4R isomer thereof:

35 The present invention also extends to the product formed between the salen catalyst, such as the compound of formula (I), (IA), (IB), (II) or (III) and the electron donating ligand.

When used herein the term 'chiral salen catalyst' refers to salen catalysts which have a predominance of one particular enantiomer and which in use provide a

predominance of one particular enantiomer of the product epoxide from the prochiral olefin substrate.

The term 'alkyl' when used alone or when forming part of other groups (for example alkoxy groups or alkylcarbonyl groups) includes straight- or branched-chain alkyl groups containing 1 to 12 carbon atoms, suitably 1 to 6 carbon atoms, examples include methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl or tert-butyl group.

When used herein the term 'aryl' includes phenyl and naphthyl optionally substituted with up to five, preferably up to three, groups selected from halogen, alkyl, phenyl, alkoxy, haloalkyl, alkylcarbonyl and phenylcarbonyl.

A preferred aryl group is a substituted or unsubstituted phenyl group.

Transition metals M include those having oxidation states of (II) or more.

Suitable substituents for aryl include alkyl, halogen and alkoxy.

Optional substituents for alkyl groups include those mentioned herein for aryl groups, phenyl is a particular example.

It should be appreciated that the carbon atoms marked with an asterisk are chiral centres and the present invention extends to each individual enantiomer and any mixtures thereof.

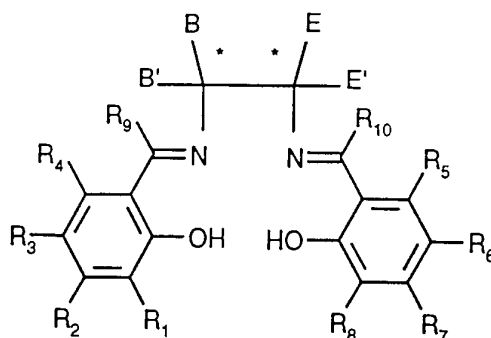
The compounds of formula (I), (IA) and (IB) may be prepared according to the procedures in described in WO 91/14694 or by procedures analogous to them.

The compounds of formula (II) may be prepared according to the procedures disclosed in International Application, Publication Number WO 91/14694 or procedures analogous the them.

The contents of WO 91/14694 and WO 94/03271, including the specific descriptions and examples therein, are incorporated herein by reference.

For the compounds of formula (III), the present invention also provides a process for the preparation of compounds of formula (III) which comprises forming a transition metal complex of the following compound of formula (IV):

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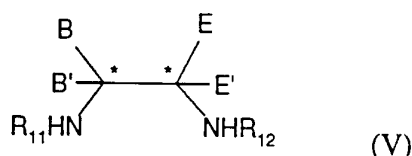


where variables $R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9$ and R_{10} , B, B', E and E' are as defined in relation to formula (III), wherein only one of the carbons marked with an asterisk is a chiral centre, and thereafter if necessary separating any enantiomers.

- 5 Suitably the transition metal ion complex may be formed by the addition of a suitable transition metal salt, such as manganese (II) or (III) acetate, preferably manganese (III) acetate, to a compound of formula (IV) in a suitable solvent such as ethanol or methylene dichloride, at elevated temperature. The optional replacement or interconversion of the counter ion may be effected by the addition of a suitable
- 10 source of the desired counter-ion such as an alkali metal salt, for example LiCl.

The separation of any enantiomers may be carried out by conventional techniques, such as crystallisation of derivatives or chromatography. However, it should be appreciated that it is preferred that separation of enantiomers is carried out before forming a transition metal complex.

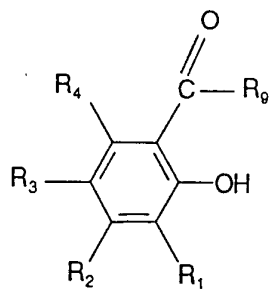
- 15 The invention further provides a process for the preparation of compounds of formula (IV) which comprises condensing sequentially, in any order, a compound of formula (V):



- 20 where B, B', E and E' are as defined in formula (III) and R_{11} and R_{12} independently represent hydrogen or an amine protecting group, providing at least one of R_{11} and R_{12} is hydrogen, with:

- (i) a compound of formula (VI);

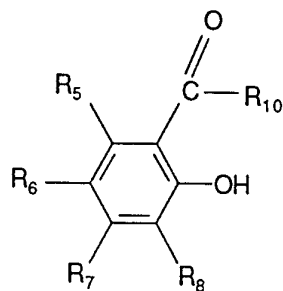
25



(VI)

wherein R₁, R₂, R₃, R₄ and R₉ are as defined in relation to formula (III); and

(ii) a compound of formula (VII),

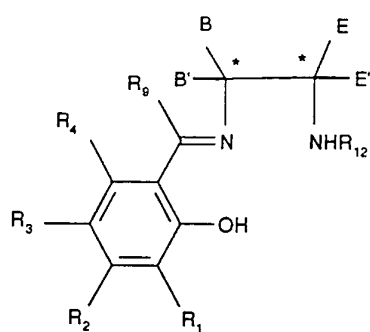


(VII)

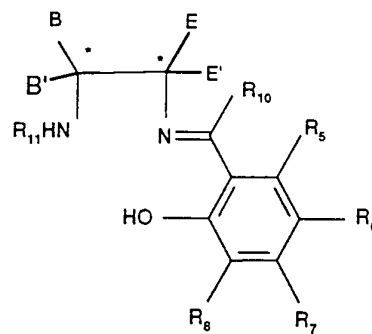
wherein R₅, R₆, R₇, R₈ and R₁₀ are as defined in relation to formula (III); and thereafter as required removing any protecting group R₁₁ or R₁₂, isolating the required compound including if necessary separating any enantiomers.

It is preferred that the compound of formula (IV) is prepared from optically pure compounds of formula (V) which are preferably prepared themselves from optically pure starting materials. Alternatively, racemates or mixtures of enantiomers of formula (VI) or (VII) may themselves be resolved using conventional techniques in the art such as crystallisation of derivatives, or chromatography.

When compounds of formula (IV) are required in which one or more of R₁, R₂, R₃, R₄ and R₉ are not the same as one or more of R₈, R₇, R₆, R₅ and R₁₀ respectively, then compounds of formula (V) may be sequentially condensed with compounds of formula (VI) and formula (VII), in any order, by heating a suitably protected compound of formula (V) with a compound of formula (VI) or (VII) (in a 1:1 mole ratio) in an inert solvent such as ethanol, if necessary, purifying the resulting intermediate compound of formula (VIII) or (IX):



(VIII)



(IX)

wherein variables R_1 to R_{12} , E, E', B and B' are as defined in relation to formula (V),
 5 (VI) or (VII) using conventional separation techniques, such as chromatography;
 removing any protecting group R_{11} or R_{12} and then as required repeating the
 reaction using a compound of formula (VI) or (VII).

Suitable protecting groups R_{11} or R_{12} include conventional amine protecting
 groups the insertion and removal of which are compatible with the nature of the
 10 molecules being protected, such as benzyl groups, silyl groups or acyl groups such as
 benzoyl groups, preferably silyl groups.

The removal of R_{11} or R_{12} when representing protecting groups may be
 carried out using conventional techniques in the art depending upon the nature of the
 protecting group.

15 It should be appreciated that when each of R_1 , R_2 , R_3 , R_4 and R_9 is the same
 as each of R_8 , R_7 , R_6 , R_5 and R_{10} respectively the compounds of formula (VI) and
 (VII) are the same, therefore, compounds of formula (V) in which R_{11} and R_{12} is
 hydrogen are preferably used and two moles of a compound of formula (VI) or (VII)
 are utilised.

20 Suitably, the reaction is carried out in an inert solvent, such as ethanol, at
 elevated temperature, for example at reflux temperature of the chosen solvent.

Compounds of formula (V) are either known compounds or may be prepared
 according to known methods or analogously to known methods or analogously to the
 methods described herein.

25 Compounds of formula (VI) and (VII) are either commercially available, are
 known compounds or may be prepared according to known methods or analogously
 to known methods for examples such as these described by G.Casiraghi et al J. Chem
 Soc. Perkin Transactions I. 1980 p1862 - 1865.

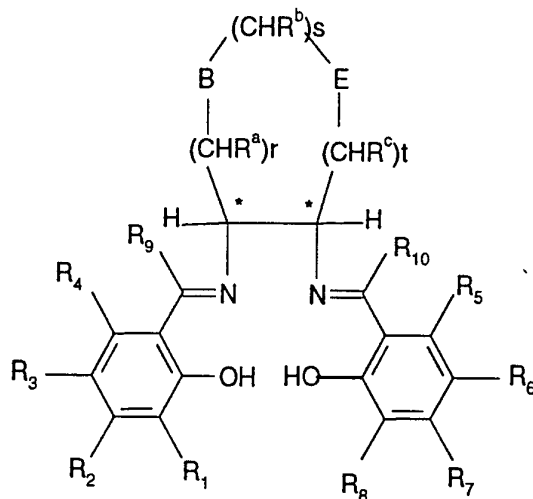
30 Novel compounds of formula (IV), (VI), (VII), (VIII) and (IX) form an aspect
 of the present invention.

As stated above the compounds of formula (II) herein may be prepared using
 the methods disclosed in co-pending International Patent Application Number

PCT/GB93/01666 (now International Patent Application, Publication Number WO 94/03271). For the avoidance of doubt these methods involve the following:

The compounds of formula (II) may be prepared by forming a transition metal complex of the following compound of formula (X):

5



(X)

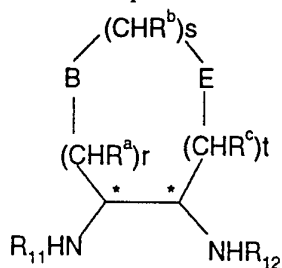
where variables R_1 to R_{10} , B, E, r, s, t, R^a , R^b and R^c are as defined in relation to formula (II), and thereafter if necessary separating any enantiomers.

Suitably the transition metal ion complex may be formed by the addition of a suitable transition metal salt such as manganese (II) or (III) acetate, preferably manganese (III) acetate, to a compound of formula (II) in a suitable solvent such as ethanol or methylene dichloride, at elevated temperature. The optional replacement or interconversion of the counter ion may be effected by the addition of a suitable source of the desired counter-ion such as an alkali metal salt, for example LiCl.

The separation of any enantiomers may be carried out by conventional techniques, such as crystallisation of derivatives or chromatography. However, it should be appreciated that it is preferred that separation of enantiomers is carried out before forming a transition metal complex.

The compounds of formula (X) may also be prepared by condensing sequentially, in any order, a compound of formula (XI):

20



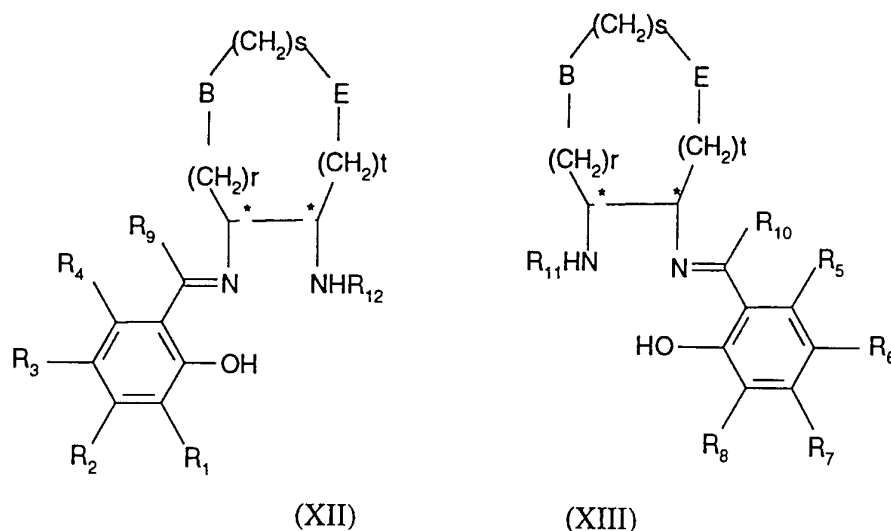
(XI)

where r, s, t, R^a , R^b and R^c , E, B are as defined in formula (II) and R_{11} and R_{12} independently represent hydrogen or an amine protecting group, providing at least one of R_{11} and R_{12} is hydrogen, with a compound of the above defined formulae

(VI) and (VII). The reaction conditions are analogous to those mentioned above in relation to the reaction between the compound of formula (V) and the compounds of formulae (VI) and (VII).

It is preferred that the compound of formula (X) is prepared from optically pure compounds of formula (XI) which are preferably prepared themselves from optically pure starting materials. Alternatively, racemates or mixtures of enantiomers of formula (X) or (XI) may themselves be resolved using conventional techniques in the art such as crystallisation of derivatives, or chromatography.

When compounds of formula (X) are required in which one or more of R_1 , R_2 , R_3 , R_4 and R_9 are not the same as one or more of R_8 , R_7 , R_6 , R_5 and R_{10} respectively, then compounds of formula (XI) may be sequentially condensed with compounds of formula (VI) and formula (VII), in any order, by heating a suitably protected compound of formula (XI) with a compound of formula (VI) or (VII) (in a 1:1 mole ratio) in an inert solvent such as ethanol, if necessary, purifying the resulting intermediate compound of formula (XII) or (XIII):



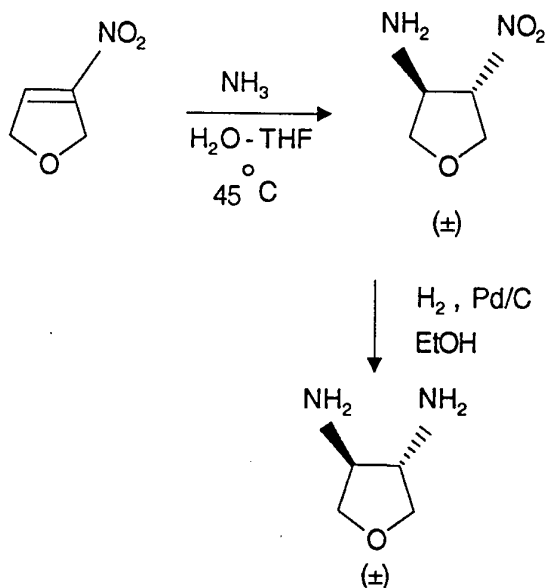
wherein variables R_1 to R_{12} , r , s , t , R^a , R^b , R^c , E and B are as defined in to formula (XI), (VI) and (VII) using conventional techniques such as chromatography removing any R_{11} or R_{12} protecting groups and then repeating the reaction using a compound of formula (VI) or (VII) as required.

Suitable protecting groups R_{11} and R_{12} and the methods for the removal of such groups are as described above.

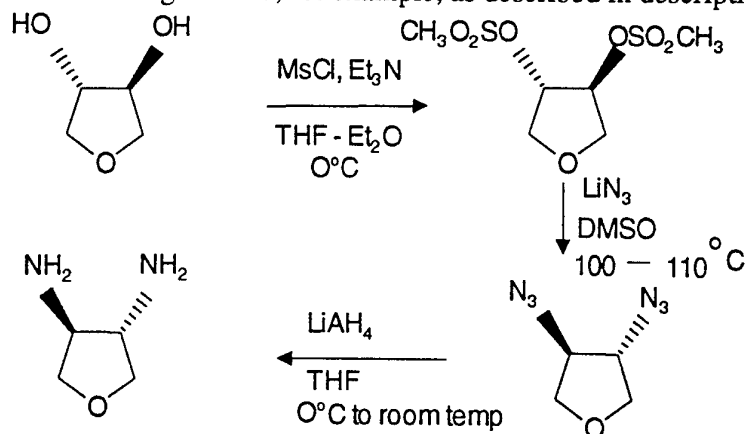
It should be appreciated that when each of R_1 , R_2 , R_3 , R_4 and R_9 is the same as each of R_8 , R_7 , R_6 , R_5 and R_{10} respectively the compounds of formula (VI) and (VII) are the same, therefore, compounds of formula (XI) in which R_{11} and R_{12} is hydrogen are preferably used and two moles of a compound of formula (VI) or (VII)

are utilised, in an inert solvent, such as ethanol, at elevated temperature, for example at reflux.

Compounds of formula (XI) are either known compounds or may be prepared according to known methods or analogously to known methods or analogously to the methods described herein, for example when a compound of formula (XI) is 3,4-diaminotetrahydrofuran, such a compound may be prepared according to the following scheme, for example, as described in descriptions 1 and 2.



Alternatively, (S,S)trans 3,4-diaminotetrahydrofuran may be prepared according to the following scheme, for example, as described in descriptions 4 to 6.



The 5R, 6R-diamino-1,3-dioxepane may be prepared according to the procedures, as described in descriptions 8 to 13.

The 3R, 4S-diamino tetrahydropyran may be prepared according to the procedures as described in descriptions 15 to 17.

The 3R,4S-diamino-(2S)(triphenylmethoxymethyl)tetrahydropyran may be prepared according to the procedures as described in descriptions 21 to 24.

The (\pm) trans-1-benzoyl-3,4-diaminopiperidine may be prepared according to the procedures as described in descriptions 25 to 27.

The catalysts, of formula (III) are preferably prepared in a chiral form by using a resolved compound of formula (XI) which may be resolved using conventional techniques. The compound of formula (XI) may itself be prepared from suitable precursor compounds such as these outlined in hereinbefore which may be resolved using conventional techniques or may be purchased in a resolved form. Alternatively, the coupled compound of formula (X) may be resolved using conventional techniques.

The present invention also provides a process for preparing compounds of formula (A) (as defined in WO 93 17026) or, where appropriate, a pharmaceutically acceptable salt thereof, or a pharmaceutically acceptable solvate thereof which comprises reacting a compound of formula (I), a source of oxygen, a compound of formula (C) and a source of the electron donating ligand, and thereafter converting the resulting compound of formula (B) into a compound of formula (A) or, where appropriate, a pharmaceutically acceptable salt thereof, or a pharmaceutically acceptable solvate thereof.

The present invention also extends to the product formed between the compound of formula (I) and the electron donating ligand provided by the above mentioned source.

Compounds of formula (C) are commercially available or may be prepared according to the procedures referred to or outlined in EP-A-0 376 524.

The following descriptions and examples illustrate the present invention.

(A) Examples Using the Catalysts of WO 91/14694

Example 1: The preparation of (3R,4R)-6-acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran, using pyridine N-oxide as electron donating ligand.

5 A solution of sodium hypochlorite (54ml, 13.7% w/v), 0.05M NaHPO₄ (50ml) and water (70 ml) were adjusted to pH 11.3 with 8N NaOH. 6-Acetyl-2,2-dimethyl chromene (10g 0.049 mol) and R,R-[1,2-bis (3,5-di-tert-butylsalicylideamino)cyclo-hexane]manganese (III) chloride catalyst (320mg 1 mol%), pyridine N-oxide (9.5g, 2eq) and dichloromethane (50ml) were mixed
10 together and the mixture was stirred for 1 hour.

The solution was diluted with DCM (200ml) and filtered through celite and the layers separated. The aqueous layer was re-extracted with DCM (200ml) then the organic layers combined. The organic phase was washed with water (2 x 400ml) and evaporated to dryness to give a brown oil 12g, ee 95% (chiral hplc). The oil was
15 crystallised from IPE (2½ volumes) seeded with epoxide to give the title compound as an off-white/brown solid (6.45g, 60%) ee>99%.

The same reaction without an electron donating ligand added, such as pyridine N-oxide, typically requires 1 mole% of catalyst to achieve complete conversion at room
20 temperature in about 4 hrs (crude epoxide e.e. 92%).

Example 2: The Preparation of (3R,4R)-2,2-dimethyl-3,4-epoxy-6-pentafluoroethyl-2H-1-benzopyran, using isoquinoline N-oxide as electron donating ligand.

25 A solution of sodium hypochlorite (44 ml, 17% w/v), water (70 ml) and 0.05M NaH₂PO₄ (50 ml) was adjusted to pH 11.3 with dilute orthophosphoric acid. 2,2-Dimethyl-6-pentafluoroethyl-2H-1-benzopyran (13.6g, 50 mmol), dichloromethane (100 ml), isoquinoline N-oxide (0.725g, 10 mole%) and R,R-[1,2-bis(3,5-di-tert-butylsalicylideamino)cyclohexane]manganese (III) chloride (64 mg,
30 0.2 mole%) were added and the mixture stirred rapidly at room temperature. After 2 hrs HPLC analysis indicated 95% conversion of chromene to epoxide. The reaction mixture was allowed to stir at room temperature for another 3 hrs but no further conversion of chromene to epoxide occurred. The e.e. of the crude (3R,4R)-epoxide was measured as 92.5% according to chiral HPLC. The mixture was diluted with
35 dichloromethane (200 ml) and filtered through celite, and the layers separated. The organic phase was washed with water (3 x 100 ml) then evaporated to dryness to give the crude title compound (15.0g), as a yellow solid. The crude product was recrystallised from hexane (3 volumes) to give the pure title compound (8.0g, 54%) as colourless needles (e.e. > 99%).

The same reaction without an electron donating ligand, such as isoquinoline N-oxide, typically requires 2 mole% of catalyst to give complete conversion.

Example 3: The preparation of (3R,4R)-6-acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran, using isoquinoline N-oxide as electron donating ligand.

The procedure of Example 1 was repeated using 10 mole% of isoquinoline N-oxide instead of pyridine N-oxide. The amount of catalyst was also reduced to 0.1 mole%. Complete conversion to the required epoxide (e.e. 96%) was achieved in less than 15 mins.

10

Example 4: The preparation of (3R,4R)-6-acetyl-2,2-dimethyl-3,4-epoxy-8-iodo-2H-1-benzopyran, using isoquinoline N-oxide as electron donating ligand.

The procedure of Example 1 was repeated using 0.2 equiv of isoquinoline N-oxide instead of pyridine N-oxide. The amount of catalyst was reduced to 0.2 mole%. Complete conversion to the epoxide (e.e. 98%) was observed after 2hrs. The crude product was recrystallised from IPE (3 volumes) to give the enantiomerically pure title compound, m.p. 123.6 - 125.4 deg. C, in a yield of 72%.

20

(B) Examples Using the Catalysts of WO 94/03271

Example 5: Preparation of (3R,4R)-6-Acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran, using pyridine N-oxide as electron donating ligand.

Sodium hypochlorite (21.5 ml, 17.3% w/v), water (34 ml) and 0.05M Na₂HPO₄ (25 ml) were adjusted to pH 13 with 8N NaOH. 6-Acetyl-2,2-dimethyl-2H-1-benzopyran (5.0g, 25 mmoles), pyridine N-oxide (5.0g, 52 mmoles) and the S,S-Mn Salen catalyst (3S,4S)-bis-(3,5-di-tert-butylsalicylideamino)tetrahydrofuran-manganese (III) chloride (D34, 152 mg, 1 mole %) were added with dichloromethane (50 ml) and the mixture stirred at room temperature. After 2 hrs the reaction was complete according to HPLC analysis. The mixture was diluted with dichloromethane and filtered through celite. The two phases were separated and the organic phase washed with water (200 ml), then evaporated to dryness under reduced pressure to give the crude title compound as a brown oil (5.0g). This was shown by chiral HPLC to have an e.e. of 94%.

35

The title compound was obtained enantiomerically pure (e.e. >99.8%) by recrystallization of the crude product from diisopropyl ether in a recovery of 44%.

Example 6: Preparation of (3S,4S)-6-Acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran without use of an electron donating ligand.

Sodium hypochlorite solution (8.0 ml, 17.3% w/v), water (14 ml) and 0.05M Na₂HPO₄ (10 ml) was adjusted to pH 13 with 8N NaOH. 6-Acetyl-2,2-dimethyl-2H-1-benzopyran (2.0g, 10 mmoles) and R,R-Mn Salen catalyst (R,R)-5,6-bis-(3,5-di-tert-butylsalicylideamino)-1,3-dioxepane]-manganese (III) chloride (D31, 63 mg, 1 mol %) were added with dichloromethane (20 ml) and the mixture stirred at room temperature overnight. HPLC analysis indicated that about 13% of the chromene still remained.

10

The mixture was diluted with dichloromethane (50 ml) and filtered through celite. The organic phase was separated then washed with water (100 ml) and evaporated to dryness to give the crude title compound as an oil (2.1g, 96% wt. yield). Analysis of this sample by chiral HPLC indicated an e.e. of 86%.

15

Example 7: Preparation of (3S,4S)-6-Acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran, using pyridine N-oxide as electron donating ligand.

The procedure of Example 6 was repeated but with the addition of pyridine N-oxide (1.9g, 20 mmoles). HPLC analysis indicated complete reaction after stirring overnight at room temperature. The crude product was isolated in the same way to give 2.3g of the title compound with an e.e. of 95%. The title compound was obtained enantiomerically pure (e.e. >99.8%) by recrystallization of the crude product from diisopropyl ether in a recovery of 50%.

Example 8: Preparation of (3R,4R)-6-Acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran, using isoquinoline-N-oxide as electron donating ligand.

The procedure of Example 5 was repeated but with the addition of isoquinoline-N-oxide (1.74g, 12 mmoles) instead of pyridine N-oxide. HPLC analysis indicated complete reaction within 30 mins., after stirring at room temperature. The crude product was isolated in the same way to give the crude title compound as a brown oil (5.1g). This was shown by chiral HPLC to have an e.e. of 94%. The title compound was obtained enantiomerically pure (e.e. >99.8%) by recrystallization from diisopropyl ether in a recovery of 48%.

Example 9: Preparation of (3S,4S)-6-Acetyl-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran

Sodium hypochlorite (31 ml, 12.1% w/v, 50 mmoles), water (34 ml) and 0.05M Na₂HPO₄ (25 ml) were adjusted to pH 13 with 8N NaOH. 6-Acetyl-2,2-dimethyl-2H-1-benzopyran (5.0g, 25 mmoles), isoquinoline N-oxide (0.362g, 5

mmoles, 0.2 equiv) and (3R,4S)-bis-(3,5-di-tert-butylsalicylideamino)tetrahydropyran manganese (III) chloride (0.032g, 0.05 mmole, 0.2 mole%) were added with dichloromethane (50 ml) and the mixture stirred at 15 - 20 deg. C. After 4 hrs the reaction was complete according to HPLC analysis. The mixture was diluted with
5 dichloromethane and filtered through celite. The two phases were separated and the organic phase washed with water (2 x 200 ml), then evaporated to dryness under reduced pressure to give the crude title compound as a pale brown oil (5.3g). This was shown by chiral HPLC to have an e.e. of 92%.

The title compound was obtained enantiomerically pure (e.e. >99.8%), m.p.
10 51°C, by recrystallization of the crude product from diisopropyl ether in a recovery of 41%.

Example 10: Preparation of (3S,4S)-6-Cyano-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran

15 The procedure described in Example 9 was repeated using 6-cyano-2,2-dimethyl-2H-1-benzopyran (4.63g, 25 mmoles) as the chromene substrate. The crude (3S,4S) epoxide formed was shown to have an e.e. of 93%. This was recrystallised from 2-propanol to give the title compound (e.e. >99%), m.p. 144-145 deg. C, in a recovery of 75%.

20

Example 11: Preparation of (3S,4S)-6-Bromo-2,2-dimethyl-3,4-epoxy-2H-1-benzopyran

The procedure described in Example 9 was repeated using 6-bromo-2,2-dimethyl-2H-1-benzopyran (5.98g, 25 mmoles) as the chromene substrate. The crude (3S,4S)
25 epoxide formed was shown to have an e.e. of 95%. This was recrystallised from hexane/ethyl acetate to give the title compound (e.e. >99%), m.p. 101-102 deg. C, in a recovery of 65%.

(C) Examples Using The Compound of Formula (III) as Catalyst

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Example 12: (R)-1-Phenyl-1,2-bis(3-tert-butyl-5-methylsalicylideamino)ethane - manganese (III) chloride (E12).

(R)-1-Phenyl-1,2-bis(3-tert-butyl-5-methylsalicylideamino)ethane (D37, 2.42g, 5.0mmol) was dissolved in ethanol (50ml) and solid manganese (II) acetate tetrahydrate (2.45g, 10.0mmol) was added. The solution was refluxed for 2 hours
35 then lithium chloride (anhydrous) 0.64g, 15.0mmol) was added and the solution was refluxed for a further 30 min. After cooling water (1ml) was added to the stirring solution. The precipitate was removed by filtration, washed with 90% aqueous

ethanol (10ml) then dried *in vacuo* over P₂O₅ to afford the title compound as a brown solid, 2.73g, 95% yield.

Example 13: The Chiral epoxidation of 2,2-dimethyl-6-pentafluoroethylchromene using E12 to give 2,2-dimethyl-6-pentafluoroethyl-1H-benzopyran-(3R,4R)-epoxide.

Aqueous sodium hypochlorite solution (8.5% w/v, 17.5ml, 20.0 mmol) was diluted to 25ml with water followed by the addition of 0.05M NaH₂PO₄ (aq) (10ml). The pH was adjusted to 11.3 and the solution cooled to 0°C, then added to a solution of 2,2-dimethyl-6-pentafluoroethyl chromene (2.78g, 10.0 mmol) and (E12) (0.115g, 0.20mmol) in methylene chloride (10ml) at 0°C. The reaction was stirred for 1 hour at 0°C then at room temperature overnight.

Hexane (100ml) and water (50ml) were added and the organic layer partitioned off. The aqueous layer was extracted with a further portion of hexane (100ml) and the combined organic layer was dried over MgSO₄ and the solvent removed *in vacuo* to give the title compound as a brown oil, 2.7g (94% yield).

The oil was purified by flash chromatography (silica gel 60, MERCK 9385, 230-400 mesh) (30g) eluting with 0-5% diethylether in hexane to give the title compound as a pale yellow, partially crystalline solid, 2.11g, 72% yield, identical (¹H NMR, TLC, HPLC) with an authentic sample, e.e. = 63% by chiral HPLC.

Example 14: (R)-1-Phenyl-1,2-bis(3,5-di-*tert*-butylsalicylideamino)ethane - manganese (III) chloride (E14).

(R)-1-Phenyl-1,2-bis(3,5-di-*tert*-butylsalicylideamino)ethane (D38, 1.70g, 3.0mmol) was dissolved in ethanol (30ml) and manganese (II) acetate tetrahydrate (1.47g, 6.0mmol) was added. The solution was refluxed for 16 hours then lithium chloride (0.38g, 9.0mmol) was added, the reaction refluxed for a further 30 min then allowed to cool to room temperature. Water (1ml) was added to the stirring solution and the resulting precipitate was removed by filtration to give the product as a brown solid which was dried *in vacuo* over P₂O₅ to afford 2.56g of the title compound, 78% yield.

Example 15: The Chiral epoxidation of 2,2-dimethyl-6-pentafluoroethylchromene using E14 to give 2,2-dimethyl-6-pentafluoroethyl-1H-benzopyran-(3R,4R)-epoxide.

Aqueous sodium hypochlorite solution (8.5% w/v, 17.5ml, 20.0 mmol) was diluted to 25ml with water followed by the addition of 0.05M NaH₂PO₄ (aq) (10ml). The pH was adjusted to 11.3 and the solution cooled to 0°C, then added to a solution of 2,2-dimethyl-6-pentafluoroethyl chromene (2.78g, 10.0 mmol) and (R)-1-phenyl-

1,2-bis(3,5-di-*tert*-butyl-salicylideamino)ethane - manganese (III) chloride (E14) (0.131g, 0.20mmol) in methylene chloride (10ml) at 0°C. The reaction was stirred for 2 hours at 0°C then at room temperature overnight.

5 Hexane (100ml) and water (50ml) were added and the organic layer partitioned off. The aqueous layer was extracted with a further portion of hexane (100ml), and the combined organic layers was dried over MgSO₄ and the solvent removed *in vacuo* to give the title compound as a yellow oil, 2.91g (99% yield).

The oil was purified by flash chromatography (silica gel 60, MERCK, 230-400 mesh) (40g) eluting with 0-5% diethyl ether in hexane to give the title compound
10 as a pale yellow crystalline solid, 1.81g, 62% yield, identical (¹H NMR, TLC, HPLC) with an authentic sample, e.e. = 68% by chiral HPLC.

Example 16: (S)-1-Methyl-1, 2-bis (3-*tert*-butyl-5-methylsalicylideamino)ethane - manganese (III) chloride (E16)

15 (S)-1-Methyl-1, 2-bis(3-*tert*-butyl-5-methylsalicylideamino)ethane (D39) (338mg, 0.8 mmol) was dissolved in EtOH (8ml) and manganese (II) acetate tetrahydrate (392 mg, 1.6 mmol) was added. The mixture was refluxed for 2h then lithium chloride (102 mg, 2.4 mmol) was added and, after a further 1h at reflux, the mixture was cooled to ambient. A few drops of water were added and the resulting
20 precipitate filtered and dried *in vacuo* over P₂O₅ to afford the title compound as a brown powder, 270 mg (66% yield).

Example 17: The chiral epoxidation of 2, 2-dimethyl-6-pentafluorethyl chromene using E16 to give 2, 2-dimethyl-6-pentafluoroethylchromene-(3S, 4S)-epoxide.

Aqueous sodium hypochlorite solution (16.75% w/v, 8.9 ml, 20 mmol) was diluted to 25ml with water followed by the addition of 0.05m NaH₂PO₄ (aq)(10ml). The pH was adjusted to 11.3 and the solution cooled to 0°C, then added to a solution of 2, 2-dimethyl-6-pentafluorethyl chromene (2.78g, 10 mmol) and (S)-1-methyl-1,
30 2-bis (3-*tert*-butyl-5-methylsalicylideamino) ethane - manganese (III) chloride (E16, 102 mg, 0.20 mmol) in methylene chloride (10ml) at 0°C. The reaction was stirred at 0°C for 1h then at room temperature overnight.

Hexane (100ml) and water (50ml) were added and the organic layer partitioned off. The aqueous layer was extracted with a further portion of hexane
35 (100ml) and the combined organic layers were dried over MgSO₄ and the solvent removed *in vacuo* to give the crude title compound as a brown oil, 2.78g (95% yield). Quantitative analysis (HPLC) showed this to contain 2.27g (77% yield) of the title compound, identical (TLC, HPLC) with an authentic sample, ee = 32% by chiral HPLC.

Example 18: (S)-1-Isopropyl-1, 2-bis (3-tert-butyl-5-methylsalicyclideamino) ethane-manganese (III) chloride. (E18)

(S)-1-isoPropyl-1, 2-bis (3-tert-butyl-5-methylsalicyclideamino) ethane (D40,
5 240 mg, 0.53 mmol) was dissolved in ethanol (10ml) and manganese (III) acetate dihydrate (0.14g, 0.53 mmol) was added. The mixture was refluxed for 2h then lithium chloride (34mg, 0.8 mmol) was added. After a further 1h at reflux the solution was cooled, solvent was removed *in vacuo* and the residue chromatographed on silica (Merck 9385, 20g, eluting with 0-6% methanol in chloroform) to afford the
10 title compound as a brown powder, 60mg (21% yield).

Example 19: The chiral epoxidation of 2, 2-dimethyl-6-pentafluorethyl chromene using E18 to give 2, 2-dimethyl-6-pentafluoroethylchromene- (3S, 4S) -epoxide

15 Aqueous sodium hypochlorite solution (15.24% w/v, 2 ml, 4 mmol) was made up to 5 ml with water. 0.05 M $\text{NaH}_2\text{PO}_4(\text{aq})$ (2 ml) was added and the pH adjusted to 11.3. The solution was cooled to 0°C then added to a solution of (0.56g, 2mmol) and the catalyst (S)-1-isopropyl-1, 2-bis (3-tert-butyl-5-methylsalicyclideamino) ethane-manganese (III) chloride. (E18, 21.5 mg, 0.04 mmol) in methylene chloride
20 (6ml). The mixture was stirred at 0°C for 1h then at room temperature overnight.

Hexane (20ml) and water (10ml) were added and the organic layer separated. The aqueous phase was extracted with further hexane (20ml) and the combined organic phase was dried (MgSO_4) and the solvent removed *in vacuo* to afford the title compound as a yellow oil (0.51g). Quantitative analysis (HPLC) showed this to
25 contain 0.42g (71% yield) of the title compound, identical (TLC, HPLC) with an authentic sample, ee = 23% by chiral HPLC.

Example 20: The chiral epoxidation of 6-acetyl-2, 2-dimethyl chromene using E14 to give 6-acetyl-2, 2-dimethyl chromene-(3R, 4R) epoxide.

30 A solution of sodium hypochlorite (8.6ml, 17.3%w/v), water (14ml) and Na_2HPO_4 (0.05M, 10ml) was adjusted to pH 11.3 with 8N NaOH. 6-Acetyl-2,2-dimethyl chromene (2g) and E14 (65.6 mg 1mol %) and dichloromethane (20ml) was added and the mixture stirred rapidly at room temperature overnight.

The mixture was diluted with dichloromethane (50ml) and filtered through
35 celite. The two layers were separated and the organic phase washed with water (100ml) the evaporated to dryness to give the title compound (2.0g 92%), ee = 67% by chiral HPLC.

Example 21 The chiral epoxidation of 6-acetyl-2, 2-dimethyl chromene using E14 to give 6-acetyl-2, 2-dimethyl chromene-(3R, 4R) epoxide, using pyridine-N-oxide as electron donating catalyst

The reaction of Example 20 was repeated with the addition of pyridine N-oxide (1.9 g, 2eq). The ee of the title product was found to be 79% using chiral HPLC.

Descriptions of Intermediates for the Preparation of Compounds of Formula (II)
(as described in WO 94/03271)

Description 1

(±) 2,5-Dihydro-3-nitrofurane (D1)

A mixture of (±) *trans* 3-chloromercurio-4-nitro-2,5-dihydrofuran¹ (38.54g, 109.6 mmol) and Et₃N (11.07g, 109.6 mmol) in CH₂Cl₂ (2.2L) at 25°C was stirred for 1.25h. 5% aqueous citric acid (1.1L) was added and stirring was continued for 5 min. The mixture was filtered through celite, separated and the organic phase washed with 5% aqueous citric acid (220 ml), dried over Na₂SO₄ and concentrated *in vacuo*. Chromatography of the residue on silica (Merck 9385, 300g) eluting with CHCl₃-Hexane (1:1 -> 1:0) afforded (D1) as a pale yellow oil which crystallised in the freezer, 5.45g (43.2%).

δ (CDCl₃) 4.95 (4H,S) and 7.10 (1H,S)

1. P. Bitha and Y - I. Lin, *J. Heterocyclic Chem.*, 1988, 25, 1035-1036.

Description 2

(±) 3,4-Diaminotetrahydrofuran (D2)

A solution of (±) 4-amino-3-nitrotetrahydrofuran, prepared from (D1) *via* the method of Bitha and Lin¹, (4.66g, 35.3 mmol) in EtOH (100 ml) containing 10% palladium on carbon (2.5g) was hydrogenated on a Parr shaker apparatus at 35 psi for 65h at 20°C. The suspension was filtered, the solids washed with EtOH (100 ml) and the combined filtrate evaporated *in vacuo* to afford (±) (D2) as a colourless oil, 3.26g (81.5%)

δ (CDCl₃) 1.40 (4H,bs), 3.20 (2H, m), 3.50 (2H,dd) and 4.08 (2H,dd).

Description 3

(±) 3,4-bis (3-*tert*-Butyl-5-methylsalicylideamino)tetrahydrofuran (D3)

A solution of the racemic diamine (D2) (855 mg, 8.38 mmol) and 3-*tert*-butyl-5-methylsalicylaldehyde (3.22g, 16.76 mmol) in EtOH (50 ml) was heated at reflux for 1.5h. The solvent was removed *in vacuo* and the residue chromatographed on silica (Merck 9385, 300g) using CHCl₃ as eluent to afford (±) (D3) as pale yellow needles, 1.35g, (35.8%).

δ (CDCl₃) 1.42 (18H,s), 2.25 (6H,s), 3.95-4.10 (2H,m), 4.43 (2H,q), 6.90 (2H,d), 7.15 (2H,d), 8.30 (2H,s) and 13.10 (2H,bs).

Description 4

5 (S,S) *trans* 3,4-bis(methanesulphonyloxy)tetrahydrofuran (D4)

A solution of 1,4-anhydro-L-threitol (2.45g, 23.5 mmol ex Aldrich Chemical company) in a mixture of THF (75 ml) and Et₂O (75 ml) at 0°C was treated sequentially with triethylamine (7.2 ml, 51.7 mmol, 2.2 eq) and methanesulphonyl chloride (3.82 ml, 49.35 mmol, 2.1 eq). The mixture was stirred for 4h then stored at
10 0°C overnight (~16h).

The reaction was filtered and the solids washed with THF (20 ml). The combined filtrate was evaporated *in vacuo* and partitioned between 10% aqueous citric acid (60 ml) and EtOAc (150 ml). The organic phase was dried (MgSO₄) and evaporated to afford (D4) as a colourless oil, 5.82g (95%).

15 δ (CDCl₃) 3.12 (6H,s) 4.00 (2H,dd), 4.18 (2H,dd) and 5.25 (2H,dd).

Description 5

(S,S) *trans* 3,4-Diazidotetrahydrofuran (D5)

A mixture of the dimesylate (D4) (5.80g, 22.3 mmol) and lithium azide (5.46, 20 111.5 mmol, 2.5 eq) in DMSO (60 ml) was heated at 100-110°C for 40h. After cooling to ambient the reaction was diluted with water (1L) and extracted with EtOAc (1L, 2 x 0.75L). The combined organic phase was washed with water (0.5L) and brine (0.5L), dried over MgSO₄ and evaporated *in vacuo* to a pale yellow oil of the title compound, 2.18g (61.5%).

25 δ (CDCl₃) 3.75 (2H,dd) and 3.90 - 4.05 (4H,m).

Description 6

(S,S) *trans* 3,4-Diaminotetrahydrofuran

To lithium aluminium hydride (2.05g, 54 mmol) in dry THF (150 ml) at 0°C
30 was added the diazide (D5) (2.08g, 13.5 mmol) in THF (50 ml) dropwise over 10 min. After 15 min the solution was allowed to warm to ambient, then stirred for 16h.

The reaction mixture was re-cooled to 0°C and quenched sequentially with H₂O (2 ml), 15% aqueous NaOH (2 ml) and further H₂O (6 ml) and warmed to ambient. After stirring for 1h the mixture was filtered through celite, rinsed with
35 THF (2 x 150 ml) and the combined filtrate evaporated *in vacuo* to afford (D6) as a pale yellow oil, 1.28g (93%).

δ (CDCl₃) 1.30 (4H,bs), 3.20 (2H,dd), 3.50 (2H,dd) and 4.08 (2H,dd).

Description 7

(S,S) trans 3,4-bis(3-tert-Butyl-5-methylsalicylideamino)tetrahydrofuran (D7)

A solution of the (S,S)-diamine (D6) (1.26g, 12.35 mmol) and 3-tert-butyl-5-methylsalicylaldehyde (4.74g, 24.70 mmol) in EtOH (75 ml) was heated at reflux for 3.5h. The solution was cooled and solvent removed *in vacuo* to afford crude (5) as a yellow oil, 5.50g (99%).

A sample of the crude material (4.55g) was chromatographed on silica (Merck 9385, gradient of CHCl₃ in hexane) to afford pure (D7) as a yellow foam, 4.39g (95.5% yield).

δ (CDCl₃) 1.42 (18H,s), 2.25 (6H,s), 3.95 - 4.10 (4H,m) 4.33 (2H,q), 6.90 (2H,d), 7.15 (2H,d), 8.30 (2H,s) and 13.15 (2H,bs).

Description 8**(2R,3R)-1,4-Dibenzyloxy-2,3-dimethanesulfonyloxybutane**

To a solution of (2R,3R)-(+)-1,4-dibenzyloxy-2,3-butanediol (25.3g, 83.7mmol ex Aldrich Chemical Company) in dichloromethane (165ml), cooled in an ice bath, was added methanesulfonyl chloride (13.0ml, 167.4 mmol), followed by slow addition of triethylamine (23.3ml, 167.4mmol) such that the temperature did not rise above 5°C. Once the addition was complete the reaction was allowed to stir with ice-bath cooling for 3 hours. Water (600ml) was then added and the organic phase separated. The aqueous phase was re-extracted with dichloromethane (200ml) and the combined organic phases washed with water (400ml) and brine (400ml), dried (MgSO₄), and the solvent evaporated to afford a pale yellow solid. Trituration with diethyl ether afforded the title compound (28.2g, 74%) as colourless crystals m.p. 72-73°C.

¹H n.m.r. (CDCl₃): δ 3.03 (s,6H,2xCH₃), 3.76 (m,4H,2xCH₂O),4.48 (d,2H,CH₂Ph), 4.57 (d,2H,CH₂Ph), 5.00 (m,2H,2xCH), 7.27-7.39 (m,10H,2xPh)

¹³C n.m.r. (CDCl₃): δ 38.8 (2xCH₃), 68.7 (2xCH₂) 73.7 (2xCH₂), 78.7 (2xCH), 128.1, 128.2, 128.6, 137.0 (2xPh).

EI-MS:m/e 459 (MH⁺), 367 (M⁺-CH₂Ph).

C₂₀H₂₆O₈S₂ requires: C: 52.39, H:5.72%.

found : C: 52.36, H:5.59%.

Description 9**(2R,3R)-Dimethanesulfonyloxybutane-1,4-diol**

(2R,3R)-1,4-Dibenzyloxy-2,3-dimethanesulfonyloxybutane (27.6g, 60.3mmol) (D8) was dissolved in acetone (500ml), a suspension of 10% Pd/C (29.9g) in acetone (300ml) added, and the mixture hydrogenated at 1 atm. pressure for 2 hours at ambient temperture. The mixture was then filtered three times through a pad

of silica and Celite, and the solvent evaporated to give the title compound as a straw-coloured oil (14.7g, 87%), which solidified on standing.

^1H n.m.r. (DMSO- d_6): δ 3.24 (s,6H,2xCH₃), 3.69 (m,4H,2xCH₂),4.76 (m,2H,2xCH), 5.33 (t,2H,2xOH).

5 ^{13}C n.m.r. (DMSO- d_6): δ 38.1 (2xCH₃), 59.7 (2xCH₂), 80.3 (2xCH).

EI-MS:m/e 279 (MH⁺), 261 (MH⁺-H₂O), 183 (M⁺-OMs), 165 (M⁺-OMs,H₂O).

Description 10**(6R,7R)-Dimethanesulfonyloxy-2,4,9,11-tetraoxadodecane**

(2R,3R)-Dimethanesulfonyloxybutane-1,4-diol (14.7g, 52.9 mmol) (D9) was dissolved in dimethoxymethane (89.5ml) and dichloromethane (30ml) at 40°C.

- 5 Lithium bromide (0.91g) and p-toluenesulfonic acid monohydrate (1.01g, 5.29mmol) were added, and the mixture heated under reflux for 3 hours. The reaction was allowed to cool to ambient temperature, and then poured into saturated sodium bicarbonate solution (200ml), extracted with ethyl acetate (2x200ml), dried (MgSO₄) and evaporated to give a colourless oil. This was purified by column chromatography
 10 on silica, eluting with 0-1% methanol in dichloromethane, to afford the title compound as a colourless oil (8.2g, 42%).

¹H n.m.r. (CDCl₃):δ 3.13 (s,6H,2xCH₃), 3.39 (s,6H,2xOCH₃), 3.87 (m,4H,2xCH₂), 4.66 (m,4H,2xOCH₂O), 5.02 (m,2H,2xCH).

- ¹³C n.m.r. (CDCl₃):δ 38.8 (2xSCH₃), 55.8 (2xOCH₃), 66.1 (2xCH₂), 78.4
 15 (2xCH), 96.8 (2xOCH₂O)

CI-MS:m/e 384 (MNH₄⁺).

C₁₀H₂₂O₁₀S₂ requires: C: 32.78, H:6.05%.

found : C: 32.22, H:5.62%.

20 Description 11**(5R,6R)-Dimethanesulfonyloxy-1,3-dioxepane**

- A solution of (6R,7R)-dimethanesulfonyloxy-2,4,9,11-tetraoxadodecane (8.2g, 22.4mmol) (D10) and p-toluenesulfonic acid monohydrate (0.26g, 1.34mmol) in toluene (165ml) was heated under reflux overnight. The solvent was evaporated
 25 and the brown residue triturated with diethyl ether to afford the title compound as an off-white solid (5.9g, 91%) m.p. 133-134°C.

¹H n.m.r. (CDCl₃):δ 3.13 (s,6H,2xCH₃), 3.84 (m,2H,CH₂), 4.06 (m,2H,CH₂), 4.77 (s,2H,OCH₂O), 4.81 (m,2H,2xCH).

- ¹³C n.m.r. (CDCl₃):δ 38.8 (2xCH₃), 64.1 (2xCH₂) 78.3 (2xCH), 94.6
 30 (OCH₂O)

EI-MS:m/e 291 (MNH⁺).195 (M⁺-OMs).

C₇H₁₄O₈S₂ requires: C: 28.96, H:4.86%.

found : C: 29.22, H:4.61%.

35 Description 12**(5R,6R)-Diazido-1,3-dioxepane**

A mixture of (5R,6R)-dimethanesulfonyloxy-1,3-dioxepane (5.0g, 17.2mmol) D11 and lithium azide (4.2g, 86mmol) in dimethylsulphoxide (60ml) was stirred and heated to 110-120°C overnight. The reaction mixture was then cooled, poured into

water (200ml), and extracted with ethyl acetate (2x150ml). The combined organic phases were washed with water (2x150ml) and brine (150ml), dried (MgSO₄) and evaporated to give the title compound as a brown oil (2.7g, 85%).

¹H n.m.r. (CDCl₃):δ 3.49 (m,2H,2xCH), 3.74 (m,2H,2xCH₂), 3.93 (m,2H,CH₂), 4.73 (s,2H,OCH₂O).

¹³C n.m.r. (CDCl₃):δ 64.3 (2xCH), 64.6 (2xCH₂) 94.3 (OCH₂O).

EI-MS:m/e 185 (MH⁺), 157 (MH⁺-N₂), 142 (M⁺-N₃).

C₅H₈N₆O₂ requires: C: 32.61, H:4.38, N:45.63%.

found : C: 32.33, H:4.67, N:45.38%.

10

Description 13

(5R,6R)-Diamino-1,3-dioxepane

To a slurry of lithium aluminium hydride (2.1g, 55.3mmol) in dry tetrahydrofuran (70ml) at 0°C under an argon atmosphere was added dropwise a solution of (5R, 6R)-diazido-1,3-dioxepane (2.6g, 14.1mmol) (D12) in dry tetrahydrofuran (50ml). During the addition the reaction temperature was maintained below 10°C with an ice-salt bath. One completion, the reaction mixture was allowed to warm to ambient temperature, and stirred for a further 1.5 hours. It was then re-cooled and the reaction quenched by addition of water (2ml), 2M NaOH (2ml), and water (4ml), the temperature again being maintained below 10°C by means of an ice-salt bath. The quenched reaction mixture was allowed to warm to ambient temperature, stirred for a further 2 hours, then filtered through Celite, and the filter pad washed well with tetrahydrofuran. The combined filtrates were evaporated to afford the title compound as a pale yellow oil (1.3g, 70%).

¹H n.m.r. (CDCl₃):δ 1.56 (brs,4H,2xNH₃), 2.62 (m,2H,2xCH), 3.58 (m,2H,CH₂), 3.77 (m,2H,2xCH₂), 4.72 (s,2H,OCH₂O)

¹³C n.m.r. (CDCl₃):δ 57.9 (2xCH), 67.5 (2xCH₂) 93.8 (OCH₂O).

C₅H₁₂N₂O₂ requires: C: 45.44, H:9.15, N:21.20%.

found : C: 45.13, H:8.76, N: 19.58%.

30

EI-MS:m/e 133 (MH⁺), 116 (M⁺-NH₂)⁺.

Description 14**Preparation of (5R,6R)-Di-(3,5-di-tert-butyl) salicylideamino-1,3-dioxepane**

(5R,6R)-Diamino-1,3-dioxepane (1.0g, 7.6mmol) (D13) and 3,5-di-tert-butylsalicylaldehyde (3.6g, 15.4mmol, 2eq.) were dissolved in ethanol (100ml), and the solution stirred under reflux for 3 hours. The reaction mixture was then allowed to cool, the solvent was evaporated, and the residue purified by column chromatography on silica, eluting with 4% diethyl ether in hexane. This afforded the title compound as a bright yellow foam (3.5g, 82%).

¹H n.m.r. (CDCl₃): δ 1.23 (s, 18H, 6xCH₃), 1.41 (s, 18H, 6xCH₃), 3.85 (m, 2H, CH₂), 4.07 (m, 2H, CH₂), 4.87 (s, 2H, OCH₂O), 6.99 (d, 2H, Ar), 7.33 (d, 2H, Ar), 8.33 (s, 2H, 2xCH=N), 13.20 (brs, 2H, 2xOH).

¹³C n.m.r. (CDCl₃): δ 29.4 (6xCH₃), 31.4 (6xCH₃), 34.1 (2xCCH₃), 35.0 (2xCCH₃), 67.7 (2xCH), 73.8 (2xCH₂), 94.2 (OCH₂O), 117.6, 126.4, 127.4, 136.6, 140.3, 157.9 (Ar), 168.4 (2xC=N)

C₃₅H₅₂N₂O₄ requires: C: 74.43, H: 9.28, N: 4.96%.

found : C: 74.56, H: 9.15, N: 4.92%.

CI-MS: m/e 565 (MH⁺).

20 Description 15**(3R, 4R)-Diacetoxytetrahydropyran (D15)**

A solution of 3,4-di-O-acetyl-D-Xylal² (11.16g) in 50% aqueous ethanol (400ml) containing PtO₂ (400mg) was hydrogenated at atmospheric pressure for 3.5 hours at 25°C. The suspension was filtered through celite, washed with 50% aqueous ethanol (50ml) and water (50ml), and the combined filtrate evaporated *in vacuo* to afford the **title compound** as a colourless oil, 9.6g (85%).

δ (CDCl₃): 1.30-1.50 (1H, m), 2.10 (6H, s), 2.10-2.20 (1H, m), 3.35-3.60 (2H, m), 3.80-4.00 (2H, m) and 4.80-5.00 (2H, m).

2. Dictionary of Organic Compounds, 5th Edition, 1982, Chapman & Hall, London, 579 and references therein.

Description 16**(3R,4R)-Dimethanesulfonyloxytetrahydropyran(D16)**

Sodium (~50mg) was dissolved in methanol (100ml) at ambient. To the resulting solution was added a solution of the diester (D15) (9.56g, 47.3mmol) in methanol (100ml) and the mixture stirred for 72 hours. Amberlite IR 120H⁺ resin (20g) was added and the mixture filtered. Concentration of the filtrate *in vacuo* afforded the diol as a colourless oil. This was dissolved in a mixture of tetrahydrofuran (220ml) and diethyl ether (220ml). Triethylamine (10.86g,

107.5mmol,) was added and the solution cooled to 0°C. Methanesulphonyl chloride (11.76g, 102.7mmol) was added dropwise at 0°C, the solution was stirred for a further hour then stored at 4°C for 16 hours. The resulting suspension was filtered and the solids washed with tetrahydrofuran (2x95ml) and diethyl ether (2x180ml).

5 The combined filtrate was evaporated *in vacuo* and the residue partitioned between ethyl acetate (200ml) and 10% aqueous citric acid (200ml). The organic phase was dried (MgSO₄), filtered and concentrated *in vacuo* to a colourless foam to afford the title compound, 12.07g (93%).

10 δ (CDCl₃): 3.10 (6H,s), 2.00-2.40 (2H,m), 3.40-4.20 (4H,m), 4.55-4.65 (1H,m) and 4.70-4.85 (1H,m).

Description 17

(3R,4S)-Diaminotetrahydropyran (D17)

The dimesylate (D16) (12.07g, 44 mmol) was dissolved in
15 dimethylsulphoxide (88ml) and treated with lithium azide (10.8g, 220mmol). The mixture was heated at 100°C for 40 hours, then cooled to ambient and poured into water (1.03L) and extracted with ethyl acetate (1.03L, 2 x 0.59L). The combined organic phase was washed with water (300ml) and brine (300ml), dried over MgSO₄ and concentrated *in vacuo* to give the crude diazide as a brown oil, 3.7g. This was
20 dissolved in tetrahydrofuran (45ml), and added dropwise to a cold (0°C) suspension of lithium aluminium hydride (3.34g, 88mmol) in tetrahydrofuran (220ml), maintaining the temperature below +10°C. After completion of addition the suspension was stirred at 0°C for 0.5 hours then warmed to ambient and stirred for 16 hours.

25 The mixture was recooled to 0°C and quenched sequentially with water (3.34ml) in tetrahydrofuran (5ml), 15% aqueous sodium hydroxide (3.34ml) and further water (10ml). The mixture was allowed to warm to ambient, stirred for one hour then filtered through celite, rinsing with tetrahydrofuran (2x400ml). The combined filtrate was concentrated *in vacuo* to give the title diamine as a colourless
30 oil, 2.62g (51%).

δ (CDCl₃): 1.20-1.90 (6H,m), 2.40-2.50 (2H,m), 2.90-3.40 (2H,m) and 3.80-4.00 (2H,m).

Description 18**(3R,4S)-bis-(3,5-Di-tert-Butylsalicylideamino)tetrahydropyran, (D18)**

To the diamine (D17) (2.55g, 22mmol) in ethanol (220ml) was added 3,5-di-tert-butylsalicylaldehyde (10.3g, 44mmol). The mixture was heated at reflux for 2 hours, cooled to ambient filtered, and the crystalline product dried *in vacuo* to afford the **title compound** as yellow crystals, 4.81g, (40%).

δ (CDCl₃): 1.20 (18H,s), 1.40 (18H,s), 1.50-2.20 (2H,m), 3.50-3.70 (4H,m), 4.00-4.15 (2H,m), 7.00 (2H,bs), 7.35 (2H,bs), 8.33 (1H,s), 8.37 (1H,s) and 13.20 (2H,bs).

Description 19**(3R,4S)-bis (3-tert-Butyl-5-methylsalicylideamino) tetrahydropyran (D19)**

A solution of the diamine (D17) (0.62g, 5.35mmol) and 3-tert-butyl-5-methylsalicylaldehyde (2.05g, 10.7mmol) in ethanol (40ml) was heated at reflux for 2 hours. The solution was cooled then stored at 4°C for 70 hours to afford a yellow precipitate. This was filtered, washed with cold 95% aqueous ethanol (5ml) and dried *in vacuo* to afford the **title compound**, 1.22g (49%).

δ (CDCl₃): 1.40 (18H,s), 1.80-2.20 (2H,m), 2.20 (6H,s), 3.40-3.70 (4H,m), 4.00-4.20 (2H,m), 6.80 (2H,bs), 7.05 (2H,bs), 8.27 (1H,s), 8.30 (1H,s) and 13.30 (2H,bs).

Description 20**(3S,4S)-bis (3,5-di-tert-Butylsalicylideamino) tetrahydrofuran (D20)**

A solution of (S,S)-diamine (D6) (0.96g, 9.4mmol) and 3,5-di-tert-butylsalicylaldehyde (4.4g, 18.8mmol) in ethanol (90ml) was heated at reflux for 2 hours. The mixture was cooled to 0°C, filtered and the solids washed with cold ethanol and dried to afford the **title compound** as yellow crystals, 3.07g (61%).

δ (CDCl₃): 1.27 (18H,s), 1.45 (18H,s), 3.95-4.10 (4H,m), 4.30-4.40 (2H,m), 7.05 (2H,d), 7.40 (2H,d), 8.35 (2H,s) and 13.20 (2H,s).

Description 21**(3S,4R)-Dihydroxy-(2R)-(hydroxymethyl)tetrahydropyran (D21)**

A solution of D-Glucal³ (16.0g, 0.11 mole) in 50% aqueous ethanol (500ml) was treated with platinum oxide (0.75g) and hydrogenated at ambient at atmospheric pressure for 5 hours. The suspension was treated with charcoal (50g) filtered through celite (200g) and the solids washed with 50% aqueous ethanol (300ml). The combined filtered was evaporated *in vacuo* and dried over P₂O₅ to afford the **title compound** as a colourless oil, 16.0g (99%).

δ (CD₃OD): 1.50-1.70 (1H,m), 1.80-2.20 (1H,m), 3.00-3.20 (2H,m), 3.30-3.70 (3H,m), 3.80-4.00 (2H,m) and 4.90 (3H,bs)

3. Dictionary of Organic Compounds, 5th Edition, 1982, Chapman and Hall, London, 2754, and references therein.

5

Description 22

(3S,4R)-Dihydroxy-(2R)-(triphenylmethoxymethyl) tetrahydropyran (D22)

A solution of the triol (D21) (1.76g, 11.9mmol) in pyridine (20ml) was treated with trityl chloride (3.31g, 11.9mmol) and 4-(dimethylamino)pyridine (50mg).

10 Diisopropylethylamine (1.92g, 14.8mmol, 1.25eq) was added and the solution stirred for 4 hour at ambient temperature.

The mixture was poured into water (200ml) and extracted with diethyl ether (2x200ml). The combined organic phase was washed with 10% aqueous citric acid (100ml) and brine (100ml), dried over MgSO₄ and concentrated *in vacuo* to an oil.

15 The residue was chromatographed on silica (eluent:gradient of methanol in chloroform) to afford the **title compound** as a colourless foam, 3.70g (79.7%).

δ (CDCl₃): 1.60-1.80 (1H,m), 1.90-2.00 (1H,m), 2.70 (2H,bs,D₂O exch), 3.25-3.50 (5H,m), 3.60-3.70 (1H,m), 3.90-4.00 (1H,m) and 7.20-7.50 (15H,m).

20 Description 23

(3R,4R)-Dimethanesulphonyloxy-(2R)-(triphenylmethoxymethyl)tetrahydropyran (D23)

To the diol (D22) (3.10g, 7.95mmol) in a mixture of diethyl ether and tetrahydrofuran (2:1, 150ml) was added triethylamine (1.76g, 17.5mmol). The mixture was cooled to 0°C and methanesulphonyl chloride (1.91g, 16.7mmol) added. After 2 hours the suspension was filtered and the filtrate concentrated *in vacuo*, then redissolved in ethyl acetate (200ml). The solution was washed with 10% aqueous citric acid (100ml) and brine (50ml), then dried over MgSO₄. Solvent was removed *in vacuo* and the residue dried to afford (12) as a colourless solid, 4.26g (95%).

30 δ (CDCl₃): 2.20-2.50 (2H,m), 2.50 (3H,s), 3.10 (3H,s), 3.20-3.30 (1H,m), 3.40-3.60 (3H,m), 3.95-4.10 (1H,m), 4.70-4.80 (2H,m) and 7.20-7.50 (15H,m).

Description 24

35 (3R,4S)-bis(3,5-Di-tert-butylsalicylideamino)-(2S)-(triphenylmethoxymethyl)tetrahydropyran (D24)

A mixture of the dimesylate (D23) (2.85g, 5.22mmol) and lithium azide (1.28g, 26.1mmol) in dimethyl sulphoxide (20ml) was heated at 100-110°C for 24 hour. The solution was cooled, poured into water (200ml) and extracted with ethyl acetate (2x300ml). The combined organic phase was washed with water (2x300ml)

and brine (300ml), and dried over MgSO_4 . Removal of the solvent afforded the intermediate diazide as a yellow foam (1.52g).

A 1.40g portion of the diazide in tetrahydrofuran (10ml) was added to a suspension of lithium aluminium hydride (470mg, 12.4mmol) in tetrahydrofuran (30ml) at 0°C . After stirring at 0°C for 1 hour the mixture was allowed to warm to ambient and stirred for 16 hours. The suspension was recooled to 0°C and quenched sequentially with water (0.5ml), 15% aqueous sodium hydroxide (0.5ml) and further water (1.5ml). After warming the ambient and stirring for 1 hour the mixture was filtered, the solids washed with tetrahydrofuran (2x20ml) and the combined filtrate evaporated to afford the crude diamine as a foam (1.28g).

A portion of the diamine (1.18g) and 3,5-di-tert-butylsalicylaldehyde (1.42g, 6.08mmol) in ethanol (30ml) was heated at reflux for 4 hour then cooled to ambient. Solvent was removed *in vacuo* and the residue chromatographed on silica (eluent: gradient of chloroform in hexane) to afford the **title compound** as a yellow powder, 210mg, in 8.4% overall yield from (D23).

δ (CDCl_3): 1.25 (9H,m), 1.30-1.60 (2H,m), 1.32 (9H,s), 1.40 (9H,s), 1.50 (9H,s), 2.40-2.55 (1H,s), 2.70-2.80 (1H,s), 3.30-3.60 (2H,m), 3.90-4.30 (3H,m), 6.85 (1H,bs), 7.00-7.35 (16H,m), 7.38 (1H,bs), 7.45 (1H,bs), 8.30 (1H,s), 8.50 (1H,s), 13.25 (1H,s) and 13.50 (1H,s).

Description 25

(\pm)*trans*-1-Benzoyl-3,4-bis(methanesulphonyloxy)piperidine (D25)

(\pm)*trans*-1-Benzoylpiperidine-3,4-diol⁴ (3g, 13.6mmol) was suspended in dichloromethane (70ml) and triethylamine (5.74ml, 43mmol) was added. The mixture was cooled to -10°C and methanesulphonyl chloride (2.6ml, 34mmol) added over 5 min. After a further 15 min the mixture was poured into ice-water (50ml) and the organic layer washed with 5% aqueous citric acid (30ml). The solution was dried over MgSO_4 and concentrated *in vacuo* to a foam, 5.3g (100%).

δ_{H} (CDCl_3): 1.95 (2H,m), 2.30 (2H,m), 3.15 (6H,s), 4.70 (2H,m), 4.85 (2H,m) and 7.45 (5H,m).

4. V. Petrow and O. Stephenson, *J Pharm. Pharmacol*, 1962, 14, 306-314.

Description 26

(\pm)*trans*-1-Benzoyl-3,4-diazidopiperidine (D26)

A mixture of the dimesylate (D25) (5.3g, 14mmol) and lithium azide (3.4g, 69mmol) in dimethylsulphoxide (36ml) was heated at 100°C for 18 hours. After cooling the reaction mixture was partitioned between dichloromethane (200ml) and water (50ml). The aqueous phase was separated and further extracted with dichloromethane (100ml, 50ml) and the combined organic extracts washed with water

(3x50ml), dried (Na₂SO₄) and concentrated *in vacuo*. The residue was chromatographed on silica (eluent: gradient of methanol in dichloromethane) to afford the **title compound** as a colourless solid, 900mg (24%).

5 δ_{H} (CDCl₃): 1.60 (2H,m), 2.10 (2H,m), 3.05 (2H,m), 3.20 (2H,m) and 7.40 (5H, m).

Description 27

(±)*trans*-1-Benzoyl-3,4-diaminopiperidine (D27)

10 A solution of the diazide (D26) (450mg, 1.7mmol) in ethanol (30ml) was treated with Lindlar catalyst (5%Pd/ CaCO₃, 250mg) and stirred under hydrogen (1 atm) for 24 hour. The mixture was filtered and solvent removed *in vacuo* to afford the title compound as oil, 350mg (94%).

δ_{H} (DMSO): 1.20 (1H,m), 1.65-1.80 (2H,m), 2.20 (2H,m), 2.70 (1H,m), 3.00 (1H,m), 3.30 (1H,m), 4.40 (1H,m) and 7.40 (5H,m).

15

Description 28

(-)*trans*-1-Benzoyl-3,4-bis(3,5-di-*tert*-butylsalicylideamino)piperidine (D28)

20 A solution of the amine (D27) (350mg, 1.6mmol) and 3,5-di-*tert*-butylsalicylaldehyde (960mg, 4.1mmol) in ethanol (40ml) was heated at reflux for 3 hours. The mixture was cooled and filtered to afford the racemic bis-imine, 652mg (63%).

A 100mg sample was separated by chiral hplc (CHIRALPAK AD, eluent 2% ethanol in hexane) to afford the **title compound** as a single enantiomer, $[\alpha]_{\text{D}}^{25} = -228^{\circ}$ (c=0.13, CHCl₃).

25 δ_{H} (CDCl₃): 1.20 (18H,s), 1.45 (18H,s), 2.00 (2H,m), 3.25 (2H,m), 3.45 (1H,m), 3.55 (1H,m), 4.35 (2H,m), 6.95 (2H,s), 7.40 (7H,m), 8.30 (2H,s) and 13.15 (2H,bs).

Description 29

(±) 3,4-bis(3-*tert*-Butyl-5-methylsalicylideamino) tetrahydrofuran manganese (III) chloride (D29)

30 A suspension of the racemic ligand (D3) (690 mg, 1.53 mmol) in EtOH (25 ml) was heated with Mn(OAc)₂·4H₂O (750 mg, 3.06 mmol) at reflux for 18h. LiCl (195 mg, 4.49 mmol) was added and reflux continued for a further 0.5h.
35 Solvent was removed *in vacuo* and the residue chromatographed on silica (Merck 9385, 100g) eluting with a gradient of MeOH in CHCl₃, to afford the title compound as a brown powder (90 mg, 11%) together with unreacted (D3), 420 mg (61% recovery).

Description 30**(S,S) trans 3,4-bis (3-tert-Butyl-5-methylsalicylideamino)tetrahydrofuran manganese (III) chloride (D30)****5 Method A (using manganese (II) acetate)**

A solution of (D7) (0.95g, 2.11 mmol) and $Mn(OAc)_2 \cdot 4H_2O$ (1.03g, 4.22 mmol) in EtOH (40 ml) was heated at reflux for 17h. Lithium chloride (268 mg, 6.33 mmol) was added and reflux continued for a further 0.5h. After cooling to ambient the solvent was removed *in vacuo* and the residue chromatographed on silica (Merck
10 9385, gradient of MeOH in $CHCl_3$) to afford (E3) as a brown powder, 26 mg (2.3%), together with unreacted (D7), 683 mg (72%).

Method B (using manganese (III) acetate)⁵

A solution of (D7) (1.53g, 3.4 mmol) in a mixture of CH_2Cl_2 (17 ml) and MeOH (17 ml) was treated with $Mn(OAc)_3 \cdot 2H_2O$ (0.01g, 3.4 mmol). The mixture
15 was heated at reflux for 3h, cooled to ambient and treated with lithium chloride (0.21g, 5.1 mmol). After stirring for 16h the solvent was reduced *in vacuo* to ca. 8 ml, Et_2O (70 ml) was added and the suspension stirred for 1h. The mixture was filtered and the solids washed with Et_2O (3 x 20 ml) and dried *in vacuo* to afford (E3) as a brown powder, 1.57g (86%).

20 5 T. Matsushita and T. Shono, Bull. Chem. Soc. Japan, 1981, 54, 3743-3748.

Description 31**Preparation of (R,R)-5,6-bis-(3,5-di-tert-butylsalicylideamino)-1,3-dioxepane]-
25 manganese (III) chloride (D31)**

(5R,6R)-Di-(3,5-di-tert-butyl)salicylideamino-1,3-dioxepane (1.0g, 1.77mmol) (D14) and manganese (II) acetate tetrahydrate (2.17g, 8.87mmol) were suspended in 95% ethanol (50ml), and the mixture stirred under reflux overnight. Lithium chloride (0.38g, 8.96mmol) was then added and heating continued for a
30 further 30 minutes. The reaction mixture was then cooled, water (60ml) added, and filtered through Celite. The dark precipitate was washed well with water, then dissolved in dichloromethane (80ml), dried ($MgSO_4$), and the solvent evaporated to give the title compound as a dark brown solid (0.9g, 78%).

$C_{35}H_{50}N_2O_4MnCl$ requires: C:64.36, H:7.72, N:4.29%.

35 found: C: 64.57, H: 7.57, N: 4.09%

CI-MS: m/e 565 (MH-Mn,Cl)⁺, 235 (3,5-di-tert-butylsalicaldehydeH)⁺.

Description 32

(3R,4S)-bis-(3,5-di-tert-butylsalicylideamino)tetrahydropyran-manganese (III) chloride (D32)

A solution of the ligand (D18) (4.81g, 8.8mmol) in dichloromethane-methanol (1:1, 88ml) was treated with manganese triacetate dihydrate (2.35g, 8.8mmol) and the mixture heated at reflux for 4 hours. Lithium chloride (0.56g, 13.2mmol) was added and heating at reflux continued for a further 1 hour. The mixture was cooled, concentrated *in vacuo* and the residue triturated with diethyl ether (220ml). The solid product was filtered, washed with diethyl ether (2 x 65ml) and dried to afford (5) as a brown powder, 5.3g (94%).

10

Description 33

(3R,4S)-bis-(3-tert-butyl-5-methylsalicylideamino)tetrahydropyran-manganese (III) chloride (D33)

A solution of the ligand (D19) (928mg, 2mmol) in dichloromethane-methanol (1:1, 20ml) was treated with manganese triacetate dihydrate (536mg, 2mmol) and heated at reflux for 3 hours. The mixture was cooled to ambient, lithium chloride (128mg, 3mmol) was added and the solution stirred for 1 hour. The reaction mixture was concentrated *in vacuo* and the residue triturated with diethyl ether (40ml). The solid product was filtered, washed with diethyl ether (2x15ml) and dried *in vacuo* to afford the **title compound** as a brown powder, 1.09g (98%).

15
20

Description 34

(3S,4S)-bis-(3,5-di-tert-Butylsalicylideamino)tetrahydrofuran-manganese (III) chloride (D34)

A solution of the ligand (D20) (1.07g, 2mmol) and manganese triacetate dihydrate (536mg, 2mmol) in a mixture of dichloromethane and methanol (1:1, 20ml) was heated at reflux for 6.5 hour. The solution was cooled to ambient, lithium chloride (128mg, 3mmol) was added and the mixture stirred for 16 hours. The reaction mixture was concentrated *in vacuo* and the residue triturated with diethyl ether (50ml). The solid product was filtered, washed with diethyl ether (2x15ml) and dried *in vacuo* to afford the **title compound** as a brown powder, 1.12g (89%).

25
30

Description 35

(3R,4S)-bis-(3,5-Di-tert-Butylsalicylideamino)-(2R)-(triphenylmethoxymethyl)tetrahydropyran-manganese (III) chloride (D35)

35

To the ligand (D24) (160mg, 195mmol) in dichloromethane-methanol (3:2, 5ml) was added NaOH (0.93ml of 0.417 molar in methanol, 390 mmol) and manganese triacetate dihydrate (52.5mg, 195 mmol). The solution was heated at

reflux for 3 hours, lithium chloride (12.5mg, 300 mmol) added and the mixture stirred for 15 hours.

Solvent was removed *in vacuo* and the residue triturated with diethyl ether (10ml). The solid product was filtered, washed with diethyl ether (2x2ml) and dried
5 with afford the title compound as a brown powder, 136mg (77%).

Description 36

(-)-trans-1-Benzoyl-3,4-bis(3,5-di-tertbutylsalicylideamino) piperidine-manganese (III) chloride (D36)

10 A mixture of the (-) ligand (D28) (20mg, 0.013mmol) and manganese triacetate dihydrate (10mg, 0.037mmol) in dichloromethane-methanol (3:2, 5ml) was heated at reflux for 4 hour. Lithium chloride (1.6mg, 0.038mmol) was added and reflux continued for a further 1 hour.

Solvent was removed *in vacuo* and the residue chromatographed on silica
15 (eluent: 10% methanol in dichloromethane) to afford the **title compound** as a brown powder, 22mg (97%).

Descriptions of Intermediates for the Preparation of Compounds Of Formula (III)

20

Description 37: (R)-1-Phenyl-1,2-bis(3-tert-butyl-5-methylsalicylideamino)ethane (D37)

(R)-1,2-Diamino-1-phenylethane (prepared from (R)-2-aminophenylacetamide⁶ via reduction to the diamine by the method of Brown and Heim⁷) (1.36g, 10.0 mmol) was dissolved in ethanol (50ml) and solid 2-hydroxy-3-tert-butyl-5-methylbenzaldehyde (prepared from 2-tert-butyl-4-methyl-phenol by the method of Casiraghi *et al*⁸) (3.84g, 20.0mmol) was added. After a 90 min at reflux the reaction was cooled and water (1ml) was added. The yellow solid formed was removed by filtration, washed with 95% aqueous ethanol (10ml) and dried *in vacuo*
30 over P₂O₅ to give the title compound as yellow solid, 3.33g, 69% yield.

δ (CDCl₃) 1.41 (9H,s), 1.43(9H,s), 2.22(3H,s), 2.23(3H,s), 3.93 (1H,dd), 4.12 (1H,dd), 4.68 (1H,dd), 6.84 (2H,d), 7.09 (2H,s), 7.30-7.50(5H,m), 8.25(1H,s), 8.37(1H,s), and 13.50(2H,bs).

35 6. C.G. Nielson and D.F. Ewing, *J. Chem. Soc. (C)*, 1966, pp 393-397.

7. H.C. Brown and P. Heim, *J. Org. Chem.*, 1973, 38, p.p. 912-916.

Description 38: (R)-1-Phenyl-1,2-bis(3,5-di-tert-butyl-salicylideamino)ethane (D38)

(R)-1,2-Diamino-1-phenylethane (0.68g, 5.0 mmol) was dissolved in ethanol (50ml) and 2-hydroxy-3,5-di-*tert*-butyl-benzaldehyde (prepared from 2,4-di-*tert*-butylphenol by the method of Casiraghi *et al*⁸) (2.34g, 10.0mmol) was added. The reaction was refluxed for 2 hours, cooled to room temperature and water (1ml) was added to the stirring solution. The product was isolated by filtration, washed with 95% aqueous ethanol (5ml) and dried *in vacuo* over P₂O₅ to give the title compound as yellow solid, 2.11g, 74% yield.

δ (CDCl₃) 1.24 (9H,s), 1.27(9H,s), 1.41(9H,s), 1.45(9H,s), 3.95 (1H,dd), 4.15 (1H,dd), 4.70 (1H,dd), 7.05 (2H,bs), 7.30-7.50(7H,m), 8.34(1H,S), 8.42(1H,s), and 13.60(2H,bs).

8. G. Casiraghi, G. Casnati, G. Puglia, G. Sartori and G. Terenghi, J. Chem. Soc. Perkin I, 1980, p.p. 1862-1865.

15 **Description 39: (S)-1-Methyl-1, 2-bis(3-*tert*-butyl-5-methylsalicylideamino)ethane (D39).**

A suspension of (S)-1, 2-diaminopropane dihydrochloride (290 mg, 2mmol) in EtOH (5ml) was treated with 1M ethanolic NaOH (4ml, 4mmol). 2-Hydroxy-5-*tert*-butyl-3-methylbenzaldehyde (770 mg, 4mmol) was added and the mixture heated at reflux for 1.5h. The suspension was filtered, partially evaporated and a small quantity of water added to precipitate the **title compound** as yellow solid. This was filtered, washed with 95% aqueous EtOH and dried *in vacuo* over P₂O₅, to afford the title compound 730 mg (86% yield).

δ (CDCl₃), 1.33 (3H, s), 1.36 (18H, d), 2.25 (6H, s), 3.62 (2H, m), 3.76 (1H, m), 6.80 (2H, s), 7.03 (2H, s), 8.20 (1H, s), 8.25 (1H, s), 13.50 (2H, bs)

Description 40: (S)-1-Isopropyl-1, 2-bis (3-*tert*-butyl-5-methylsalicylideamino) ethane (D40).

To sodium borohydride (1.13g, 30 mmol) in glyme (30 ml) under nitrogen was added (S)-Valinamide hydrochloride (1.53g, 10 mmol) suspended in glyme (35 ml) with stirring. The solution was cooled to 10°C and boron trifluoride etherate (4.9 ml, 40 mmol) in glyme (10 ml) was added dropwise over 20 min, then the mixture was heated at reflux for 16 h. After cooling to ambient water (7.5 ml), followed by 3M NaOH (15 ml), was added and the resulting clear solution refluxed for 2h.

35 Solvent was removed *in vacuo* to afford a white solid which was extracted with chloroform (3 x 10ml), the combined extract being evaporated to afford the diamine (0.34g). This was dissolved in ethanol (15 ml) and treated with 2-hydroxy-3-*tert*-butyl-5-methyl benzaldehyde (1.28g, 6.6 mmol). The solution was heated at reflux for 2h, cooled, concentrated *in vacuo* and the residue chromatographed on silica

(Merck 9385, eluting with 0-6% MeOH in chloroform) to afford the title compound, 0.73g (16% yield).

δ (CDCl₃), 1.04 (6H, m), 1.39 (18H, 2s), 2.10 (1H, m), 2.24 (6H, s), 3.3 - 4.0 (3H, bm), 6.85 (2H, m), 7.09 (2H, m), 8.24 (2H, s), 13.60 (2H, bs).

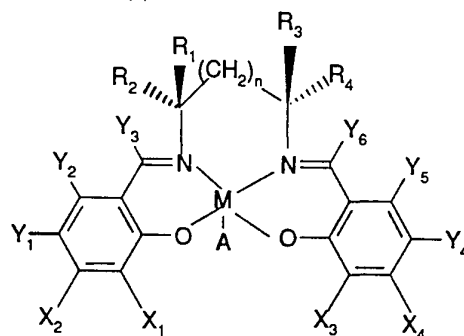
Claims:

1. A process for enantioselectively epoxidising a prochiral olefin, which process comprises reacting the prochiral olefin with a source of oxygen in the presence of a salen catalyst and a source of an electron donating ligand, characterised in that the donor ligand is isoquinoline N-oxide or a compound having donor ligand activity and having substantially the same solubility characteristics as isoquinoline N-oxide.

2. A process according to claim 1, wherein the salen catalyst is:

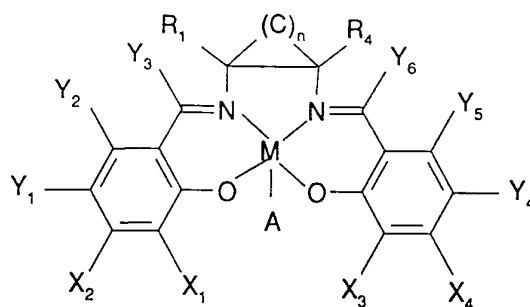
10

(i) a compound of formula (I):



in which M is a transition metal ion, A is an anion, and n is either 0, 1 or 2. At least one of X₁ or X₂ is selected from the group consisting of silyls, aryls, secondary alkyls and tertiary alkyls; and at least one of X₃ or X₄ is selected from the same group. Y₁, Y₂, Y₃, Y₄, Y₅ and Y₆ are independently selected from the group consisting of hydrogen, halides, alkyls, aryl groups, silyl groups, and alkyl groups bearing heteroatoms such as alkoxy and halide; at least one of R₁, R₂, R₃ and R₄ is selected from a first group consisting of H, CH₃, C₂H₅ and primary alkyls; if R₁ is selected from said first group, then R₂ and R₃ are selected from a second group consisting of aryl groups, heteroatom-bearing aromatic groups, secondary alkyls and tertiary alkyls; if R₂ is selected from said first group, then R₁ and R₄ are selected from said second group; if R₃ is selected from said first group, then R₁ and R₄ are selected from said second group; if R₄ is selected from said first group, then R₂ and R₃ are selected from said second group;

(ii) a compound of formula (IA):

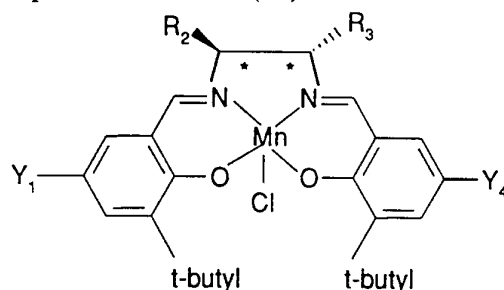


(IA)

where M is defined as a transition metal ion and A is an anion; where n is either 3,4,5 or 6; where at least one of X₁ or X₂ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where at least one of X₃ or X₄ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where at least one of Y₁ or Y₂ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where at least one of Y₄ or Y₅ is selected from the group consisting of aryls, primary alkyls, secondary alkyls, tertiary alkyls, and hetero atoms; where Y₃, and Y₆ are independently selected from the group consisting of hydrogen and primary alkyl groups; where R₁ and R₄ are trans to each other and at least one of R₁ and R₄ is selected from the group consisting of primary alkyls and hydrogen; and where the carbons in the (C)_n portion have substituents selected from the group consisting of hydrogen, alkyl, aryl, and heteroatoms;

15

(iii) a compound of formula (IB):

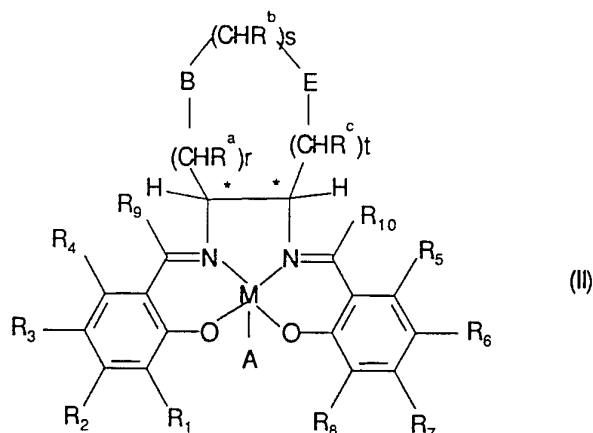


(IB)

in which Y₁ and Y₄ are the same and are selected from the group consisting of methyl t-butyl or methoxy and R₂ and R₃ are either both phenyl or together with the carbon atoms to which they are attached form a hexyl ring;

20

(iv) a compound of formula (II):



in which M is a transition metal ion;

A is a counter-ion if required;

r, s and t are independently 0 to 3 such that r+s+t is in the range of 1 to 3;

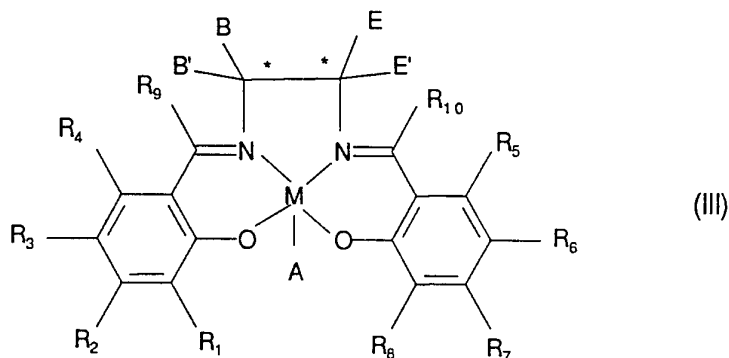
- 5 R^a, R^b, R^c are each independently hydrogen or $\text{CH}_2\text{OR}'$ where R' is hydrogen or an organic group;

B and E are independently oxygen, CH_2 , NR^d in which R^d is alkyl, hydrogen, alkylcarbonyl, or arylcarbonyl or SO_n where n is 0 or an integer 1 or 2, with the proviso that B and E are not simultaneously CH_2 and that when B is oxygen, NR^d or

- 10 SO_n , then r cannot be 0, and when E is oxygen, NR^d or SO_n , then t cannot be 0;

$R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9$ and R_{10} are independently hydrogen, alkyl or alkoxy; or

(v) a compound of formula (III):



15 in which M is a transition metal ion;

A is a counter-ion if required;

B, B', E and E' are independently selected from the group consisting of hydrogen aryl, C_{1-6} alkyl, silyl or aryl- C_{1-6} alkyl in which any aryl or alkyl moiety is optionally substituted or B' and B or E' and E together form a C_{2-6} polymethylene link; with the

- 20 proviso that only one of the carbons marked with an asterisk is a chiral centre; $R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9$ and R_{10} are independently hydrogen, alkyl or alkoxy.

3. A process according to claim 1 or claim 2, wherein the salen catalyst is selected from the list consisting of:

- 5 R,R-[1,2-bis(3,5-di-*tert*-butylsalicylideneamino)cyclo-hexane]manganese (III) chloride;
(3*S*,4*S*)-bis-(3,5-di-*tert*-butylsalicylideamino)tetrahydrofuran-manganese (III) chloride;
(*R,R*)-5,6-bis-(3,5-di-*tert*-butylsalicylidenamino)-1,3-dioxepane]-manganese (III) chloride;
10 (*R*)-1-phenyl-1,2-bis(3-*tert*-butyl-5-methylsalicylideamino)ethane - manganese (III) chloride;
(*R*)-1-phenyl-1,2-bis(3,5-di-*tert*-butyl-salicylideamino)ethane - manganese (III) chloride;
(*S*)-1-methyl-1, 2-bis (3-*tert*-butyl-5-methylsalicylideamino) ethane - manganese (III) chloride; and
15 (*S*)-1-isopropyl-1, 2-bis (3-*tert*-butyl-5-methylsalicylideamino) ethane-manganese (III) chloride

4. A process according to any one of claims 1 to 3, wherein the prochiral olefin is a compound which comprises the following groups as part of its structure:
20 cyclohexene, 5,6-dihydro-2H-pyran, 1,2,5,6-tetrahydropyridine, 1,2,3,4-tetrahydropyridine and 5,6-dihydro-2H-thiopyran.

5. A process according to any one of claims 1 to 4, wherein the prochiral olefin is a compound which comprise the following groups as part of its structure:: 1,2-
25 dihydronaphthalene, 2H-chromene, 1,2-dihydroquinoline, 1,2-dihydroisoquinoline and 2H-thiochromene.

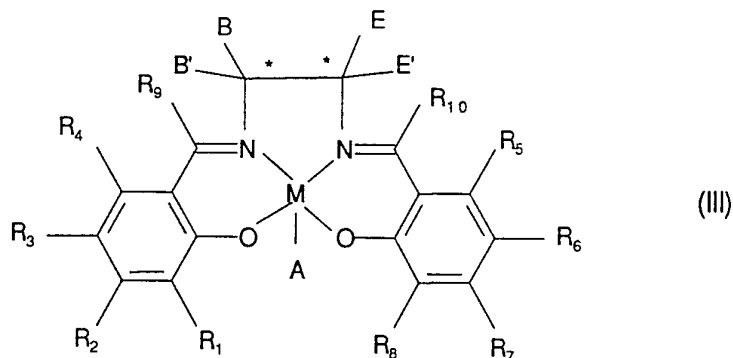
6. A process according to any one of claims 1 to 5, wherein the prochiral olefin is 2,2-dimethyl-6-pentafluoroethyl-2H-1-benzopyran or 6-acetyl-2,2-dimethyl-2H-1-
30 benzopyran.

7. A process according to any one of claims 1 to 6, wherein the oxygen is sodium hypochlorite.
35

8. A process for enantioselectively epoxidising a prochiral olefin, which process comprises reacting the prochiral olefin with a source of oxygen in the presence of a salen catalyst and a source of an electron donating ligand, characterised in that the salen catalyst is a compound of formula (II).

9. A process according to claim 8, wherein the source of electron donating ligand is isoquinoline N-oxide.

5 10. A compound of formula (III):



in which M is a transition metal ion;

A is a counter-ion if required;

10 B, B', E and E' are independently selected from the group consisting of hydrogen aryl, C₁₋₆ alkyl, silyl or aryl-C₁₋₆ alkyl in which any aryl or alkyl moiety is optionally substituted or B' and B or E' and E together form a C₂₋₆ polymethylene link; with the proviso that only one of the carbons marked with an asterisk is a chiral centre; R₁, R₂, R₃, R₄, R₅, R₆, R₇, R₈, R₉ and R₁₀ are independently hydrogen, alkyl or alkoxy.

15

11. A compound according to claim 10, wherein, R₂, R₄, R₅ and R₇ each independently represent hydrogen and R₁, R₃, R₆ and R₈ each independently represent C₁₋₆ alkyl.

20 12. A compound according to claim 10 or claim 11, wherein, one of B and E is phenyl, methyl or isopropyl and the other is hydrogen.

13. A compound according to claim 10 selected from the list consisting of:

25 (R)-1-phenyl-1,2-bis(3-*tert*-butyl-5-methylsalicylideneamino)ethane - manganese (III) chloride;

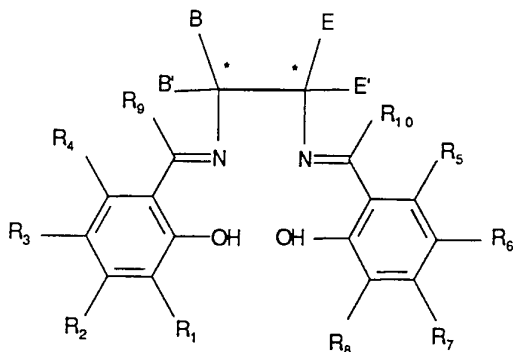
(R)-1-phenyl-1,2-bis(3,5-di-*tert*-butyl-salicylideneamino)ethane - manganese (III) chloride;

(S)-1-methyl-1,2-bis(3-*tert*-butyl-5-methylsalicylideneamino)ethane - manganese (III) chloride; and

30 (S)-1-isopropyl-1,2-bis(3-*tert*-butyl-5-methylsalicylideneamino)ethane-manganese (III) chloride

14. A process for the preparation of compounds of formula (III) which comprises:

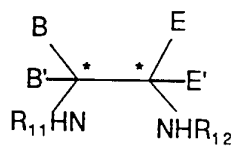
(a) forming a transition metal complex of the following compound of formula (IV):



(IV)

where variables $R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9$ and R_{10} , B, B', E and E' are as defined in relation to formula (III), and thereafter if necessary separating any enantiomers.;

10 (b) first forming a compound of formula (IV) by condensing sequentially, in any order, a compound of formula (V):

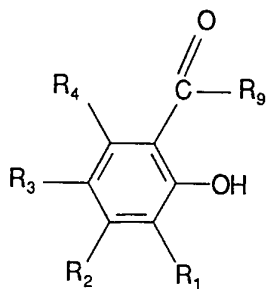


(V)

where B, B', E and E' are as defined in formula (III) and R_{11} and R_{12} independently represent hydrogen or an amine protecting group, providing at least one of R_{11} and

15 R_{12} is hydrogen, with:

(i) a compound of formula (VI);

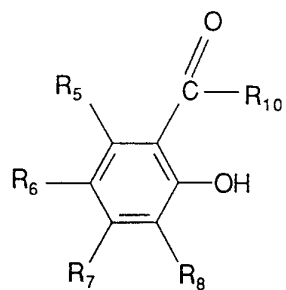


(VI)

wherein R_1, R_2, R_3, R_4 and R_9 are as defined in relation to formula (III); and

20

(ii) a compound of formula (VII),



(VII)

- wherein R₅, R₆, R₇, R₈ and R₁₀ are as defined in relation to formula (III); and thereafter as required removing any protecting group R₁₁ or R₁₂, isolating the required compound including if necessary separating any enantiomers.; and
- 5 thereafter forming the transition metal complex as described in reaction (a) above.
14. An intermediate compound of formula (IV), (VI), (VII), (VIII) or (IX).

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 95/00370

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C07D493/04 C07F13/00 C07C47/565 C07C211/09 C07C251/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C07D C07F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE,A,27 36 523 (MONTEDISON) 16 February 1978 Examples 2-6,8,10-12 see claim 1 ---	14
X	US,A,3 787 501 (KALLIANOS) 22 January 1974 Examples I-V see claim 1 ---	14
P,Y	WO,A,94 03271 (SMITHKLINE BEECHAM) 17 February 1994 see claim 1 ---	1-13
Y	US,A,5 281 578 (BRADLEY) 25 January 1994 see claim 1 ---	1-13
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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "&" document member of the same patent family

Date of the actual completion of the international search

21 June 1995

Date of mailing of the international search report

- 6. 07. 95

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Gettins, M

INTERNATIONAL SEARCH REPORT

 International Application No
 PCT/EP 95/00370

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO,A,91 14694 (RESEARCH CORPORATION TECHNOLOGY) 3 October 1991 cited in the application see claim 1 ---	1-13
Y	J.ORG.CHEM., vol. 56, 1991 pages 2296-2298, ZHANG ET AL 'Asymmetric Olefin Epoxidation with Sodium Hypochlorite Catalysed by Easily Prepared Mn (III) Salen Complexes' see the whole document ---	1-13
Y	DE,C,42 38 076 (FRAUENHOFER-GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG) 16 September 1993 see claim 1 ---	1-13
Y	EP,A,0 376 524 (BEECHAM GROUP PLC) 4 July 1990 cited in the application see claim 1 ---	1-13
Y	US,A,4 861 904 (SUGIE) 29 August 1989 see claim 1 -----	1-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 95/00370

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A-2736523	16-02-78	CH-A- 629740	14-05-82
		FR-A, B 2361327	10-03-78
		GB-A- 1530248	25-10-78
		JP-A- 53034737	31-03-78
		NL-A- 7708811	15-02-78
		US-A- 4151201	24-04-79
US-A-3787501	22-01-74	US-A- 3900521	19-08-75
		US-A- 3605760	20-09-71
WO-A-9403271	17-02-94	AU-B- 4722393	03-03-94
		CA-A- 2141790	17-02-94
		CN-A- 1098415	08-02-95
		EP-A- 0655950	07-06-95
US-A-5281578	25-01-94	AU-B- 650534	23-06-94
		AU-A- 1629792	03-12-92
		EP-A- 0525938	03-02-93
		JP-A- 5148274	15-06-93
		NO-A- 9202148	01-12-92
		NZ-A- 242891	22-12-94
WO-A-9114694	03-10-91	AU-B- 648301	21-04-94
		AU-A- 7555391	21-10-91
		EP-A- 0521099	07-01-93
DE-C-4238076	16-09-93	EP-A- 0597276	18-05-94
EP-A-376524	04-07-90	AT-T- 120459	15-04-95
		AU-B- 614203	22-08-91
		AU-A- 4616989	21-06-90
		DE-D- 68921972	04-05-95
		EP-A- 0633256	11-01-95
		JP-A- 2237985	20-09-90
US-A-4861904	29-08-89	JP-C- 1669371	12-06-92
		JP-B- 3059748	11-09-91
		JP-A- 62244470	24-10-87
		JP-C- 1677363	13-07-92
		JP-B- 3070533	08-11-91

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 95/00370

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4861904		JP-A- 63001422 JP-A- 63093789	06-01-88 25-04-88
