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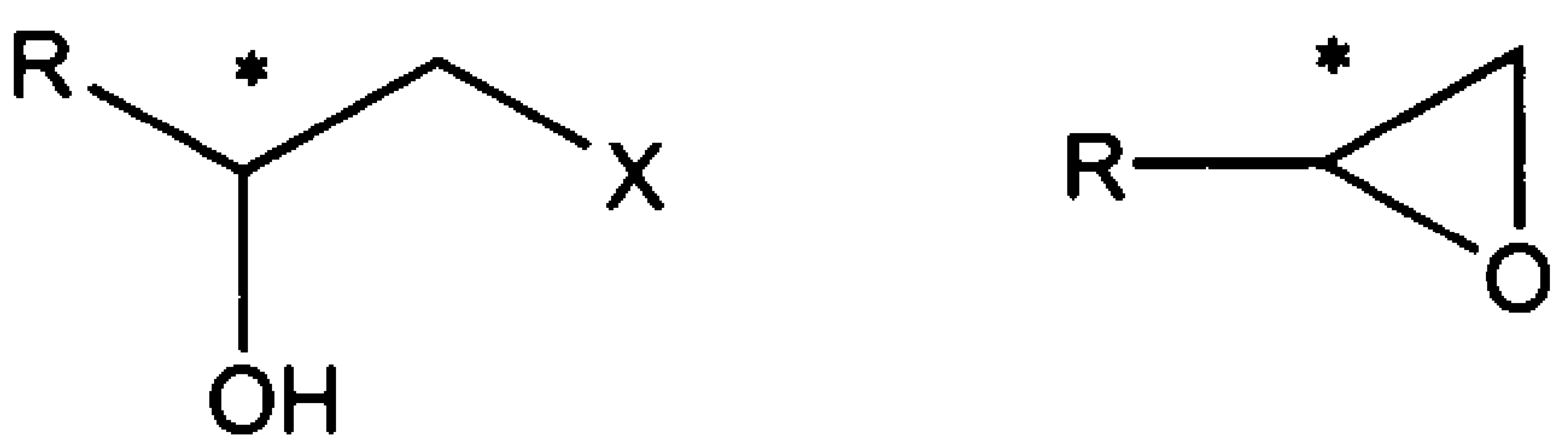
(54) **Titre : PROCEDE DE FABRICATION DU NEBIVOLOL**
(54) **Title: PROCESS FOR PREPARING NEBIVOLOL**



(I)

(57) **Abrégé/Abstract:**
The present invention relates to a process for preparing Nebivolol and, more particularly, to an improved process for synthesizing enantiomerically enriched 6-fluoro chroman alcohol or epoxide derivatives of formula, wherein R and X is defined in the description; as useful intermediates in the preparation of Nebivolol.

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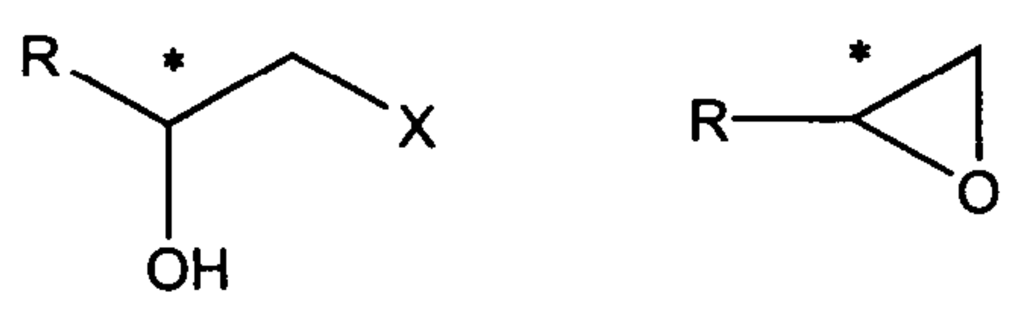
(54) **Title:** PROCESS FOR PREPARING NEBIVOLOL



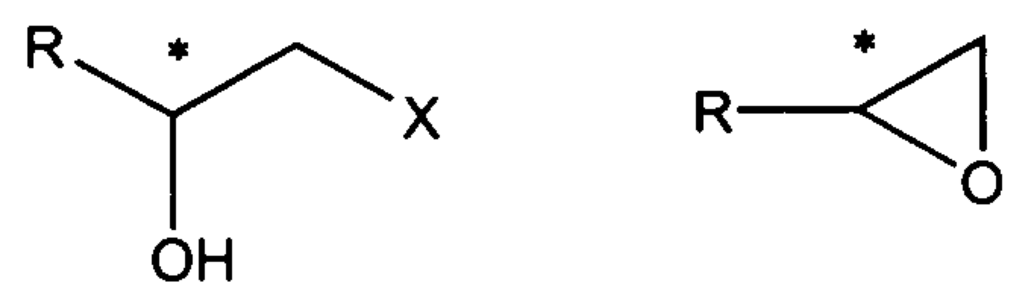
(I)

(57) Abstract: The present invention relates to a process for preparing Nebivolol and, more particularly, to an improved process for synthesizing enantiomerically enriched 6-fluoro chroman alcohol or epoxide derivatives of formula, wherein R and X is defined in the description; as useful intermediates in the preparation of Nebivolol.

PROCESS FOR PREPARING NEBIVOLOL

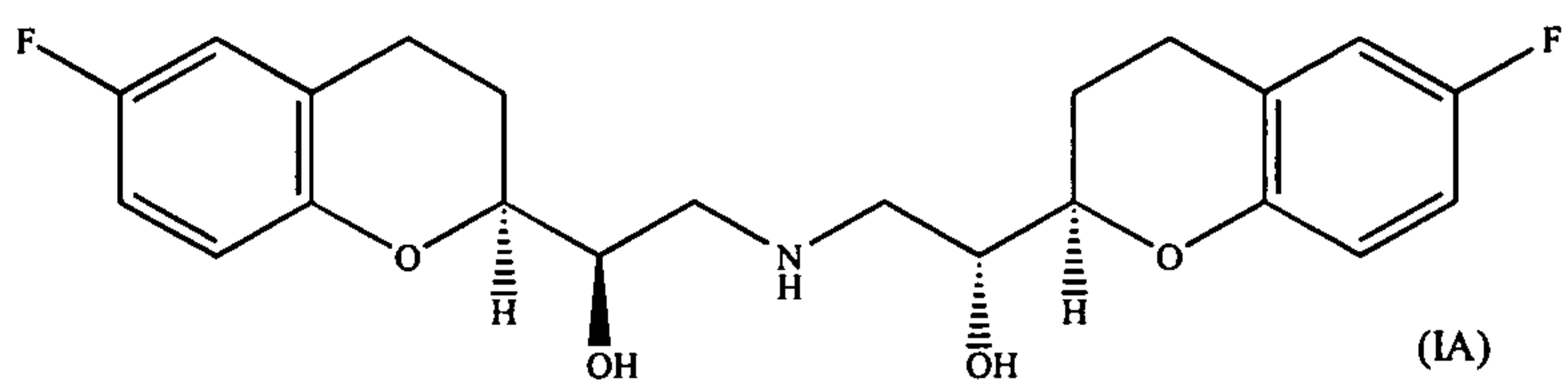
****

The present invention relates to a process for preparing Nebivolol and, more particularly, to an improved process for synthesizing enantiomerically enriched 6-fluoro chroman alcohol or epoxide derivatives of formula



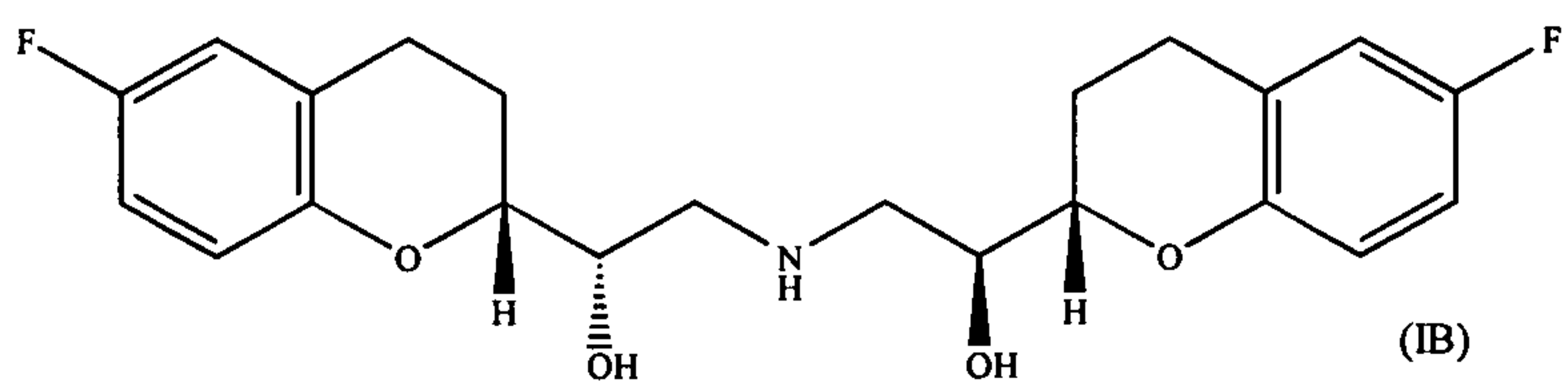
wherein R and X is hereinafter defined; as useful intermediates in the preparation of Nebivolol.

Nebivolol (hereinafter also referred to as NBV), is a mixture of equal amounts of [2S [2R* [R [R*]]]] α,α'-[imino-bis (methylene)] bis [6-fluoro-chroman-2-methanol] (hereinafter also referred to as *d*-NBV) of formula (IA)



(IA)

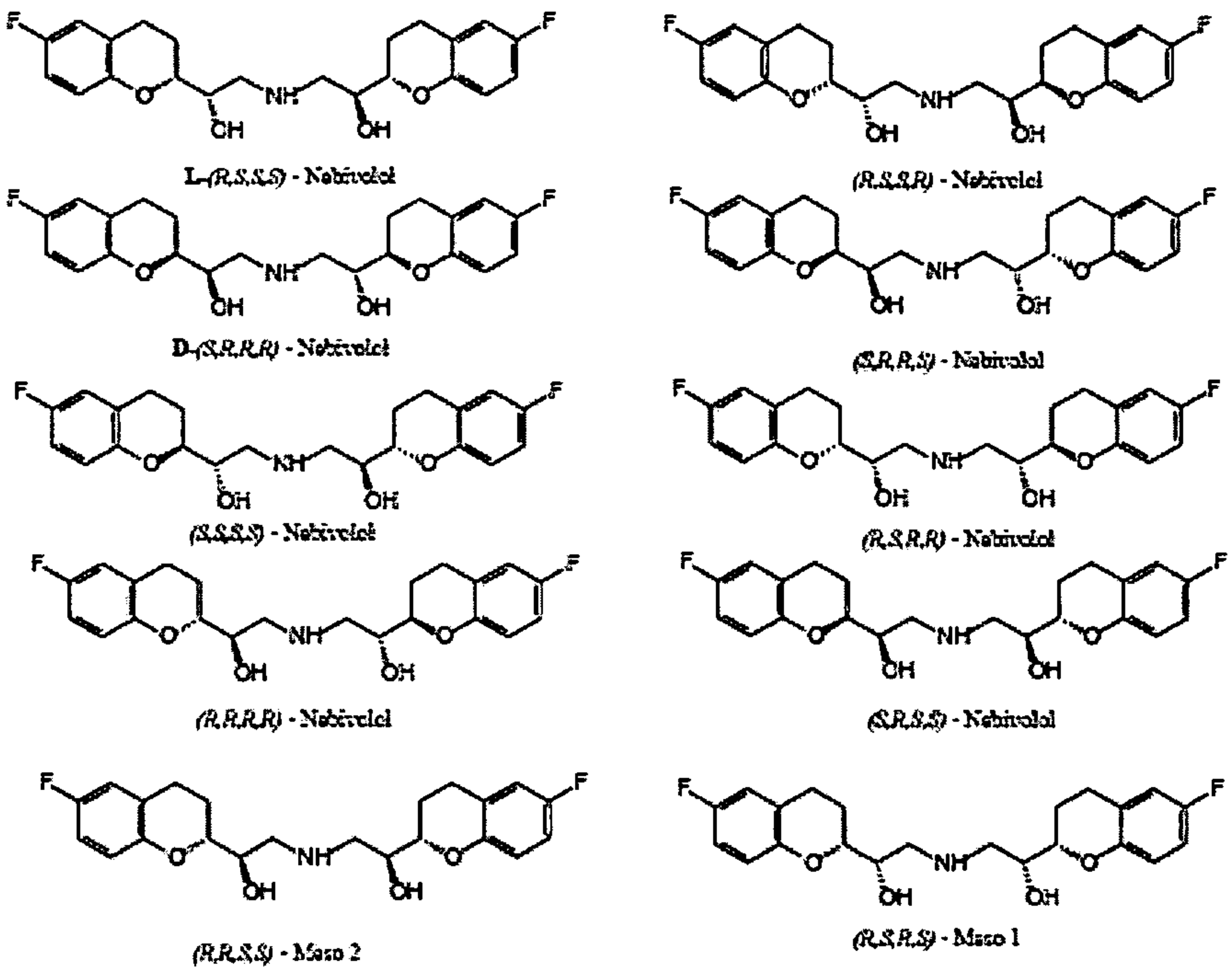
and its [2R [2S* [S [S*]]]] enantiomer (hereinafter also referred to as *l*-NBV) of formula (IB)



(IB)

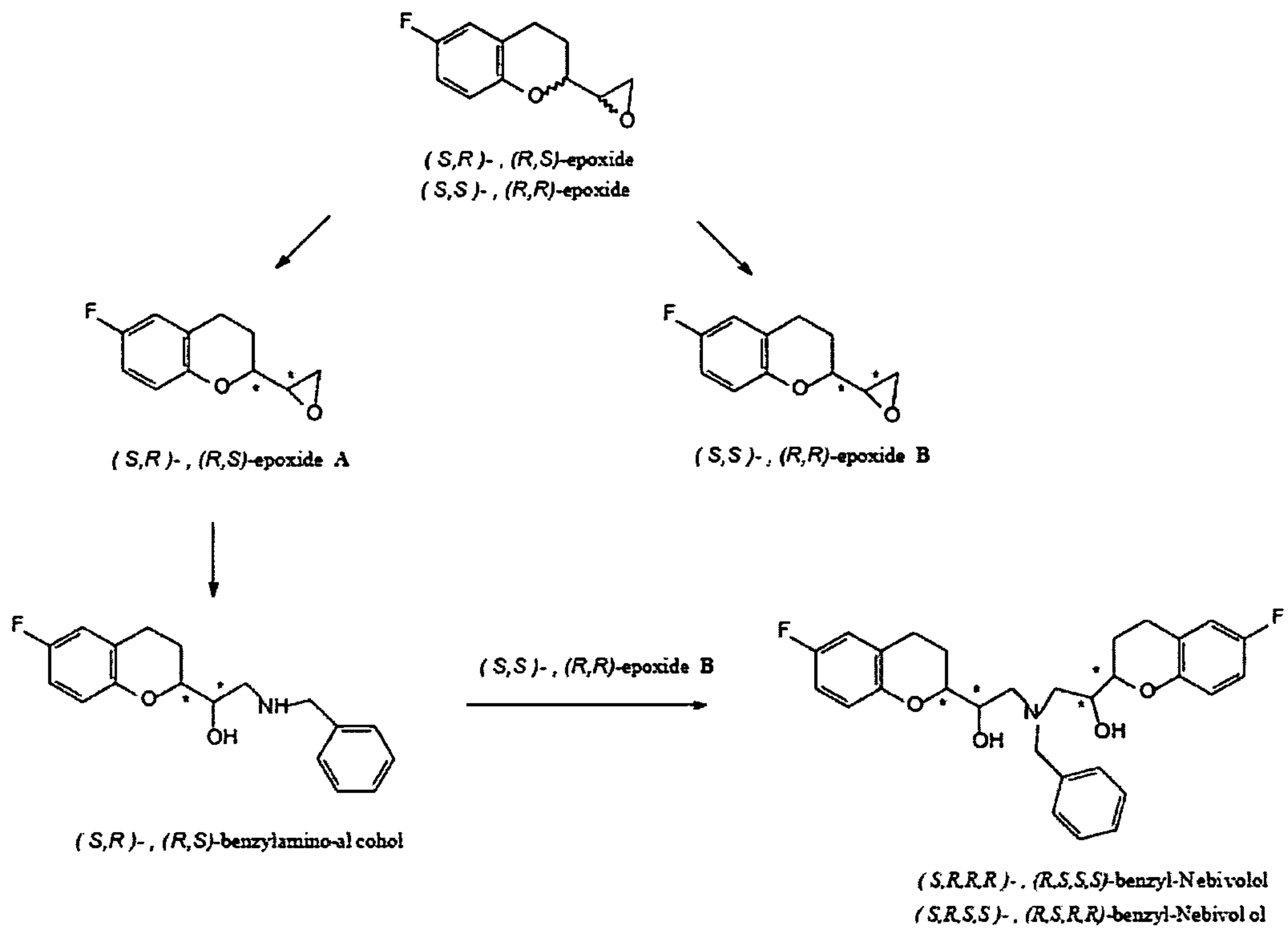
Nebivolol is characterized by β-adrenergic blocking properties and is useful for the treatment of essential hypertension. It has basic properties and may be converted into its pharmaceutically acceptable acid addition salt forms by treatment with appropriate acids. The hydrochloride acid addition salt is the marketed product.

It is well understood in the art that the synthesis of α,α'-[imino-bis (methylene)] bis [chroman-2-methanol] molecular structures is challenging for the skilled person, because of the 4 asymmetric carbon atoms producing a mixture of 16 stereoisomers (in case of asymmetrical substitution) or a mixture of 10 stereoisomers (in case of symmetrical substitution). As apparent from the presence of the topological symmetry in the structure of the α,α'-[imino-bis (methylene)] bis [6-fluoro-chroman-2-methanol], the following 10 stereoisomers can be generated.



The European patent application EP 145067 describes methods for the preparation of substituted α,α'-[imino-bis (methylene)] bis [chroman-2-methanol] including the 6,6' bisfluoro derivatives, which comprises reducing chroman-2-carboxylic acid into the corresponding aldehyde and then transforming the aldehyde into the corresponding epoxide as a mixture of four (R,S), (S,R), (RR) and (SS) stereoisomers. Epoxide stereoisomers are separated by column chromatography into racemic (R,S) and (S,R) epoxide (hereinafter mixture A) and racemic (R,R) and (S,S) epoxide (hereinafter mixture B), which represent the key intermediates of the process.

Mixture A (R,S ; S,R) or, alternatively, mixture B (R,R ; S,S) is treated with benzyl amine to give the racemic benzylated product, which is subsequently reacted with mixture B (R,R ; S,S) or mixture A (R,S ; S,R), respectively, to give a racemic mixture comprising four of the possible isomers of benzylated Nebivolol in accordance with the following synthetic scheme:



The above Nebivolol racemic mixture can be separated by chromatography to give the desired diastereomer as a pair of enantiomers (R,S,S,S ; S,R,R,R) which are debenzylated to give pure Nebivolol (racemate).

Alternatively, the racemic mixture of four isomers of benzyl-Nebivolol can be debenzylated and, according to Patent US 5,759,580, the pure Nebivolol (R,S,S,S ; S,R,R,R) is separated from the undesired diastereoisomers (R,S,R,R ; S,R,S,S) by crystallizing the former as an hydrochloride salt.

Nevertheless, both these procedures show, as main drawback, the lost of, at least, 50 wt% of the material. In fact, during the chromatographic separation or the crystallization the two undesired diastereoisomers, which are present in equal amount compared to Nebivolol, are wasted.

The European patent application EP 334429 describes a process for the preparation of Nebivolol which comprises the resolution of 6-fluoro-chroman-carboxylic acid by using (+)-dehydroabiethylamine, the conversion of single enantiomers into two separated mixture of diastereoisomeric epoxides and the separation of the so obtained mixtures into four enantiomerically pure epoxides which are favourably combined to give *l*-NBV and *d*-NBV. Nevertheless, the above synthetic process suffers of some significant drawbacks: resolution reaction of chroman-carboxylic acid is not easy and it requires many procedural steps such as acyl chloride formation, amidation, hydrolysis, etc.; resolving agent is expensive and is used in stechiometric amount; yields are very low, respectively 11,3 % for (+)-(S)-chroman-carboxylic acid and 9,2 % for (-)-(R)-chroman-carboxylic acid; transformation of carboxylic acid to epoxide is carried out at very low temperatures and it requires special precautions to avoid racemization; the whole process involves a very large number of steps thereby requiring increased costs on manufacturing scale in terms of utilities, manpower and time required to complete the production cycle.

The existence of the 4 stereogenic centres moved the skilled person towards the exploration of stereoselective methods for preparing the *l*-NBV and the *d*-NBV. For example, Johannes C.W. et al. (J. Am. Chem. Soc., 120, 8340-8347, 1998) and Chandrasekhar S. et al. (Tetrahedron 56, 6339-6344, 2000) describe enantioselective total preparations of *d*-NBV; An-Guang Yu et al. (Synlett, 9, 1465-1467, 2005) illustrate a method for the construction of chiral chroman intermediates, and Yang Yun-Xu et al. (Chinese Journal of Organic Chemistry, 25(2), 201-203, 2005 and the Chinese patent application CN 1629154) show the synthesis and resolution of (R) and (S) 6-fluorochroman carboxylic acids intermediates useful for the synthesis of *d*-NBV and *l*-NBV.

Additional alternative total synthetic approaches for the preparation of NBV can be found in the following international patent applications: WO 2004/041805, WO 2006/016376 and WO 2006/025070.

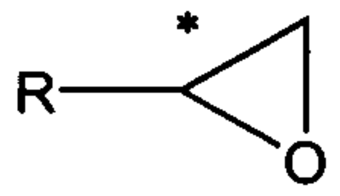
It is known in the art the key role of 6-fluoro-chroman epoxide derivatives in the preparation of NBV.

It results still more critical the function of said epoxides in enantiomerically pure form in light of specific stereochemistry of the pharmaceutically active ingredient and loss in yields in desired racemic product NBV due to resolution reactions in the final steps of classic preparation.

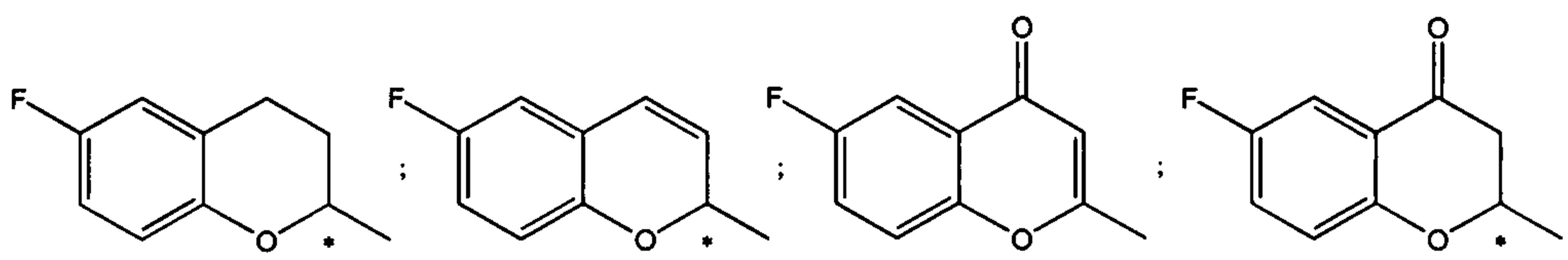
Thus, it would be desirable to study alternative methods for the preparation of enantiomerically enriched epoxides or direct precursors thereof which allow to overcome the drawbacks of the process described in the art.

We have now surprisingly found an easy and efficient synthesis of key intermediates useful in the preparation of *l*-NBV and *d*-NBV, via an hydrolytic or aminolytic kinetic resolution carried out on 6-fluoro-chroman racemic terminal epoxide derivatives.

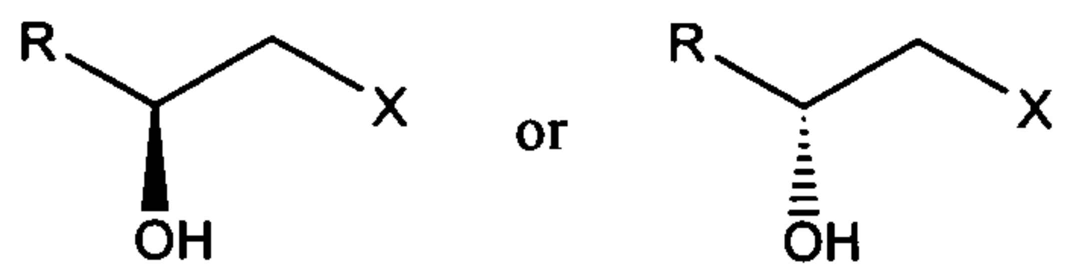
It is therefore a first object of the present invention a process for the separation of racemic terminal epoxide of formula


(I)

wherein R is a group of formula

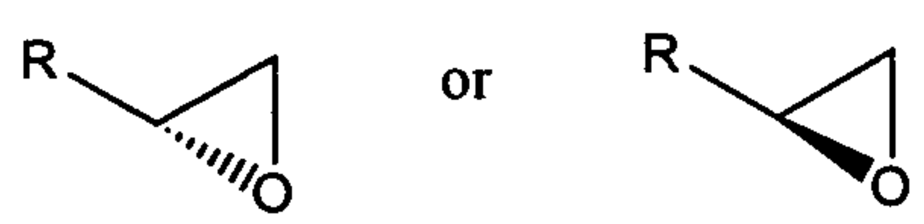


to give an enantiomerically enriched substituted alcohol of formula


(IIa) (IIb)

wherein X is hydroxy or amino group;

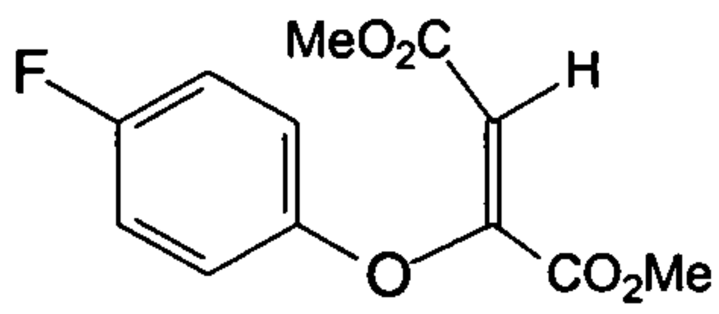
and, respectively, an enantiomerically enriched epoxide of formula


(IIIa) (IIIb)

which comprises a hydrolytic or aminolytic kinetic resolution carried out in the presence of a non-racemic transition metal-ligand catalyst complex.

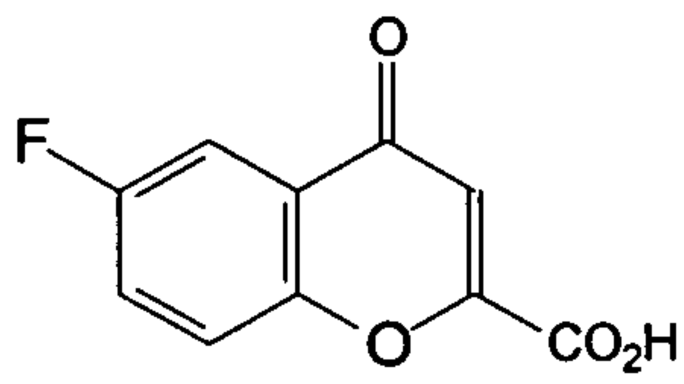
The racemic terminal epoxides of formula I are intermediates in the preparation of NBV and they are obtained in accordance with known methods. Some synthetic processes for the preparation of the above substrates of the present invention are described in the following documents: EP 0331078, US 4654362, WO 2004/041805, Synlett 2005, 9, pages 1465-1467.

A compound of formula Ia wherein R is a 6-fluoro-3,4-dihydro-1-benzopyran group is prepared according to the above cited EP 145067. 4-fluoro-phenol is reacted with dimethyl acethylenedicarboxylate to give a phenoxy-ethylene compound of formula



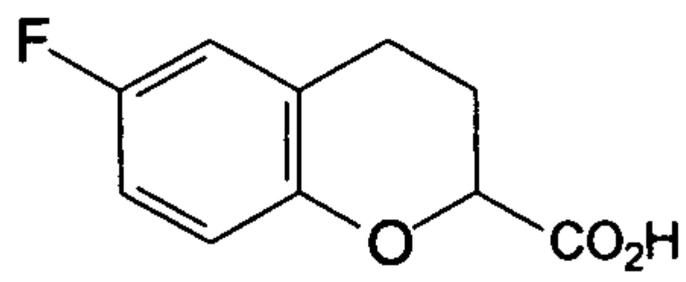
IV

which is hydrolysed in alkali media; so obtained dicarboxylic acid derivative is reacted with sulphuric acid to give a compound of formula



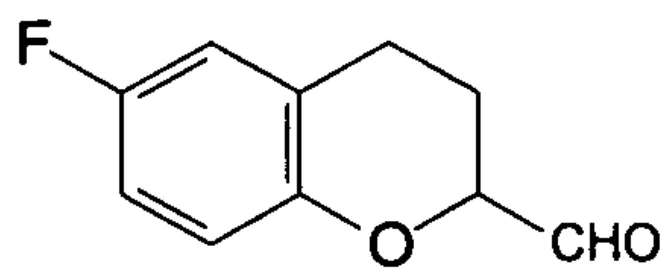
V

which is converted by catalytic hydrogenation into a compound of formula



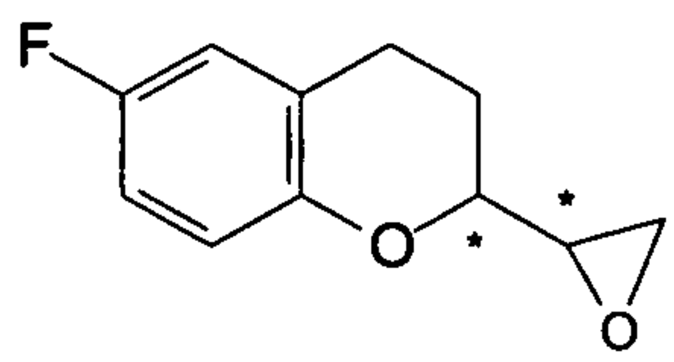
VI

racemic 6-fluoro-chroman-carboxylic acid (VI) is treated with 1,1'-carbonyldiimidazole and is reduced with diisobutylaluminum hydride into a compound of formula



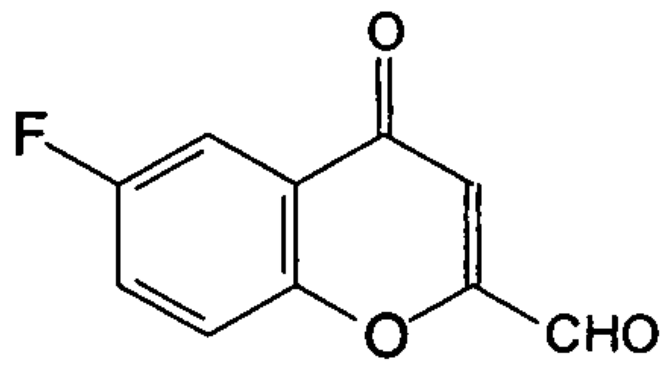
VII

which is reacted with sodium hydride and trimethyl sulfoxonium iodide to give the corresponding epoxide as a mixture of four (R,S), (S,R), (R,R), and (S,S) stereoisomers of formula

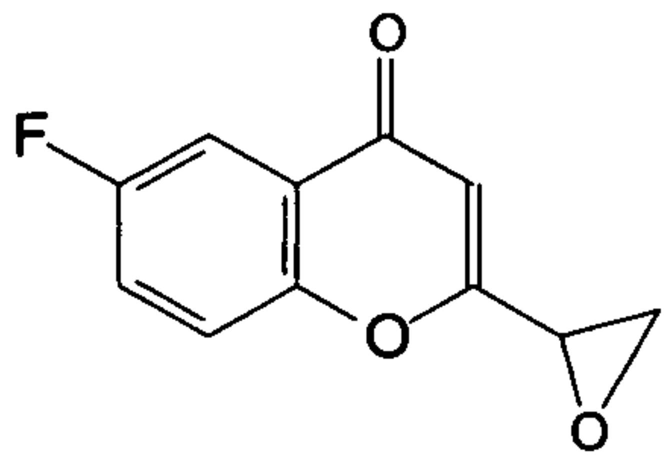


Ia

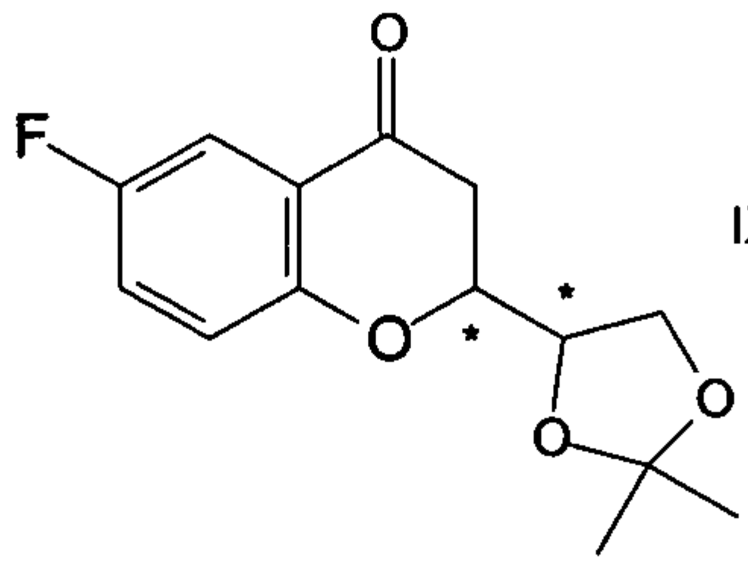
A compound of formula Ib wherein R is a 6-fluoro-4-oxo-4H-1-benzopyran group is prepared by the following procedure. A compound of formula V is treated with 1,1'-carbonyldiimidazole and is reduced with diisobutylaluminum hydride to give a compound of formula


VIII

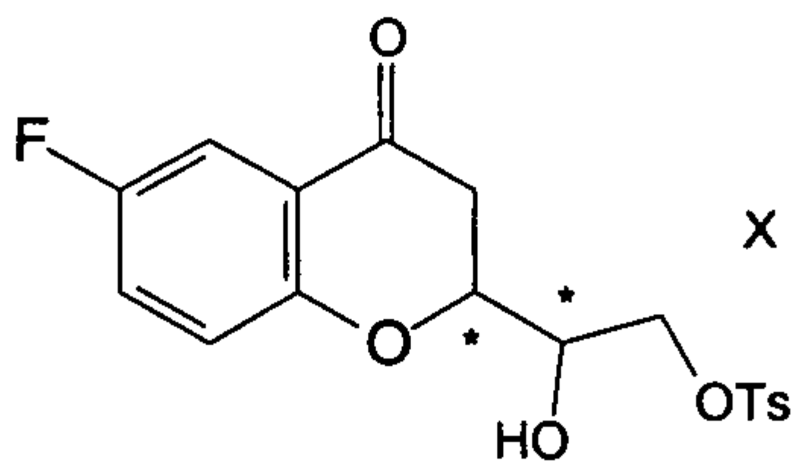
which is reacted with sodium hydride and trimethyl sulfoxonium iodide into the corresponding racemic epoxide of formula


Ib

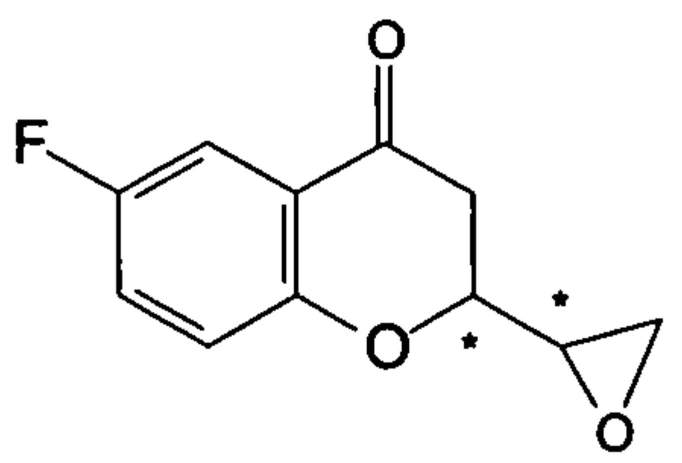
A compound of formula Ic wherein R is a 6-fluoro-4-oxo-1-benzopyran group is prepared by the following procedure. 5'-fluoro-2'-hydroxyacetophenone is reacted with racemic 2,2-dimethyl-1,3-dioxane-4-carbaldehyde in alkali media to obtain a mixture of stereoisomers of formula


IX

which is treated in acid media; so obtained diol is reacted with p-TsCl into the corresponding tosylated compound of formula

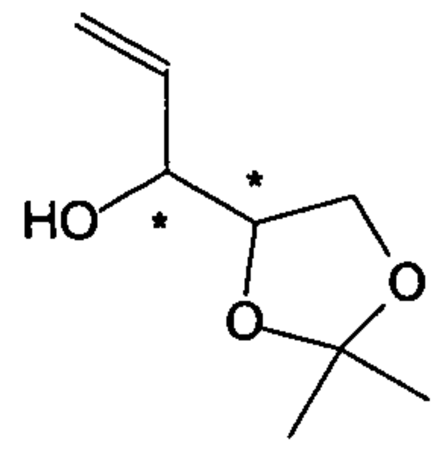

X

which is treated in alkali media to obtain the corresponding epoxide as a mixture of four (R,S), (S,R), (R,R), and (S,S) stereoisomers of formula



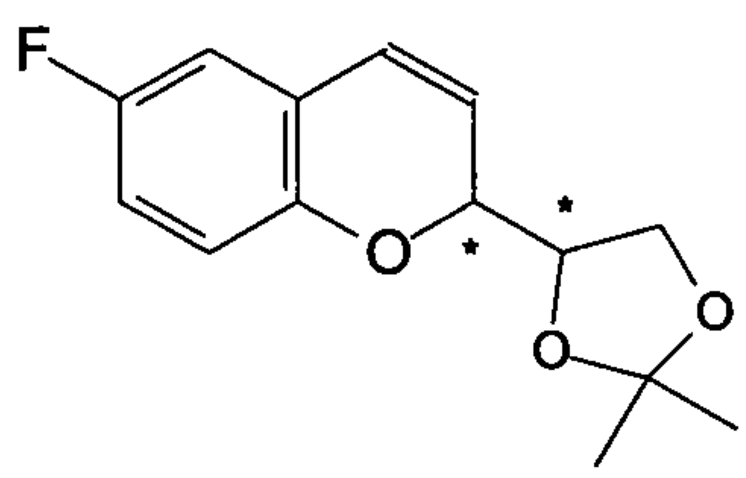
Ic

A compound of formula Id wherein R is a 6-fluoro chromen-2-yl group is prepared by the following procedure. 2,2-dimethyl-1,3-dioxane-4-carbaldehyde is reacted with vinyl Grignard reagent to obtain a mixture of stereoisomers of formula



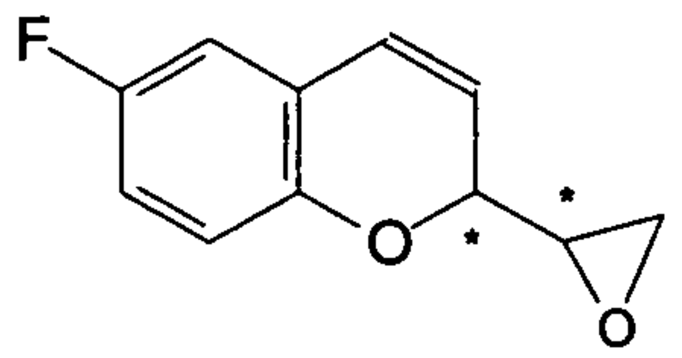
XI

which is reacted with 2-bromo-4-fluorophenol or 2-bromo-4-fluorophenyl acetate by palladium catalyst to obtain a mixture of stereoisomers of formula



XII

which is treated according to procedure used for compound IX to obtain corresponding epoxide as a mixture of four (R,S), (S,R), (R,R), and (S,S) stereoisomers of formula



Id

Hydrolytic kinetic resolutions of terminal epoxides catalyzed by chiral catalyst complexes are well known in the art. Examples of kinetic resolution of cyclic substrates such as epoxides in US 5665890, US 5929232, US 5663393, US 6262278 and US 2003/073855 are described.

The hydrolytic or aminolytic kinetic resolution of the invention comprises contacting a nucleophile and a racemic or diastereoisomeric mixture of a compound of formula I in the presence of a non-racemic transition metal-ligand catalyst complex.

In particular, the kinetic resolution comprises:

a) dissolution of a catalyst complex in a suitable aprotic or protic solvent;

b) activation of a catalyst complex by reaction with a suitable oxidizing agent in the presence of an organic or inorganic acid;

c) contacting the active catalyst complex with a racemic or diastereoisomeric mixture of a compound of formula I and a suitable nucleophile; and

(d) filtrating the reaction mixture.

Alternatively, the kinetic resolution comprises the activation of the catalyst in the presence of the terminal epoxide in accordance with the following steps:

a') contacting an oxidizing agent with a mixture comprising a racemic or diastereoisomeric compound of formula I, a non racemic catalyst complex, an organic or inorganic acid and a suitable nucleophile; and

b') filtrating the reaction mixture.

Suitable aprotic solvent useful in the dissolution step are toluene, dichloro methane, chloroform and the like.

Suitable protic solvent useful in the dissolution step are alcohols, preferably, methanol, ethanol and the like.

Preferred oxidizing agent is oxygen, more preferably, introduced in the form of air.

Suitable acid useful to prepare the active catalyst complex are Bronsted acids. Preferably, in the activation process of the invention organic Bronsted acids are used. More preferably, aryl or alkyl carboxylic acid such as acetic, propionic, isobutyrric, fluoroacetic, benzoic, nitro benzoic, fluoro benzoic, chloro benzoic and cyano benzoic acids are used. Still more preferably, acetic, benzoic and nitrobenzoic acids are used.

In contacting step, the active catalyst complex can be used directly as a solution or in solid form after precipitation.

Contacting step can be carried out at a temperature comprised between about -10°C and about 50°C. Preferably, contacting step is carried out at around room temperature.

Generally the resolution takes place in around 1 to 48 hours, preferably, overnight.

Step d/b', filtration, allows to separate an enantiomerically enriched substituted alcohol of formula IIa or IIb, which precipitates from the reaction mixture, from an enantiomerically enriched epoxide of formula IIIa or IIIb, which remains in the mother liquor. Said epoxide of formula IIIa or IIIb can be, optionally, isolated as benzyl-amino alcohol derivative in accordance with known techniques.

The hydrolytic or aminolytic kinetic resolution of the invention can be run with or without addition of solvents.

Generally the reaction is carried out in ethers, alcohols, aromatic or aliphatic solvents, halogenated solvents or mixture thereof.

Preferred solvents are tert-butyl methyl ether, isopropyl alcohol, toluene, heptane, dichloromethane and the like.

In general, any compound having a reactive pair of electrons and able to join an oxygen or nitrogen atom to the substrate of formula I, is suitable as nucleophile of the kinetic resolution of the invention.

In particular, suitable nucleophiles according to the invention are oxygen nucleophiles such as water, hydroxide, alcohols, alkoxides, carboxylates or peroxides and nitrogen nucleophile such as azide, imide, ammonia, hydrazine, carbamate or amine.

Said nucleophiles are used to introduce an oxygen or nitrogen atom in the stereoselective epoxide opening reaction to give a compound of formula IIa or IIb wherein X is above defined.

In one embodiment of the invention, the kinetic resolution is carried out in the presence of suitable nucleophile able to directly give a compound of formula IIa or IIb wherein X is hydroxy or an amino group.

The skilled person will realize that the reaction of terminal epoxide according to the invention with further nucleophiles can yield functionalized compounds which are easily converted to useful intermediates in the NBV preparation wherein residue X is hydroxy or amino group, in accordance with known techniques.

Preferred oxygen nucleophiles are water, hydroxide and carboxylates such as acetate, benzoate, formate, chloroformate and the like.

Preferred nitrogen nucleophiles are carbamate, azide such as sodium azide or trimethylsilyl azide, imide such as phthlimide or succinimide and the like.

More preferred nucleophiles according to the invention are water and carbamate, in particular, a (C_1-C_4)-alkyl or benzyl carbamate.

Water and benzyl carbamate are the still more preferred ones.

Non-racemic metal complex catalysts according to the invention are composed of a large organic ligand complexed to a transition metal atom.

Generally, organic ligand are asymmetric tetradentate or tridentate ligand complexed with a metal atom.

Preferably, chiral salen or salen-like ligands are used in the process of the invention. Particularly preferred are salen ligands disclosed in the above mentioned US 5665890, US 5929232, US 5663393 and US 6262278.

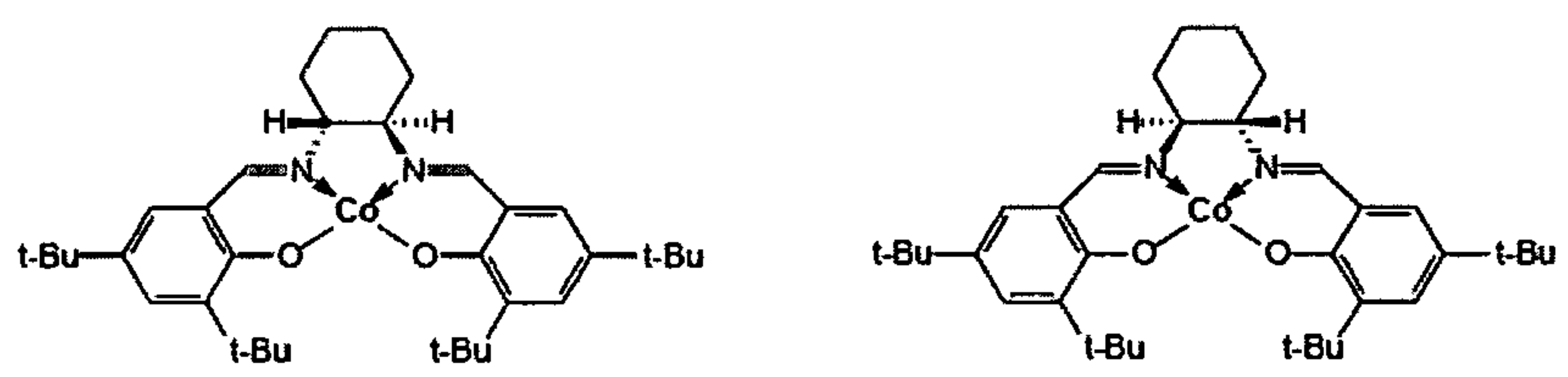
In a preferred embodiment the transition metal is selected from Mn, Cr, V, Fe, Co, Mo, W, Ru and Ni.

Preferably, the transition metal is Co or Cr, the former being the more preferred one.

Preferred non-racemic Co(II) complex catalysts are the (S,S)-Co(II) (salen) catalyst and (R,R)-Co(II) (salen) catalyst, respectively, represented by formulae

Jacobsen's Catalyst

(salen)- Co(II) Complex



(R,R)-(-)-*N,N'* - Bis(3,5 -di-*tert*-butylsalicylidene)-1,2-cyclo-hexanediaminocobalt (II)

CAS N° 176763-62-5

(S,S)-(+)-*N,N'* - Bis(3,5 -di-*tert*-butylsalicylidene)-1,2-cyclo-hexanediaminocobalt (II)

CAS N° 188264-84-8

In an embodiment of the invention (salen) Co(II) complex catalyst is readily converted to the desired active (salen) Co(III) catalyst having a carboxylate counter-anion by exposing to air and in the presence of an organic acid.

Preferred organic acids are acetic acid, benzoic acid and p-nitro-benzoic acid.

Alternatively, active Co (III) catalyst isolated by precipitation is directly used in the kinetic resolution of the invention.

Preferred non-racemic Co(III) complex catalysts are (S,S)-Co(III)(salen) (p-nitro-benzoate), (R,R)-Co(III)(salen)(p-nitro-benzoate), (S,S)-Co(III)(salen) (acetate) and (R,R)-Co(III)(salen) (acetate).

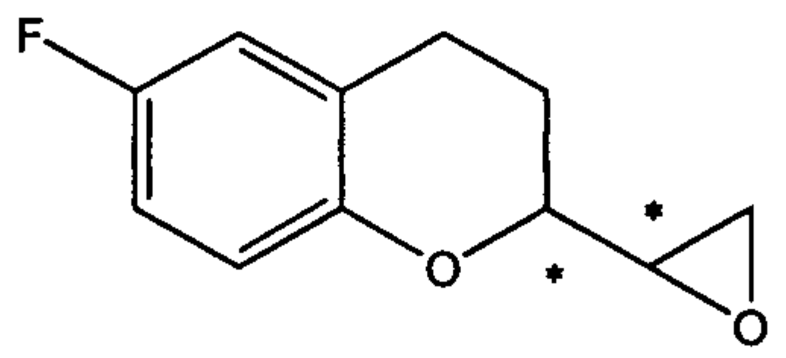
The catalyst complex is present in an amount comprised from 0.01 to 10 mol % with regard to a compound of formula I, preferably from 0.01 to 5 mol % and from 0.05 to 1 mol % representing the more preferred embodiment of the invention.

In a preferred embodiment of the invention, the kinetic resolution comprises the step of contacting oxygen with a mixture of a racemic terminal epoxides of formula I, a non-racemic Co(II) complex catalyst, an aryl or alkyl carboxylic acid and water or a suitable carbamate of formula H_2NCOOR wherein R is defined above, at a temperature and for a time sufficient to produce a mixture of the enantiomerically enriched 2-substituted alcohols of formula II and correspondent enantiomerically enriched epoxides of the formula III.

Alternatively, said racemic terminal epoxides of formula I are contacted with water or a suitable carbamate of formula H_2NCOOR wherein R is defined above in the presence of an active non racemic complex of Co(III) having an aryl or alkyl carboxylate counterion.

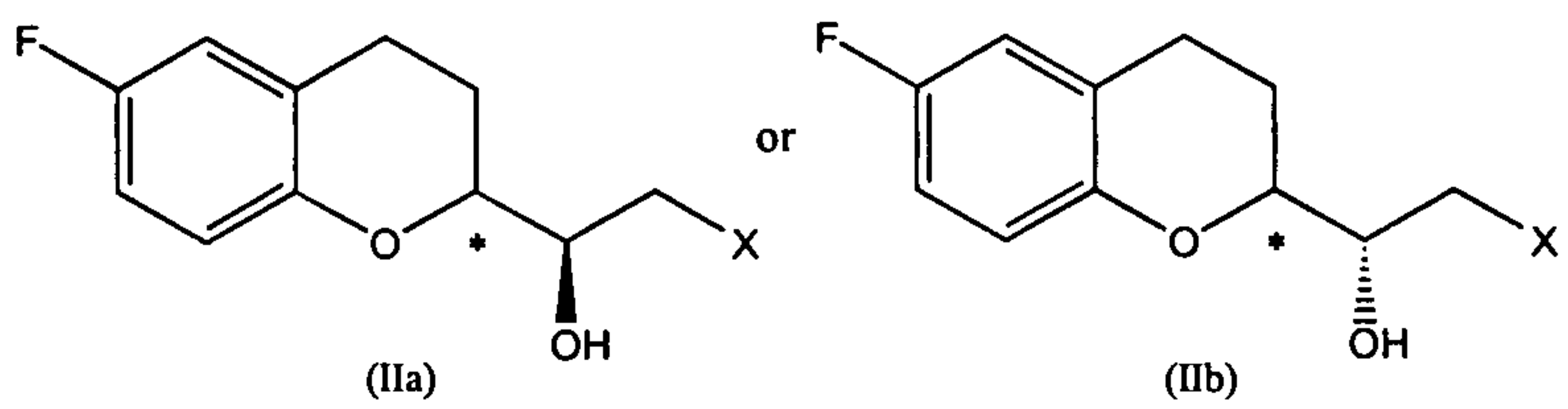
At the end of the resolution process the enantiomerically enriched 2-substituted alcohols of formula II is isolated by filtration and correspondent enantiomerically enriched epoxides of formula III is recovered in the mother liquor.

It is another object of the present invention a process for the separation of racemic terminal epoxide of formula



(Ia)

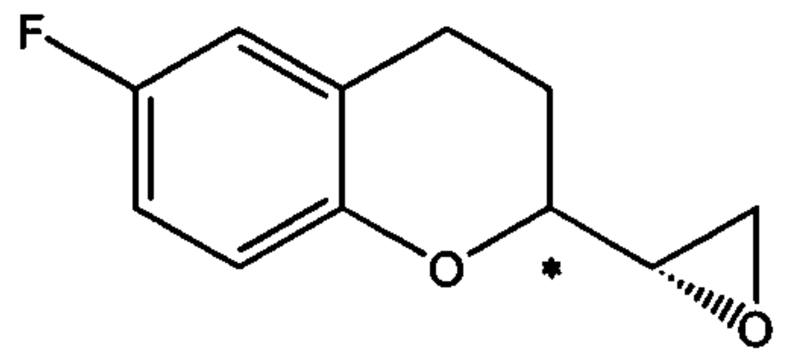
to give an enantiomerically enriched substituted alcohol of formula



(IIa) (IIb)

wherein X is defined above;

and, respectively, an enantiomerically enriched epoxide of formula



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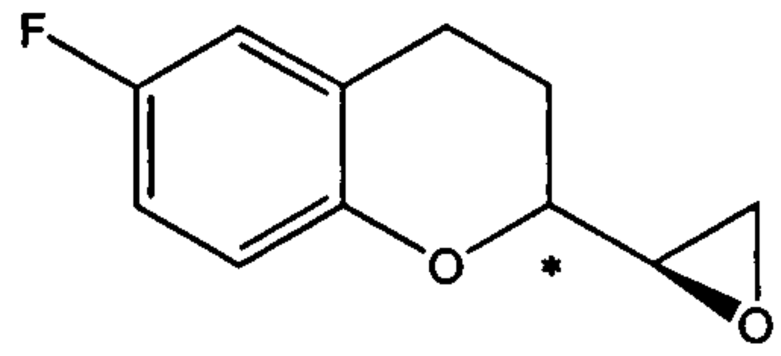


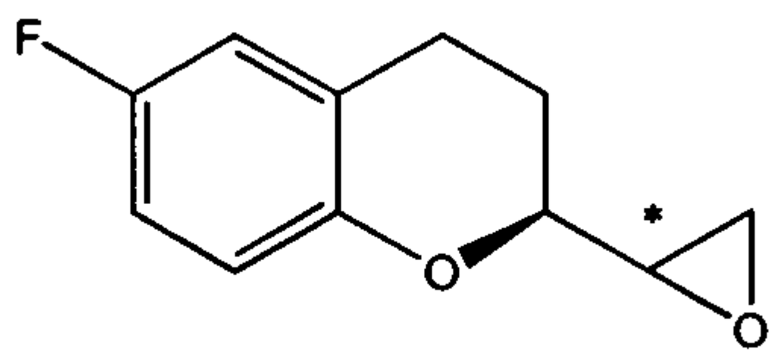
(IIIa) (IIIb)

which comprises a hydrolytic or aminolytic kinetic resolution carried out in the presence of a non-racemic transition metal-ligand catalyst complex.

The process according to the invention is directed to kinetic resolution of racemic or diastereoisomeric mixture of 6- fluoro chroman terminal epoxides and derivatives thereof.

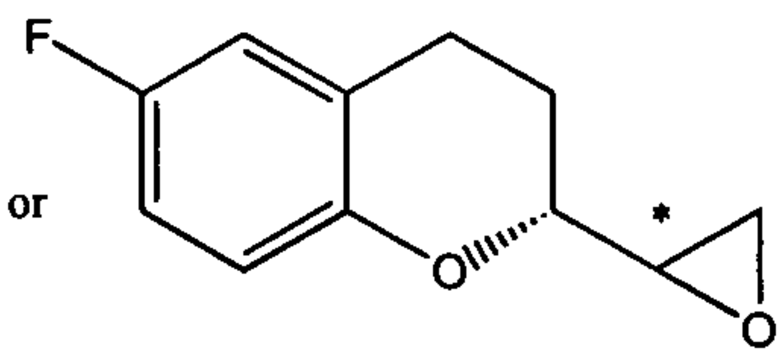
Thus, it is evident to the skilled person that the process of the invention can be applied to partially resolved compounds of formula Ia.

In one embodiment of the invention the kinetic resolution is carried out on partially resolved compounds of formula Ia



(S,R)-,(S,S)-epoxide

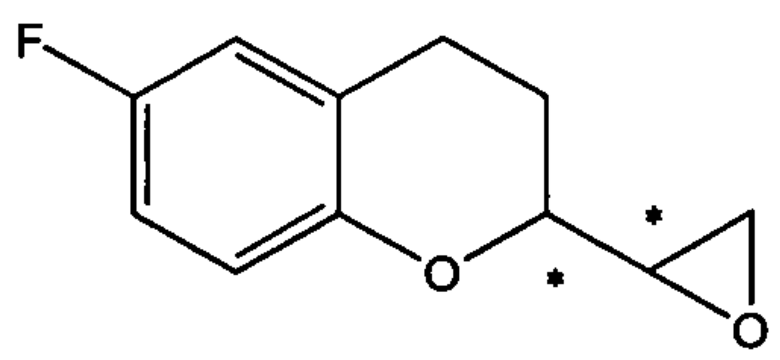
or



(R,R)-,(R,S)-epoxide

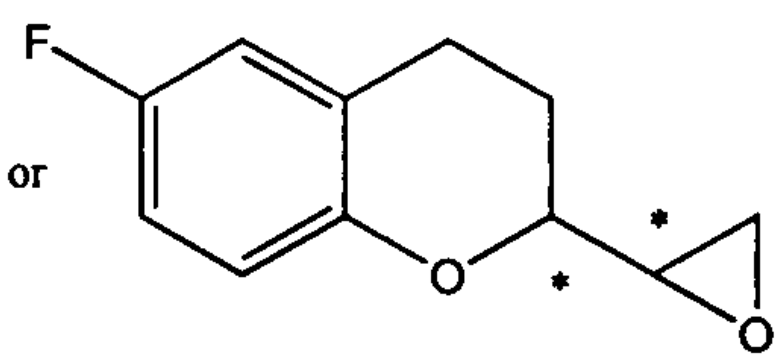
in the form of diastereoisomeric mixtures prepared according to known methods such as those reported in the above cited EP334429 documents.

In a preferred embodiment of the invention the kinetic resolution is carried out on partially resolved compounds of formula Ia



(S,R)-,(R,S)-epoxide A

or



(S,S)-,(R,R)-epoxide B

in the form of racemic mixtures (mixture A or mixture B).

The two racemic mixtures are obtained according to known techniques, in particular by chromatography in accordance with the above cited EP145067 documents.

It is another object of the present invention a process for the separation of racemic terminal epoxide of formula Ia further comprising the partial resolution of the four stereoisomers of formula Ia into mixture A and mixture B.

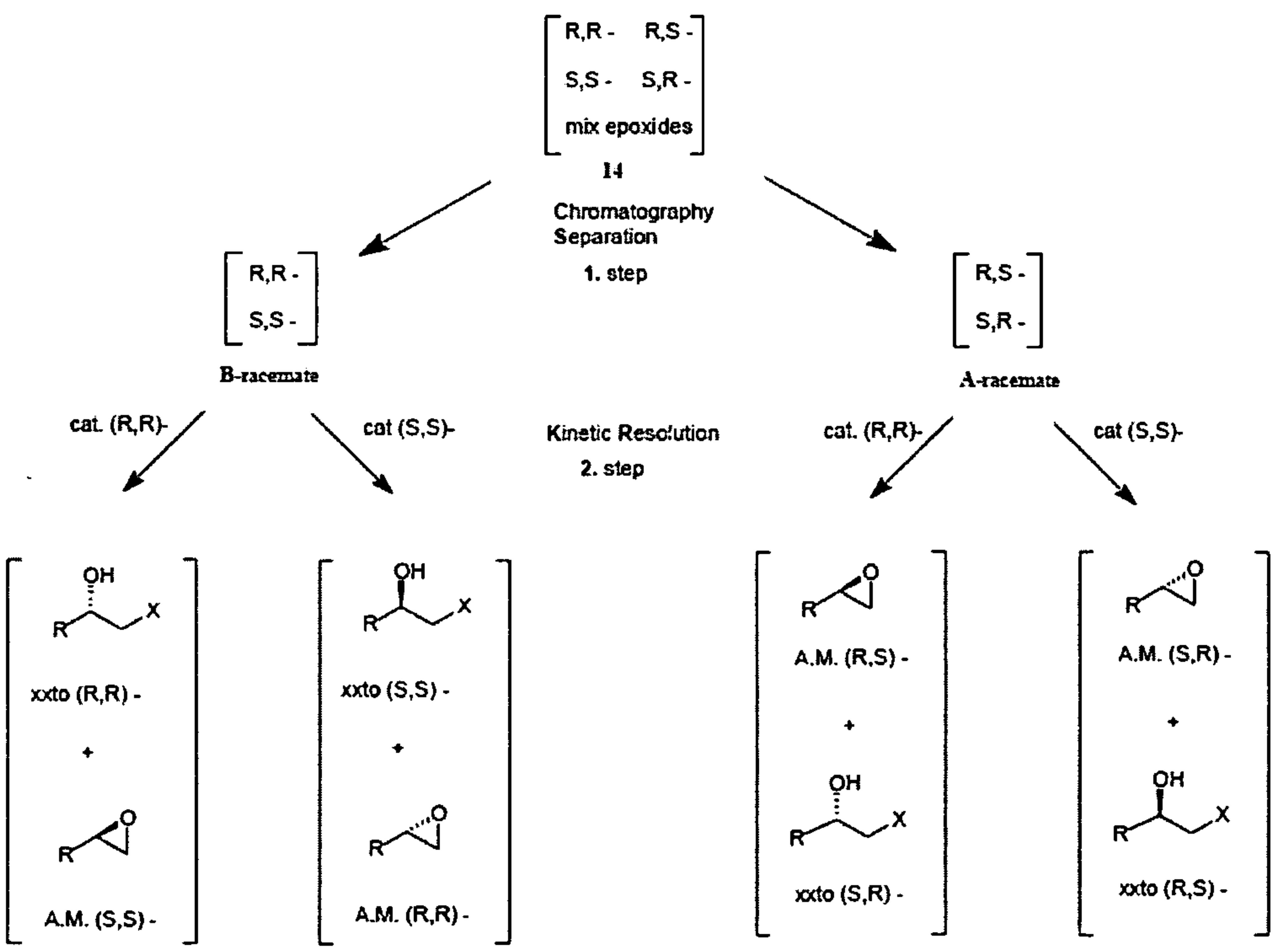
Thus, a mixture of four epoxides stereoisomers of formula Ia is separated, for instance by chromatography, to obtain two epoxides diastereoisomers each of them being a racemic mixture e.g. epoxide A as a mixture of (R,S) and (S,R) enantiomers (mixture A) and epoxide B as a mixture of (R,R) and (S,S) enantiomers (mixture B).

Preferably, the two epoxides A and B, (R,S;S,R) racemate and (R,R;S,S) racemate are separately contacted with, alternatively:

(a) a non-racemic Co (II) complex catalyst, an aryl or alkyl carboxylic acid and water or benzyl carbamate in the presence of oxygen;

(b) water or benzyl carbamate in the presence of a non-racemic complex of Co (III) having an aryl or alkyl carboxylate counter-anion;

wherein the contacting is carried out at a temperature and for a time sufficient to produce a mixture of the enantiomerically enriched 2-substituted alcohol of formula IIa or IIb (diol or carbamate) and of correspondent enantiomerically enriched epoxide of formula IIIa or IIIb in accordance with the following synthetic scheme

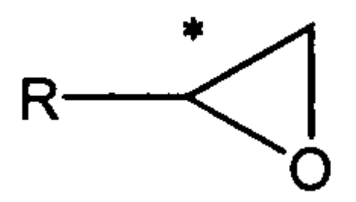


wherein X and R are defined above

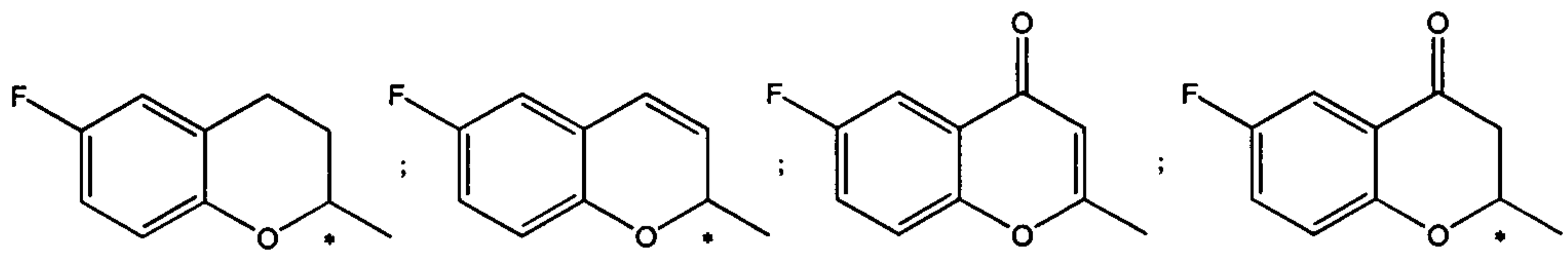
As above reported, the enantiomerically enriched 2-substituted alcohols of formula II is isolated by filtration (xxto) and correspondent enantiomerically enriched epoxides of the formula III is recovered in the mother liquors (A.M.) or, optionally, converted in correspondent benzyl-amino alcohol derivative in accordance with known techniques.

The present invention further provides a process for producing Nebivolol by a kinetic resolution of key terminal epoxide intermediates of formula I.

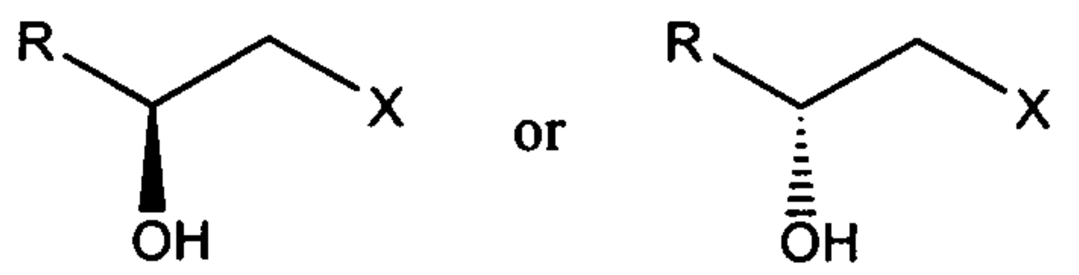
It is another object of the present invention a process for preparing NBV which comprises the separation of racemic terminal epoxide of formula


(I)

wherein R is a group of formula

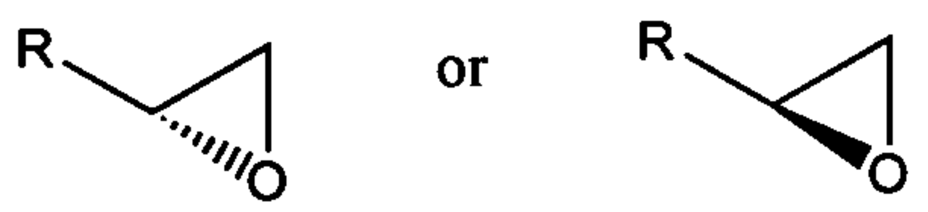


to give an enantiomerically enriched substituted alcohol of formula


(IIa) (IIb)

wherein X is hydroxy or amino group;

and, respectively, an enantiomerically enriched epoxide of formula


(IIIa) (IIIb)

which comprises a hydrolytic or aminolytic kinetic resolution carried out in the presence of a non-racemic transition metal-ligand catalyst complex.

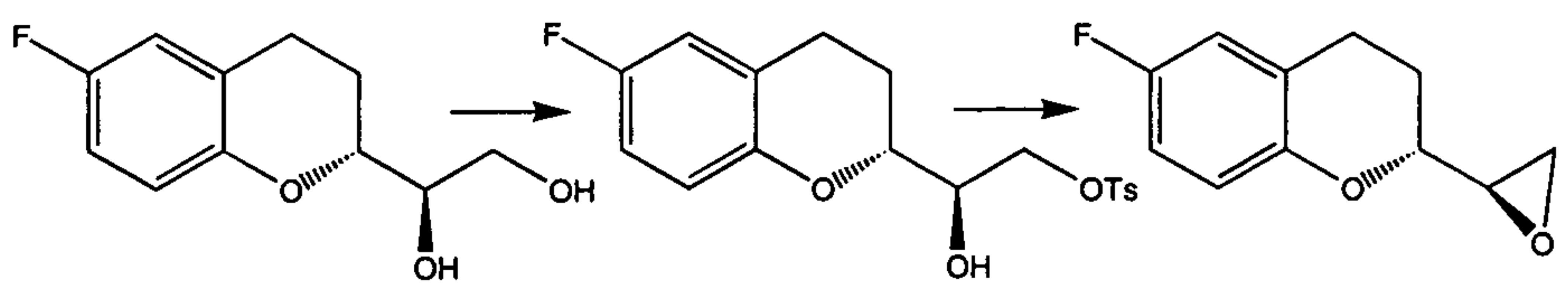
Optionally, a compound of formula IIa or IIb wherein X derives from a suitable oxygen nucleophile of the invention, is converted in a compound of formula IIa or IIb wherein X is a hydroxy group according to known techniques.

An enantiomerically enriched diol of formula IIa or IIb is, in turn, easily transformed into correspondent epoxide wherein stereochemistry is maintained according to known techniques. For example, a diol of formula IIa or IIb can be subjected to a tosylating reaction and then reacted with a base to give the desired epoxide compound.

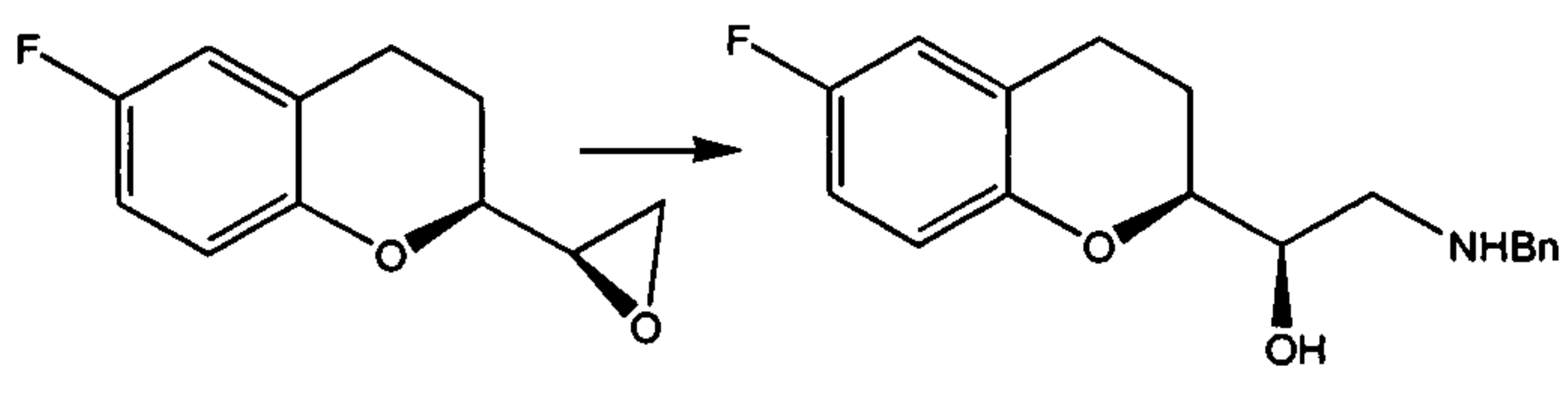
Thus, starting from enantiomerically enriched epoxides is possible to obtain *l*-NBV and *d*-NBV by favourably combine single stereoisomers in accordance with known methods.

So, the compounds of formula IIa or IIb and, respectively, IIIa or IIIb wherein R is a 6-fluoro-4-oxo-1-benzopyran group are converted in *l*-NBV and *d*-NBV in accordance with what is disclosed in WO 2004/041805.

In a preferred embodiment of the invention, the enantiomerically enriched (R,R)-diol of formula II or a precursor thereof, isolated by filtration from the reaction mixture produced by contacting non racemic (R,R)-Co catalyst with epoxide racemate B (R,R;S,S) and optionally hydrolysed to give diol derivative, is tosylated to the corresponding (R,R)-tosylate; subsequently, the (R,R)-tosylate is converted into the corresponding (R,R)-epoxide of formula III in accordance with the following scheme



The enantiomerically enriched (S,R)-epoxide of formula III, recovered from mother liquor of the reaction mixture produced by contacting non racemic (S,S)-Co catalyst with epoxide racemate A (R,S;S,R), is reacted with benzyl amine to give the corresponding (S,R)-benzylamino-alcohol in accordance with the following scheme



The (S,R)-benzylamino-alcohol is reacted with (R,R)-epoxide of the formula III to give (S,R,R,R)-benzyl Nebivolol; which is, in turn, debenzylated by catalytic hydrogenation to obtain *d*-NBV.

On the other side, the enantiomerically enriched (S,S)-epoxide of formula III is converted into the corresponding (S,S)-benzylamino-alcohol which is then reacted with the (R,S)-epoxide obtained from the enantiomerically enriched (R,S)-diol of formula II, to give (R,S,S,S)-benzyl Nebivolol. The latter is debenzylated by catalytic hydrogenation to obtain *l*-NBV.

The above described sequence of operations represents only one of the possible combinations by which it is possible to prepare the desired *l*-NBV and *d*-NBV.

For example, if non racemic (S,S)-Co catalyst is applied in the kinetic resolution on epoxide racemate B (R,R;S,S), and non racemic (R,R)-Co catalyst is applied on epoxide racemate A (R,S;S,R), we obtain, as a result, that the coupling procedure is carried out between the correspondent chiral intermediates derived from the enantiomerically enriched (S,S)-diol of formula II and the (R,S)-epoxide of formula III to give (R,S,S,S) Nebivolol (*l*-NBV) and, between the corresponding chiral intermediates derived from the enantiomerically enriched (S,R)-diol of formula II and the (R,R)-epoxide of formula III to give (S,R,R,R) Nebivolol (*d*-NBV)

The above reported procedures are not limiting the scope of invention, the skilled person will realize that other combinations of epoxides and substituted alcohols are still possible and do not depart from the scope of the invention.

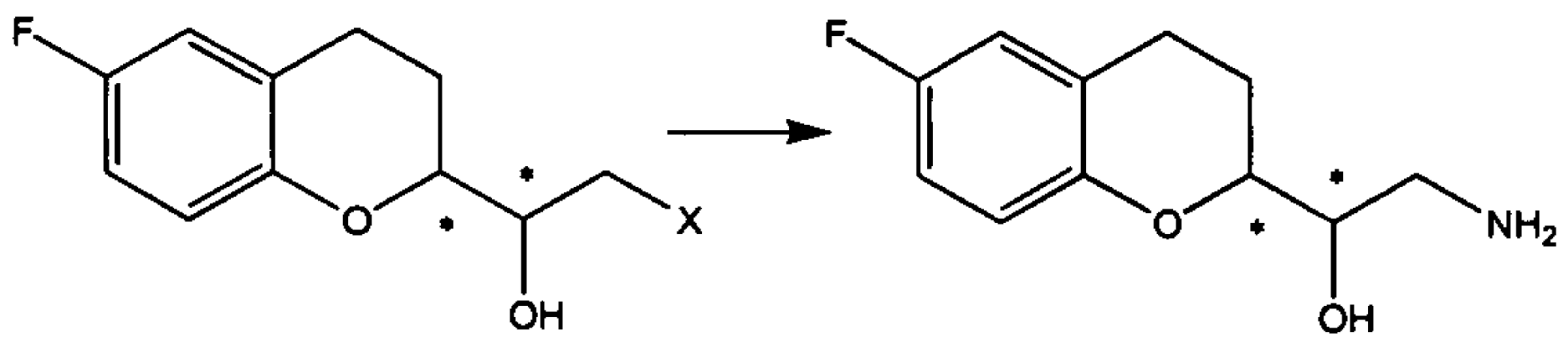
Alternatively, a compound of formula IIa or IIb wherein X derives from a suitable nitrogen nucleophile of the invention, is optionally converted in a compound of formula IIa or IIb wherein X is an amino group according to known techniques.

Thus, an enantiomerically enriched amino alcohol of formula IIa or IIb is, in turn, favourably combined with the correspondent suitable enantiomerically enriched epoxide of formula IIIa or IIIb to give, again, desired *l*-NBV and *d*-NBV.

In a preferred embodiment of the invention, the coupling reaction of a compound of formula IIa or IIb wherein R is a 6-fluoro-3,4-dihydro-1-benzopyran group and X is a –

NHC(=O)OR_1 group and R_1 is defined above comprises the following steps.

An enantiomerically enriched compound of formula IIa or IIb is, separately, hydrolysed into the corresponding amino-alcohol in accordance with the following scheme



wherein X is –NHC(=O)OR_1 and R_1 is a (C_1-C_4)-alkyl or benzyl group;

and so obtained enantiomerically enriched amino-alcohol is reacted with correspondent enantiomerically enriched epoxide of formula IIIa or IIIb to give desired *l*-NBV and *d*-NBV in accordance with known methods (Tetrahedron 2000, 56, 6339-6344).

The compounds of formula IIa or IIb and IIIa or IIIb wherein R is a 6-fluoro chromen-2-yl group or 6-fluoro-4-oxo-4H-1-benzopyran are converted in compounds of formula IIa or IIb and IIIa or IIIb wherein R is a 6-fluoro-3,4-dihydro-1-benzopyran group and, respectively, 6-fluoro-4-oxo-1-benzopyran group according to know techniques such as by reduction reaction.

As used herein, the symbols R and S show the absolute configuration at the asymmetric carbon atoms; a solid triangle represents a bond in the up configuration; a dashed triangle represents a bond in the down configuration; a wavy line denotes that the bond may be either in the up or in the down configuration and the asterisk means that the adjacent carbon atom is an asymmetric carbon atom.

The term “racemic mixture” refers to a compound in the form of a mixture of stereoisomers which are enantiomers. The term “diastereomeric mixture” refers to a compound in the form of a mixture of stereoisomers which are not enantiomers.

The term “non racemic” with regard to the chiral catalyst refers to a preparation of catalyst having greater than 50% of a given enantiomer, preferably at least 75%.

The abbreviation “Ph” as used herein represents the phenyl group. The abbreviation “Bn” as used herein represents the benzyl group. The abbreviation “Ts” as used herein represents the tosyl group.

The term "Bronsted acid" as used herein refers to any molecular entity which is capable of donating a proton.

The present invention develops a simple stereoselective route which allows to synthesize the single, active, NBV stereoisomers. According to the invention, the key chroman epoxides are separated into two diastereoisomers both in racemic mixture and, subsequently, converted into the four stereoisomers of said epoxide or correspondent amino alcohol derivatives.

A careful combination of said stereoisomers, in accordance with known techniques, leads only to the desired *l*-NBV and *d*-NBV forms.

There are several advantages in this synthesis.

The resolving agent is used in catalytic amount.

The resolution of the racemic epoxide by hydrolytic or aminolytic kinetic resolution of the invention is a very easy process because it only requires a filtration step to separate one enantiomer as an enantiomerically enriched 2-substituted alcohol of formula IIa or IIb ,which precipitates from the reaction mixture, from the second enantiomer as an enantiomerically enriched epoxide of formula IIIa or IIb, which remains in the mother liquors.

The enantiomerically enriched epoxide of formula IIIa or IIIb, recovered from mother liquors, can be used without purification or, optionally, isolated as benzyl-amino alcohol derivative.

The hydrolytic or aminolytic kinetic resolution of the invention provides enantiomerically enriched 2-substituted alcohol of formula IIa or IIb and, respectively, enantiomerically enriched epoxide of the formula IIIa or IIIb endowed with very high optical purity (e.e. greater than 99%).

The whole process involves a lower number of steps than the previously described methods and allows avoiding the formation of undesired diastereoisomers of Nebivolol that would be wasted. In this way the overall efficiency of the process is greatly increased and as a consequence the manufacturing cost of the pharmaceutically active ingredient can, in principle, be lowered.

In fact, in accordance with the invention the epoxide racemic mixture A and B are only converted in chiral substrates which are entirely used in the preparation of NBV.

In other words, the process of the invention leads only to intermediates endowed with stereochemistry suitable to prepare desired *l*-NBV and *d*-NBV by avoiding loss in useful material.

A further aspect of the present invention refers to a compound of formula:

[(R)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester;

[(S)-2-((S)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester;

[(R)-2-((S)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester;

[(S)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester;

as useful intermediates in the preparation of *d*-NBV and *l*-NBV.

A further aspect of the present invention refers to the use of (S,S)-Co (salen) or (R,R)-Co (salen) catalysts in the resolution reaction of terminal epoxide of formula I.

A further aspect of the present invention refers to the use of (S,S)-Co (salen) and (R,R)-Co (salen) catalysts in the preparation of NBV.

A practical embodiment of the process object of the present invention comprises the optional separation of a compound of formula Ia into racemic mixture A and racemic mixture B; said racemic mixtures A and B are, separately, subjected to an aminolytic or hydrolytic kinetic resolution in the presence of a suitable non racemic transition metal-ligand catalyst complex preferably a non racemic (R,R or S,S) salen Co catalyst complex, to give an enantiomerically enriched substituted alcohol of formula IIa or IIb and, respectively an enantiomerically enriched epoxide of formula IIIa or IIIb; then, a substituted alcohol of formula IIa or IIb coming from the resolution of mixture A or mixture B is converted into corresponding epoxide or amino alcohol, wherein the stereochemistry is maintained, and reacted with an enantiomerically enriched epoxide of formula IIIa or IIIb coming from the resolution of mixture B or, respectively, mixture A or correspondent benzyl amino alcohol derivative thereof; the latter compounds are then converted in *d*-NBV or *l*-NBV or salts thereof in accordance with known methods.

It is to be understood that while the invention is described in conjunction of the preferred embodiments thereof, those skilled in the art are aware that other embodiments could be made without departing from the scope of the invention.

For better illustrating the invention the following examples are now given.

Example 1

Synthesis of (R)-1-((R)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol.

The catalyst (R,R)-(-)-*N,N'*-Bis-(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (29.6 mg) was dissolved in toluene (0.5 ml) and treated with 4-nitro-benzoic acid (16.5 mg). The solution was allowed to stir at rt open to air for 1 h over which time the colour changed from orange-red to dark brown.

To the solution of catalyst the (±)-[1S*(S*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (5.121 g) and MTBE (6 ml) were added and the mixture obtained was treated with H_2O (0.237 g).

The reaction was left to stir at 25°C for 3 h over which time the heterogeneous mixture was obtained.

The reaction was diluted with heptane (5 ml) and cooled to 0°C. After 2 h the solid was collected by vacuum filtration and rinsed with heptane/MTBE 1/1 (10 ml) to give the title diol as a white powder (2.47 g, HPLC purity: 99%, e.e. > 99%).

NMR: δ_H(400 MHz; $CDCl_3$) 6.82-6.73 (3H, m), 4.10-4.03 (1H, m), 3.89-3.75 (3H, m), 2.93-2.74 (2H, m), 2.65 (1H, b), 2.10 (1H, b), 2.04-1.90 (2H, m).

Example 2

Synthesis of (R)-1-((S)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol.

The catalyst (R,R)-(-)-*N,N'*-Bis-(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (54.9 mg) was dissolved in toluene (2 ml) and treated with acetic acid (11 mg). The solution was allowed to stir at rt open to air for 1 h and was concentrated in vacuum to obtain a crude brown solid.

The resulting catalyst residue was dissolved in (±)-[1S*(R*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (1 g) and MTBE (2 ml) and the mixture obtained was treated with H_2O (0.046 g).

The reaction was left to stir at 25°C for 21 h over which time the heterogeneous mixture was obtained.

The reaction was cooled to 0°C and after 1h the solid was collected by vacuum filtration and rinsed with MTBE (2 ml) to give the title diol as a white powder (0.417 g, HPLC purity: 98 %, e.e. > 99 %).

NMR: δ_H(400 MHz; $CDCl_3$) 6.83-6.69 (3H, m, Ar), 4.05-3.98 (1H, m), 3.90-3.80 (3H, m), 2.91-2.74 (2H, m), 2.18-2.11 (1H, m), 1.91-1.81 (1H, m).

Example 3

Synthesis of (S)-1-((R)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol.

The catalyst (S,S)-(-)-*N,N'*-Bis-(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (54.9 mg) was dissolved in toluene (2 ml) and treated with AcOH (11 mg). The solution was allowed to stir at rt open to air for 1 h and was concentrated in vacuo to obtain a crude brown solid.

The resulting catalyst residue was dissolved in (±)-[1S*(R*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (1 g) and MTBE (2 ml) and the mixture obtained was treated with H_2O (0.046 g).

The reaction was left to stir at 25°C for 21 h over which time the heterogeneous mixture was obtained.

The reaction was cooled to 0°C and after 1h the solid was collected by vacuum filtration and rinsed with MTBE (2 ml) to give the title diol as a white powder (0.417 g, HPLC purity: 98 %, e.e. > 99 %).

NMR: δ_H(400 MHz; $CDCl_3$) 6.83-6.69 (3H, m, Ar), 4.05-3.98 (1H, m), 3.90-3.80 (3H, m), 2.91-2.74 (2H, m), 2.18-2.11 (1H, m), 1.91-1.81 (1H, m).

Example 4

Synthesis of (R)-1-((S)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol and of (S)-2-(benzylamino)-1-((R)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethanol.

Part A: the catalyst (R,R)-(-)-*N,N'*-Bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (60 mg) was dissolved in toluene (5 ml) and treated with 4-nitro-benzoic acid (34.9 mg). The solution was allowed to stir at rt open to air for 1 h and was concentrated in vacuo to obtain a crude brown solid.

The resulting catalyst residue was dissolved in (±)-[1S*(R*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (4 g) and MTBE (4 ml) and the mixture obtained was treated with H_2O (0.96 g).

The reaction was left to stir at 25°C for 16 h over which time the heterogeneous mixture was obtained.

The reaction was diluted with heptane (4 ml) and cooled to 0°C. After 2h the solid was collected by vacuum filtration and rinsed with heptane/MTBE 1/1 (4 ml) to give the title diol as a white powder (1.2 g, HPLC purity: 99 %, e.e. > 99 %).

Part B: the filtrate was concentrated by rotary evaporation and ethanol (10 ml) and benzylamine (3.3 g) were added to the residue. The mixture was heated to 80°C and after 2 h was concentrated in vacuum to obtain an oil residue. This was diluted with toluene (20 ml) and washed with H_2O (3 x 20 ml). The organic phase was concentrated and the residue was purified by crystallization with ethanol to give the title benzylamino-alcohol as a white powder (1.4 g, HPLC purity: 94 %, e.e. > 99 %).

NMR: δ_H(400 MHz; $CDCl_3$) 7.37-7,27 (5H, m, Ar), 6.82-6.67 (3H, m, Ar), 3.9-3.7 (4H, m), 3.0-2.95 (1H, dd), 2.88-2.71 (3H, m), 2,18-2,09 (1H, m), 1,9-1,75 (1H, m).

Example 5

<u>Synthesis of (S)-1-((S)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol and of (R)-2-(benzylamino)-1-((R)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethanol.</u>

Part A: the catalyst (S,S)-(+)-*N,N'*-Bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (18.2 mg) was dissolved in toluene (3 ml) and treated with 4-nitro-benzoic acid (10.8 mg). The solution was allowed to stir at rt open to air for 1 h and was concentrated in vacuum to obtain a crude brown solid.

The resulting catalyst residue was dissolved in (±)-[1S*(S*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (3 g) and MTBE (4 ml) and the mixture obtained was treated with H_2O (0.139 g).

The reaction was left to stir at 25°C for 18 h over which time the heterogeneous mixture was obtained.

The reaction was diluted with heptane (8 ml) and cooled to 0°C. After 2 h the solid was collected by vacuum filtration and rinsed with heptane/MTBE 1/1 (2 ml) to give the title diol as a white powder (1.24 g, HPLC purity: 97.5 %, e.e. > 99 %).

Part B: the filtrate was concentrated by rotary evaporation and the heptane/toluene 9/1 (10 ml) and benzylamine (2.48 g) were added to the residue. The mixture was heated to 80°C and after 4 h was allowed to warm to rt and the solid was collected by vacuum filtration to give the title benzylamino-alcohol as a white powder (0.94 g, HPLC purity: 99 %, e.e. > 99 %).

NMR: δ_H(400 MHz; $CDCl_3$) 7.39-7,27 (5H, m, Ar), 6.82-6.67 (3H, m, Ar), 4.0-3.76 (4H, m), 3.97-2.7 (4H, m), 2.0-1.8 (2H, m).

Example 6

Synthesis of [(R)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester.

The catalyst (R,R)-(-)-*N,N'*-Bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (42 mg) was dissolved in MTBE (2 ml) and treated with 4-nitro-benzoic acid (22 mg). The solution was allowed to stir at rt open to air for 1 h over which time the colour changed from orange-red to dark brown.

To the solution of catalyst benzyl carbamate (116 mg) and MTBE (0.5 ml) were added and the mixture was stirred at rt for 0.5 h, then the (±)-[1S*(S*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (324 mg) and MTBE (1 ml) were added and stirring was continued over night.

An heterogeneous mixture was obtained and the solid was collected by vacuum filtration and rinsed with MTBE (1.5 ml) to give the title CBZ-amino-alcohol as a white powder (HPLC purity: 99 %, e.e. > 99 %).

NMR: δ_H(400 MHz; $CDCl_3$) 7.37-7.27 (5H, m, Ar), 6.82-6.72 (3H, m, Ar), 5.34 (1H, sb), 5.10 (2H, s), 3.93-3.87 (1H, ddd), 3.85-3.75 (1H, m), 3.55-3.37 (2H, m), 2.9-2.7 (3H, m), 2.1-2.0 (1H, m), 1.95-1.80 (1H, m)

Example 7

Synthesis of [(S)-2-((S)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester.

The catalyst (S,S)-(+)-*N,N'*-Bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (14.5 mg) was dissolved in toluene (1 ml) and treated with 4-nitro-benzoic acid (8 mg). The solution was allowed to stir at rt open to air for 1 h and was concentrated in vacuum to obtain a crude brown solid.

To the resulting catalyst residue benzyl carbamate (97 mg), MTBE (0.5 ml) and (±)-[1S*(S*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (250 mg) were added and the mixture was stirred at rt over night.

An heterogeneous mixture was obtained and the solid was collected by vacuum filtration and rinsed with MTBE to give the title CBZ-amino-alcohol as a white powder (HPLC purity: 99 %, e.e. > 99 %).

Example 8

<u>Synthesis of [(S)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester.</u>

The catalyst (S,S)-(+)-*N,N'*-Bis-(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (58 mg) was dissolved in dichloromethane (3.0 ml) and treated with 4-nitro-benzoic acid (35 mg). The solution was allowed to stir at rt open to air for 1 h over which time the colour changed from orange-red to dark brown and then was concentrated in vacuo to obtain a crude brown solid.

To the resulting catalyst residue benzyl carbamate (176 mg), MTBE (0.5 ml) and (±)-[1S*(R*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (450 mg) were added and the mixture was stirred at rt over night.

An heterogeneous mixture was obtained and the solid was collected by vacuum filtration and rinsed with MTBE to give the title CBZ-amino-alcohol as a white powder (112 mg, HPLC purity: 99 %, e.e. > 99 %).

NMR: δ_H(400 MHz; $CDCl_3$) 7.42-7.32 (5H, m, Ar), 6.84-6.70 (3H, m, Ar), 5.25 (1H, sb), 5.14 (2H, s), 3.97-3.91 (1H, m), 3.87-3.81 (1H, m), 3,74-3.65 (1H, m), 3.44-3.34 (1H, m), 2.91-2.74 (2H, m), 2.25-2.15 (1H, m), 1.90-1.78 (1H, m)

Example 9

<u>Synthesis of [(R)-2-((S)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester.</u>

The catalyst (R,R)-(+)-*N,N'*-Bis-(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (29 mg) was dissolved in dichloromethane (1.5 ml) and treated with 4-nitrobenzoic acid (16 mg). The solution was allowed to stir at rt open to air for 1 h over which time the colour changed from orange-red to dark brown and then was concentrated in vacuo to obtain a crude brown solid.

To the resulting catalyst residue benzyl carbamate (175 mg), MTBE (0.5 ml) and (±)-[1S*(R*)]-6-fluoro-3,4-dihydro-2-(oxiran-2-yl)-2H-chromene (450 mg) were added and the mixture was stirred at rt over night.

An heterogeneous mixture was obtained and the solid was collected by vacuum filtration and rinsed with MTBE to give the title CBZ-amino-alcohol as a white powder (HPLC purity: 99 %, e.e. > 99 %).

Example 10

Synthesis of 2-amino-1-[6-fluoro-(2R)-3H,4H-2-2chromenyl]-(1R)-ethan-1-ol.

To a solution of [(R)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester (0.250 g) in dry methanol (5 ml) at room temperature was added 10% Pd-charcoal (8 mg) and stirred under hydrogen atmosphere (3 bar).

After 8 h the reaction mixture was filtered and the filtrate was concentrated under vacuum to give the title compound (0.14 g) as an oil.

Example 11

Synthesis of 2-amino-1-[6-fluoro-(2R)-3H,4H-2-2chromenyl]-(1S)-ethan-1-ol.

To a solution of [(S)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester (0.250 g) in dry methanol (5 ml) at room temperature was added 10% Pd-charcoal (8 mg) and stirred under hydrogen atmosphere (3 bar).

After 8 h the reaction mixture was filtered and the filtrate was concentrated under vacuum to give the title compound (0.14 g) as an oil.

Example 12

Synthesis of (-)-(R,S,S,S)-α,α'-imino-bis-(methylene)-bis-(6-fluoro-3,4-dihydro-2H,1-benzopyran-2-methanol)-hydrochloride.

The mother liquor obtained in Example 6 was concentrated by rotary evaporation and the residue was dissolved in dry t-butanol (5 ml). 2-amino-1-[6-fluoro-(2R)-3H,4H-2-

2chromenyl]-(1S)-ethan-1-ol and a catalytic amount of $BF_3.O(Et)_2$ were added and the resulting mixture was refluxed for 4 h.

The solvent was removed under vacuum and washed with brine and extracted with ethyl acetate and dried over Na_2SO_4. The volatiles were concentrated and the residue dissolved in EtOH and dry HCl gas was passed through the solution to form the title hydrochloride salt.

NMP: δ_H(400 MHz; CD_3OD) 6.84-6.74 (6H, m), 4.12-3.89 (4H, m), 3.52-3.18 (4H, m), 2.96-2.77 (4H, m), 2.28-2.20 (1 H, m), 2.05-1.86 (2H, m), 1.83-1.72 (1H, m).

Example 13

Synthesis of (+)-(S,R,R,R)-α,α'-imino-bis-(methylene)-bis-(6-fluoro-3,4-dihydro-2H,1-benzopyran-2-methanol)-hydrochloride.

The mother liquor obtained in Example 8 was concentrated by rotary evaporation and the residue was dissolved in dry t-butanol (5 ml). 2-amino-1-[6-fluoro-(2R)-3H,4H-2-2chromenyl]-(1R)-ethan-1-ol and a catalytic amount of $BF_3.O(Et)_2$ were added and the resulting mixture was refluxed for 4 h.

The solvent was removed under vacuum and washed with brine and extracted with ethyl acetate and dried over Na_2SO_4. The volatiles were concentrated and the residue dissolved in EtOH and dry HCl gas was passed through the solution to form the title hydrochloride salt.

NMR: δ_H(400 MHz; CD_3OD) 6.84-6.74 (6H, m), 4.12-3.89 (4H, m), 3.52-3.18 (4H, m), 2.96-2.77 (4H, m), 2.28-2.20 (1 H, m), 2.05-1.86 (2H, m), 1.83-1.72 (1H, m).

Example 14

Synthesis of (S)-1-((R)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol and of (R)-2-(benzylamino)-1-((R)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethanol.

Part A: the catalyst (S,S)-(-)-*N,N'*-Bis-(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) (12.0 mg) was dissolved in toluene (0.1 ml) and treated with AcOH (6.6 mg). The solution was allowed to stir at rt open to air for 1 h and was concentrated in vacuo to obtain a crude brown solid.

The resulting catalyst residue was dissolved in (2R)-6-fluoro-2-[(2S)-oxiran-2-yl]-3,4-dihydro-2H-chromene (0.97 g), (2R)-6-fluoro-2-[(2R)-oxiran-2-yl]-3,4-dihydro-2H-chromene (0.97 g) [(R,R)-,(R,S)-epoxide diastereoisomeric mixture)] and MTBE (2.36 ml) and the mixture obtained was treated with H_2O (0.099 g).

The reaction was left to stir at 25°C for 24 h over which time the heterogeneous mixture was obtained.

The reaction was cooled to 5°C and after 1h the solid was collected by vacuum filtration and rinsed with MTBE (2.8 ml) to give the title diol as a white powder (0.613g, HPLC purity: 97.7 %, e.e. > 99 %).

Part B: the filtrate was treated according to experimental procedure described in Example 5, Part. B, to give the title benzylamino-alcohol as a white powder.

NMR: δ_H(400 MHz; $CDCl_3$) 6.83-6.69 (3H, m, Ar), 4.05-3.98 (1H, m), 3.90-3.80 (3H, m), 2.91-2.74 (2H, m), 2.18-2.11 (1H, m), 1.91-1.81 (1H, m).

NMR: δ_H(400 MHz; $CDCl_3$) 7.39-7,27 (5H, m, Ar), 6.82-6.67 (3H, m, Ar), 4.0-3.76 (4H, m), 3.97-2.7 (4H, m), 2.0-1.8 (2H, m).

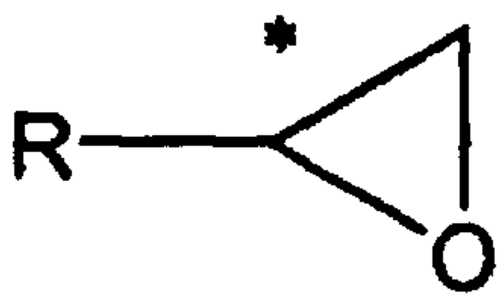
Example 15

Synthesis of (R)-1-((S)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethane-1,2-diol and of (S)-2-(benzylamino)-1-((S)-6-fluoro-3,4-dihydro-2H-chromen-2-yl)-ethanol.

By working according to experimental procedure described in Example 14 but in the presence of (R,R)-(-)-*N,N'*-Bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclo-hexane-diamino-cobalt-(II) catalyst, a hydrolytic kinetic resolution was carried out on the (S,R)-,(S,S)-epoxide diastereoisomeric mixture to give the title diol and benzylamino-alcohol compounds as white powders.

Claims

1. A process for the separation of racemic terminal epoxide of formula



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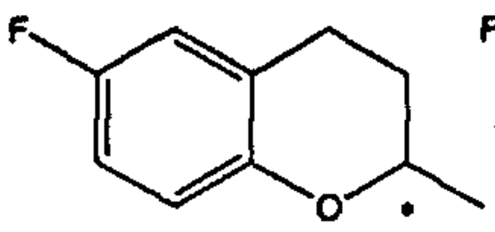
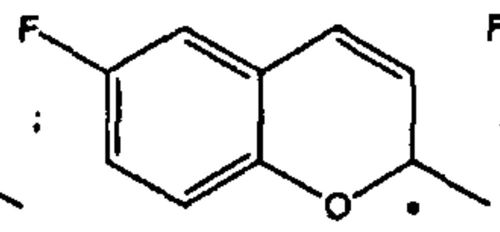
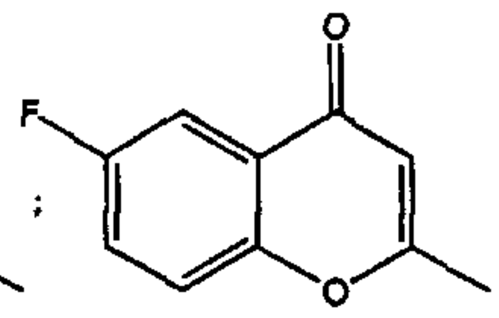
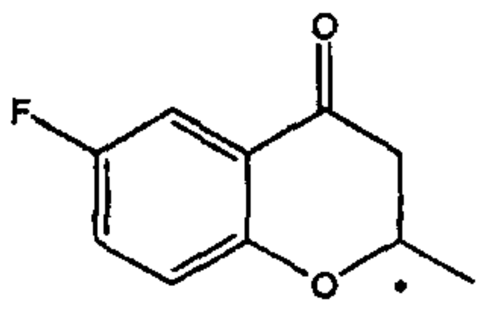
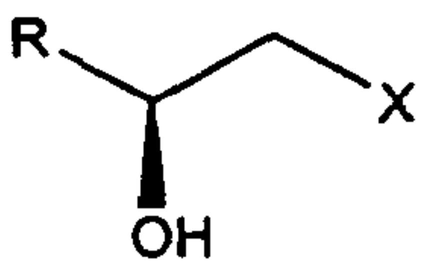
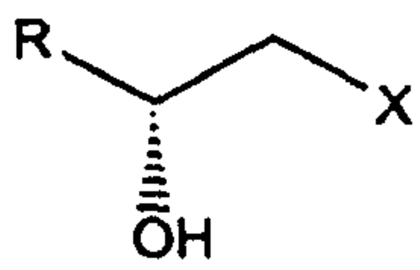
wherein R is  ;  ;  ; or 

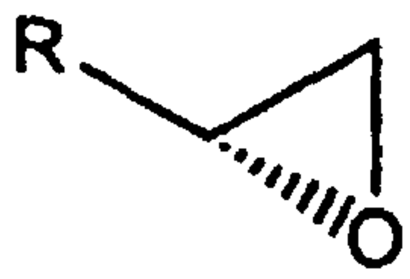
to give an enantiomerically enriched substituted alcohol of formula

 or 

(IIa) (IIb)

wherein X is hydroxy or amino group;

and, respectively, an enantiomerically enriched epoxide of formula

 or 

(IIIa) (IIIb)

which comprises a hydrolytic or aminolytic kinetic resolution carried out in the presence of a non-racemic transition metal-ligand catalyst complex.

2. The process according to claim 1 wherein the ligand is a chiral salen ligand.

3. The process according to claim 1 or claim 2 wherein the transition metal is Co.

4. The process according to claim 1 wherein the non-racemic transition metal-ligand catalyst complex is a Co-(salen) catalyst complex.

5. The process according to claim 4 wherein the non-racemic catalyst complex is (S,S)-Co(II) (salen) catalyst or (R,R)-Co(II) (salen) catalyst.

6. The process according to claim 4 wherein the non-racemic catalyst complex is selected from the group consisting of (S,S)-Co(III)-(salen)-(p-nitro-benzoate), (R,R)-Co(III)-(salen)-(p-nitro-benzoate), (S,S)-Co(III)-(salen)-(acetate) and (R,R)-Co(III)-(salen)-(acetate).

7. The process according to claim 1 wherein the amount of the catalyst complex is comprised from 0.01 to 10 mol% with regard to a compound of formula I.

8. The process according to claim 7 wherein said amount is comprised from 0.01 to 5 mol%.

9. The process according to claim 8 wherein said amount is comprised from 0.05 to 1 mol%.

10. The process according to claim 1 wherein said hydrolytic or aminolytic kinetic resolution comprises contacting a nucleophile and a racemic or diastereoisomeric mixture of a compound of formula I in the presence of the non-racemic transition metal-ligand catalyst complex.

11. The process according to claim 10 wherein said contacting step is carried out at a temperature comprised between -10°C and 50°C.

12. The process according to claim 11 wherein said contacting step is carried out at around room temperature.

13. The process according to claim 10 wherein said nucleophile is water, hydroxide, carboxylate, carbamate, azide or imide.

14. The process according to claim 13 wherein said nucleophile is water.

15. The process according to claim 13 wherein said nucleophile is benzyl carbamate.

16. The process according to claim 10 wherein said kinetic resolution comprises:
a) dissolution of the catalyst complex in a suitable aprotic or protic solvent;
b) activation of the catalyst complex by reaction with a suitable oxidizing agent in the presence of an organic or inorganic acid;
c) contacting the active catalyst complex with the racemic or diastereoisomeric mixture of the compound of formula I and a suitable nucleophile; and
d) filtrating the reaction mixture.

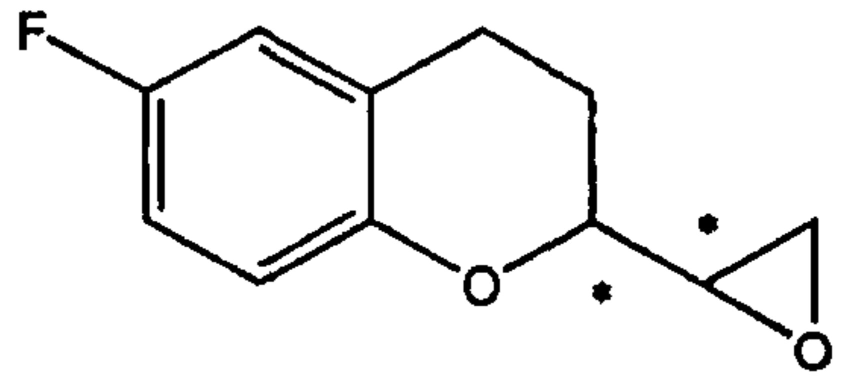
17. The process according to claim 10 wherein said kinetic resolution comprises:
a') contacting an oxidizing agent with a mixture comprising the racemic or diastereoisomeric compound of formula I, the non-racemic catalyst complex, an organic or inorganic acid and a suitable nucleophile; and
b') filtrating the reaction mixture.

18. The process according to claim 16 or claim 17 wherein the oxidizing agent is oxygen.

19. The process according to claim 18 wherein said oxygen is introduced in the form of air.

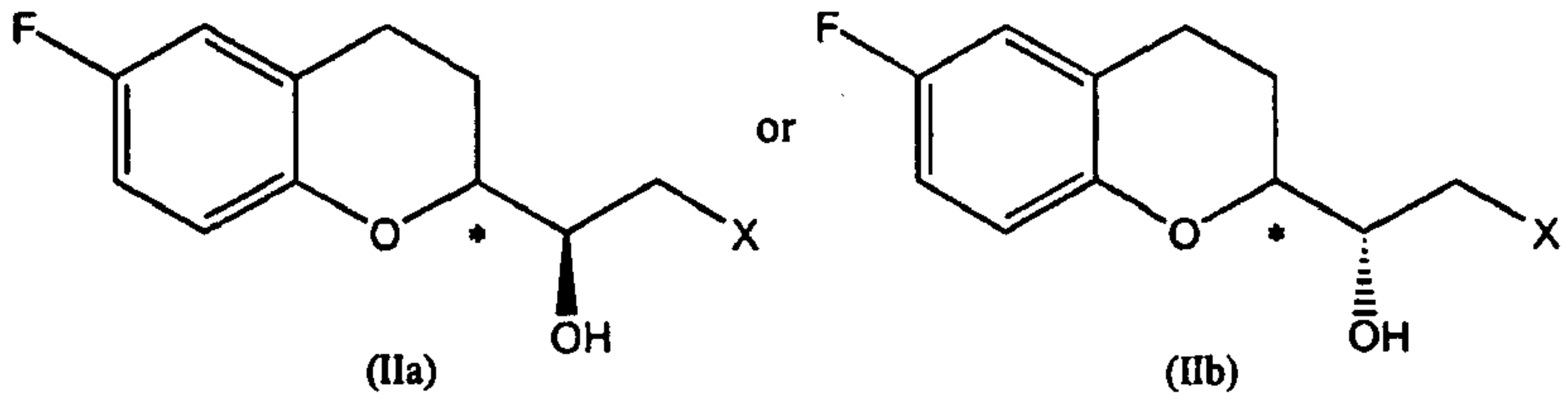
20. The process according to claim 16 or claim 17 wherein in the activation of the catalyst complex organic Bronsted acids are used.

21. A process for the separation of racemic terminal epoxide of formula



(Ia)

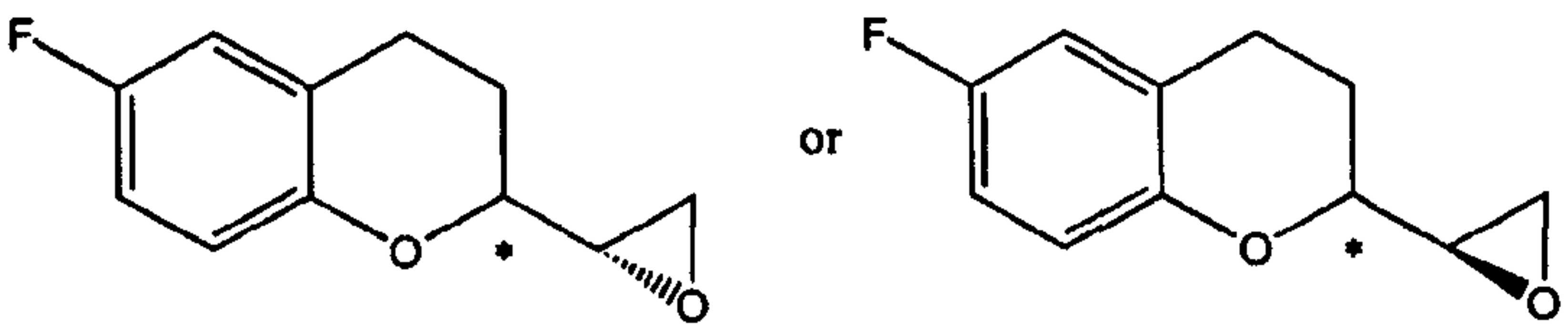
to give an enantiomerically enriched substituted alcohol of formula



(IIa) (IIb)

wherein X is hydroxy or amino group;

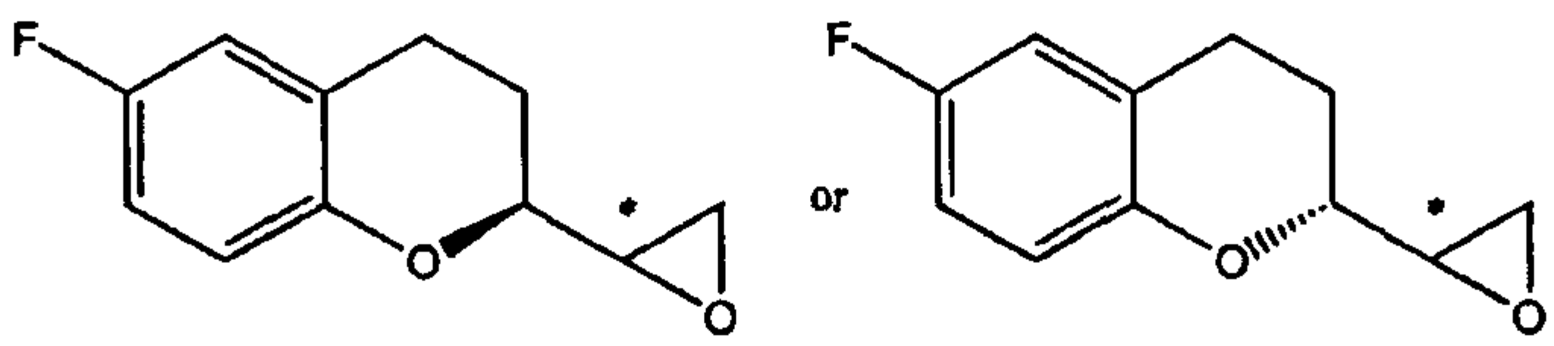
and, respectively, an enantiomerically enriched epoxide of formula



(IIIa) (IIIb)

which comprises a hydrolytic or aminolytic kinetic resolution carried out in the presence of a non-racemic transition metal-ligand catalyst complex.

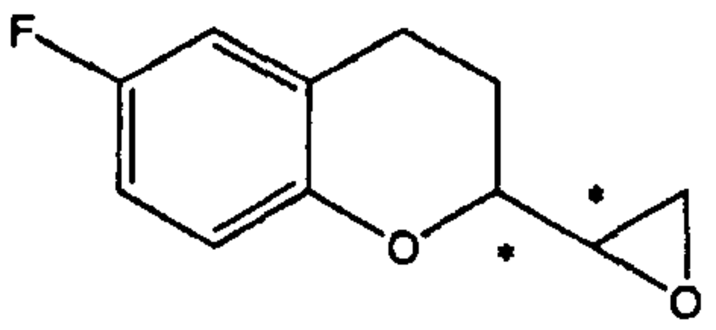
22. The process according to claim 21 wherein said hydrolytic or aminolytic kinetic resolution is carried out on partially resolved compounds of formula Ia



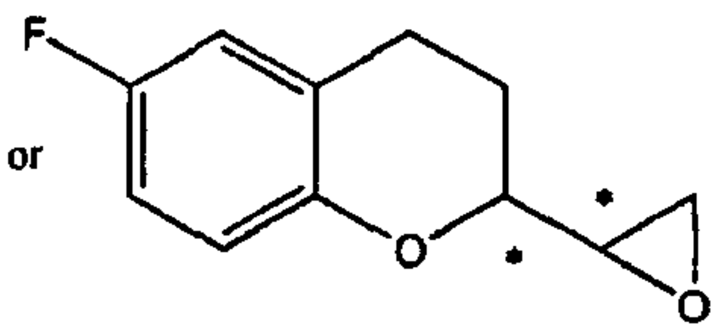
(S,R)-,(S,S)-epoxide (R,R)-,(R,S)-epoxide

in the form of diastereoisomeric mixtures.

23. The process according to claim 21 wherein said hydrolytic or aminolytic kinetic resolution is carried out on partially resolved compounds of formula Ia


(S,R)-,(R,S)-epoxide A

or


(S,S)-,(R,R)-epoxide B

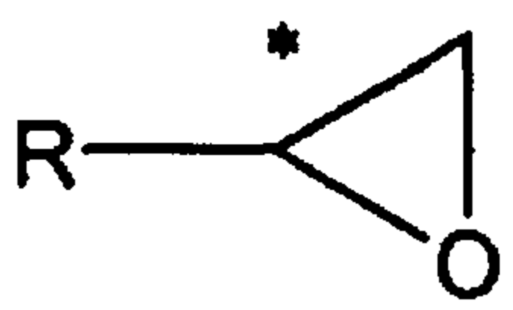
in the form of racemic mixtures.

24. The process according to claim 23 further comprising the partial resolution of the four stereoisomers of formula Ia into a mixture A of the (S,R) and (R,S) stereoisomers and a mixture B of the (S,S) and (R,R) stereoisomers.

25. In a process for preparing nebivolol (NBV), the improvement comprising separating racemic terminal epoxide by a process according to claim 1.

26. A compound of formula:
[(R)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester;
[(S)-2-((S)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester;
[(R)-2-((S)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester; or
[(S)-2-((R)-6-fluoro-chroman-2-yl)-2-hydroxy-ethyl]-carbamic acid benzyl ester.

27. Use of (S,S)-Co (salen) or (R,R)-Co (salen) catalyst complex in the separation of racemic terminal epoxide of formula I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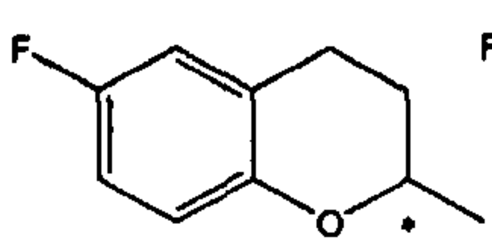
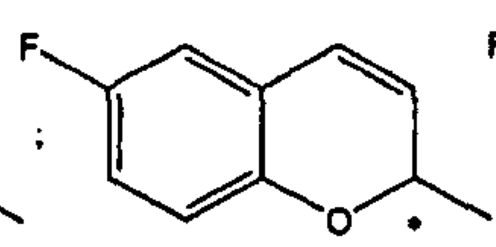
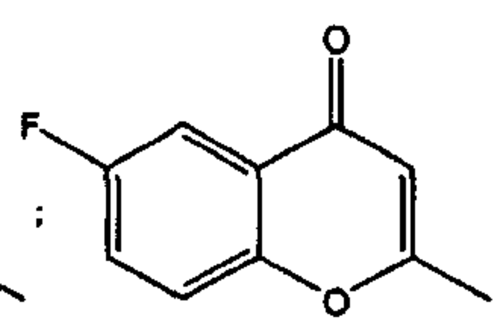
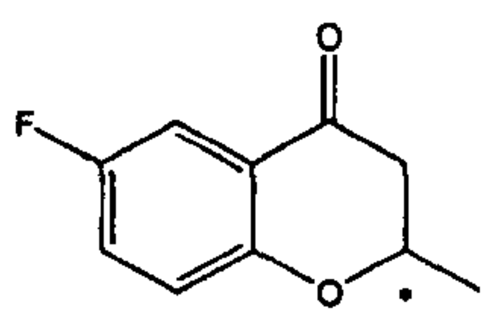
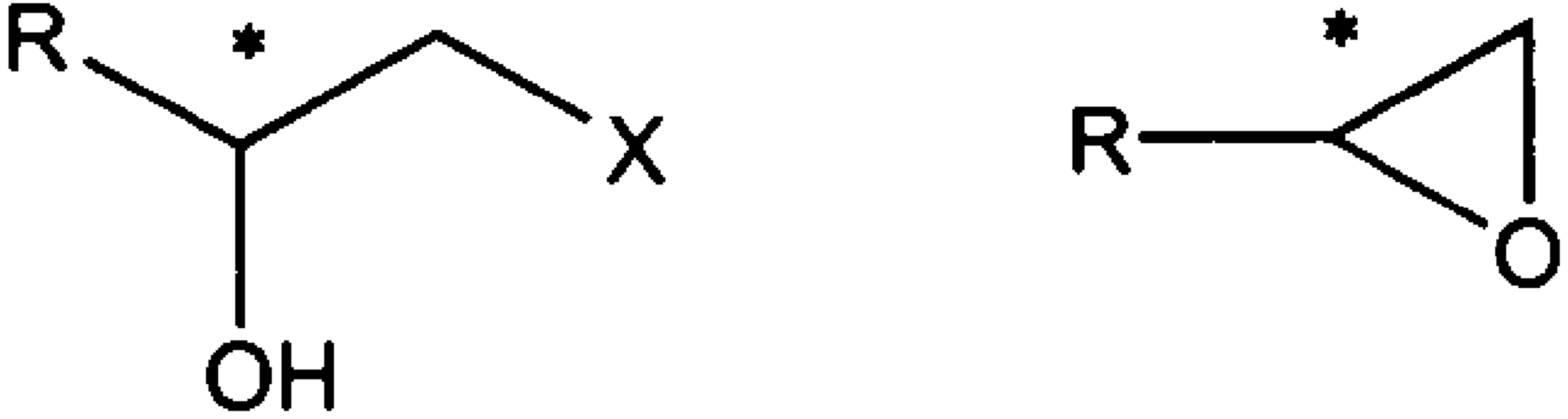
wherein R is  ;  ;  ; or  .

28. Use of (S,S)-Co (salen) or (R,R)-Co (salen) catalyst complex as the non-racemic transition metal-ligand catalyst complex in the process for preparing NBV according to claim 25.



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