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(54) Titre : PROCEDE POUR L'AMINATION DIRECTE D'ALCOOLS SECONDAIRES AVEC DE L'AMMONIAC EN AMINES PRIMAIRES
(54) Title: PROCESS FOR THE DIRECT AMINATION OF SECONDARY ALCOHOLS BY MEANS OF AMMONIA TO FORM PRIMARY AMINES

(57) **Abrégé/Abstract:**

The invention provides a process for preparing primary amines, comprising the steps of A) providing a solution of a secondary alcohol in a fluid, non-gaseous phase, B) contacting the phase with free ammonia and/or with at least one ammonia donor compound and a homogeneous catalyst, and optionally C) isolating the primary amine formed in step B), characterized in that the ratio of the volume of the liquid phase to the volume of the gas phase in step B) is greater than or equal to 0.25 and/or in that the ammonia in step B) is used in a molar ratio, relative to the hydroxyl groups in the secondary alcohol, of at least 5:1.



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- 24 -

Abstract

The invention relates to a process for preparing primary amines which comprises the process steps

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- A) provision of a solution of a secondary alcohol in a fluid, nongaseous phase,
- B) contacting of the phase with free ammonia and/or at least one ammonia-releasing compound and a homogeneous catalyst and optionally
- C) isolation of the primary amine formed in process step B),

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characterized in that the volume ratio of the volume of the liquid phase to the volume of the gas phase in process step B is greater than or equal to 0.25, and/or in that the ammonia is used in process step B) in a molar ratio based on the hydroxyl groups in the secondary alcohol of at least 5:1.

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- 1 -

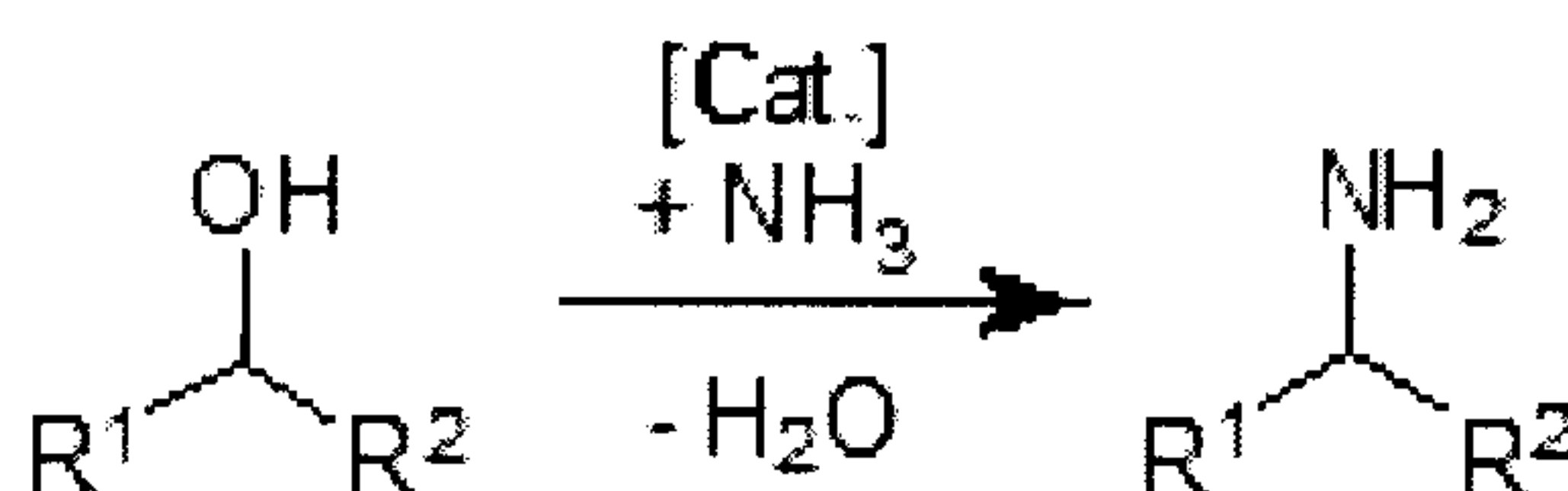
Process for the direct amination of secondary alcohols by means of ammonia to form primary amines

The present invention relates to a chemocatalytic liquid-phase process for the direct single-stage
5 amination of optionally polyhydric and/or functionalized secondary alcohols to optionally
polyvalent and/or functionalized primary amines by means of ammonia in high yields with the aid
of a homogeneous catalyst system.

Prior art

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The conversion of oxygen-containing functional groups into nitrogen-containing functional groups
represents an essential transformation for the synthesis of many organic compounds. A series of
classical methods are known in the literature and industry in order to achieve the stated object.
In the great majority of publications, a primary or secondary alcohol is reacted with a primary or
15 secondary organic amine. The reaction of a primary or secondary alcohol with ammonia to form
primary amines as per scheme 1, on the other hand, has been described only for use of
particular process conditions, catalysts and only for a few alcohols.



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Scheme 1: General reaction scheme for obtaining primary amines from primary or secondary alcohols

The challenge faced by all known processes is to achieve high selectivities to the primary
amines, since these are more nucleophilic than ammonia and consequently can react
25 preferentially to form higher amines. While the conversion of an isolated hydroxyl function into an
amino function is approximately thermally neutral, the formation of secondary and tertiary amines
is exothermic with an enthalpy of reaction of in each case about 30 kJ/mol and is therefore also
thermodynamically preferred over the formation of primary amines.

201000282

- 2 -

Direct amination in the gas phase

The single-stage direct conversion of a primary or secondary hydroxyl group by means of ammonia into a primary amine is in the case of lower, readily vaporizable alcohols restricted mainly to gas-phase reactions. Here, the appropriate alcohol is vaporized and reacted under suitable conditions (pressure, temperature, hydrogen partial pressure and optionally inert gas partial pressure) over a predominantly heterogeneous catalyst. This mode of operation is described, for example, in the publications US 4314084, US 5530127, US 5932769, FR 1347648, US 3270059, US 4111840, US 4123462, DE 1667193, Fischer et al. (J. Catal., 1999, 182, 289-291) or Jenzer et al. (Catal. Lett., 1999, 61, 111-114).

A disadvantage of most heterogeneously catalyzed gas-phase processes is the use of high temperatures (up to 400°C) and pressure (up to 300 bar), as a consequence of which frequently considerable amounts of higher amines, alkenes and alkanes are formed in addition to the desired primary amines. In addition, owing to the characteristic pressure and temperature conditions of a gas-phase reaction, only substrates which can be vaporized and reacted without losses or in the case of which the amines can be condensed or resublimed without losses can be converted in economical yields into amines by means of the abovementioned processes. Substrates or their corresponding amines, which are subject to decomposition under such conditions, are therefore reacted in liquid-phase syntheses in the literature and industry.

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Reductive amination

Processes known to those skilled in the art for preparing primary amines from alcohols by means of reductive amination utilize a multistage procedure which can be associated with a change in the oxidation state of the carbon atom bearing the hydroxyl groups. Processes which are carried out with retention of the oxidation state (direct amination) can be distinguished therefrom. With a change in the oxidation state of the carbon atom bearing the hydroxyl group (reductive amination), amines can classically be prepared by oxidation to the corresponding carbonyl compound, subsequent formation of the imine by reaction with an amine component (primary, secondary amine or ammonia) and subsequent homogeneously or heterogeneously catalyzed reduction of the imine by means of hydrogen. However, the two-stage mode of operation with isolation of the carbonyl compound is time-consuming and costly.

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201000282

- 3 -

Special multistage processes

With retention of the oxidation state of the carbon atom bearing the hydroxyl group (direct amination) alcohols can be converted by means of multistage substitution reactions into amines.

5 Apart from the outlay for isolation of the intermediates, handling of, in particular, the explosive and toxic azides which are frequently employed here is disadvantageous in such processes.

An exception to the multistage mode of operation for the direct amination of alcohols with retention of the oxidation state of the carbon atom bearing the hydroxyl group is, for example, the sequential reaction of primary alcohols with dialkyl azodicarboxylates, bis-tert-butyl
10 iminodicarbonate and immobilized triphenylphosphane, which according to Sun et al. (Tetrahedron Lett., 2007, 48, 7745-7746), allows, after addition of trifluoroacetic acid, direct access to the primary amine without prior isolation of intermediates.

Fabiano et al. (Synlett, 1987, 1987, 190-192) use the toxic hydrazoic acids instead of bis-tert-butyl iminodicarbonate for the same purpose.

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Direct liquid-phase amination of alcohols

The direct single-stage liquid-phase amination of optionally polyhydric primary alcohols by means of ammonia has been described for some time in the scientific and patent literature. In some
20 cases, the processes described cannot be classified unambiguously as gas- or liquid-phase processes because of the process conditions employed.

According to DE 19507007, ethanolamine can be aminated over oxide-supported ruthenium catalysts at temperatures of about 170°C and a pressure of 200 bar to form ethylenediamine, with the achievable yields remaining below 40%.

25 The preparation of monovalent, optionally functionalized primary amines in high yields from the corresponding monohydric, optionally functionalized primary alcohols is described in the studies of Milstein et al. (Angew. Chem. Int. Ed., 2008, 47, 8661-8664). Here, the direct single-stage amination of sometimes heteroatom-substituted primary aliphatic and benzylic alcohols by reaction with excess ammonia in a solvent at 7.5 bar and a reaction temperature of 135-180°C
30 for from 12 to 36 hours is described. The air-stable acridinyl-based pincer complex carbonylchlorohydrido[4,5-(di-i-propylphosphinomethylacridino) ruthenium(II)] is used as catalyst, and yields in the range from 78 to 96% are achieved.

In addition, WO 2010018570 describes the use of quinolinylnyl-based pincer ligands with

201000282

- 4 -

comparable yields.

A disadvantage of both published processes is that exclusively primary alcohols can be converted into amines thereby; this also corresponds to expectations, since it has frequently been stated that catalysts suitable for primary alcohols are not suitable for secondary alcohols. For example, Beller, M. et al., *ChemSusChem*, 2009, 2, 551-557, state that the catalyst mentioned there selectively converts the more reactive OH groups of a diol (primary OH group before secondary OH group; frequently secondary OH group before sterically hindered secondary OH group). Furthermore, Baiker et al. (*J. Mol. Catal. A: Chem.*, 1999, 149, 197-204), show that the amination behaviour of primary diols is sensitive to the substitution pattern of the other carbon atoms present in the substrate, which again makes it obvious that the completely different environment of a secondary alcohol compared to a primary alcohol makes the use of a catalyst which works for primary alcohols unpromising.

A decrease in the selectivity of the formation of primary amines with increasing chain length of the alcohol substrate is known in the literature for functionalized secondary alcohols. Thus, Imm et al. (S. Imm, S. Bähn, L. Neubert, H. Neumann, M. Beller, *Angew. Chem.* 2010, 122(44), 8303-6) describe a considerable decrease in the selectivity to the primary amine from 76 to 58%, when 4-phenyl-2-butanol instead of 3-phenyl-2-propanol is aminated in the presence of homogeneous Ru catalysts. In an analogous way, a significantly lower amine yield (51.2%) can be observed for 2-nonanol in the amination of aliphatic secondary alcohols than in the case of the lower homologue 2-octanol (67.1%) (D. Pinggen, C. Müller, D. Vogt, *Angew. Chem.* 2010, 122(44), 8307-10). It can therefore be assumed that higher and optionally additionally functionalized alcohols cannot be converted in high yields into the corresponding amines in this way.

The direct single-stage liquid-phase amination of functional, polyhydric alcohols by means of ammonia has been described exclusively over heterogeneous catalysts. The ether diol diethylene glycol was aminated in DE 3903367 by means of liquid ammonia over various zirconium dioxide-supported Cu-Co-Ni-catalysts at 200°C in a 30 bar hydrogen atmosphere. However, in no case was the ether diamine isolated as reaction product; merely aminoethoxyethanol and morpholine were obtained.

According to DE 1570542, polyether diols such as polypropylene glycol can be directly converted in high yields of up to 95.8% into the corresponding diamines when the reaction is carried out at

201000282

- 5 -

240°C in the presence of Raney nickel catalysts. However, this mode of operation is also unsuitable for the conversion of thermolabile substrates, for example substrates derived from carbohydrates.

According to US 4153581, polyether amines can be successfully prepared using a Co-Cu-Zn catalyst even at 140°C, but the catalyst is not suitable for secondary alcohols.

In related heterogeneously catalyzed processes, catalysts based on Co-Cr-Mn in the presence of P₂O₅ at 140-230°C and 200-300 bar hydrogen pressure (DE 1543377), based on Ni/Al₂O₃ at 200-230°C and 15-20 bar hydrogen pressure (RO 63243) or based on calcium silicoaluminates at 10 260-300°C and 200 bar hydrogen pressure (DE 1278432) are also described.

Under comparable conditions, alcohols are aminated by the processes described in DE 19859776 (180-230°C over Cu-CuO/TiO₂), DE 102006061045 (180-250°C over Ni-Cu/ZrO₂), DE 102006061042 (180-220°C over Ni-Cu-Ru/ZrO₂), WO 2008072428 (180-250°C over Ru/ZrO₂) and WO2007077903 (180-250°C over Ru/Al₂O₃); however, a hydrogen atmosphere is 15 additionally required here.

The abovementioned examples indicate by way of example the need for processes which achieve activation of the alcohol even without the stoichiometric use of difficult-to-obtain and toxic auxiliaries. In addition, a critical disadvantage of all processes used hitherto for direct liquid- 20 phase amination is that time-consuming and costly additional working steps have to be carried out for the formation and the optionally required isolation and purification of the intermediates occurring in the synthetic sequence.

Amino derivatives of anhydrohexitols such as isosorbide, isomannide or isoidide in particular, have hitherto been described in the literature as only obtainable by means of complicated processes. 25 Thus, WO2008/145921 describes the formation of bisaminoalkyl derivatives of isosorbide which are obtained from the latter by addition onto acrylonitrile and subsequent hydrogenation. Apart from the high temperatures frequently necessary in the above-described processes, a further disadvantage of the processes mentioned is that they have to be carried out in the presence of high hydrogen partial pressures in order to be able to obtain the target products in 30 the desired yields.

The indicated prior art does not disclose any process which allows the direct, single-stage, hydrogen-free liquid-phase amination of optionally polyhydric secondary and optionally functionalized alcohols by means of ammonia to form primary amines in high yields under mild

201000282

- 6 -

reaction conditions.

It was therefore an object of the present invention to provide a process for preparing primary amines from secondary alcohols, which avoids at least one of the abovementioned
5 disadvantages and can be carried out economically advantageously.

Description of the invention

We have now surprisingly found a process which allows the direct amination of secondary alcohols
10 by means of ammonia in high yields in the presence of a catalyst as described in Claim 1, with the secondary hydroxyl group of the alcohol being aminated.

The present invention therefore provides a process which allows the direct, homogeneously catalyzed liquid-phase amination of optionally polyhydric and/or functionalized, secondary alcohols using a superstoichiometric amount of ammonia based on hydroxyl groups to be aminated,
15 preferably in the absence of hydrogen, where the process conditions employed allow in particular also the reaction of thermolabile alcohols, for example alcohols obtained from renewable raw materials.

An advantage of the process of the invention is that the isolation and purification of intermediates
20 which is otherwise necessary in the reaction is avoided.

Another advantage is that the use of problematical auxiliaries such as azides can be avoided. A further advantage is that the formation of coproducts is avoided by the process of the invention. It is also advantageous that the alcohol is reacted in the dissolved state.

Another advantage is that the amination of the alcohol can be effected without isolation and/or
25 purification of intermediates.

The process of the invention for preparing primary amines comprises the steps

- A) provision of a solution of a secondary alcohol in a fluid, nongaseous phase,
- 30 B) contacting of the phase with free ammonia and/or at least one ammonia-releasing compound and a homogeneous catalyst and optionally
- C) isolation of the primary amine formed in process step B),

and is characterized in that

201000282

- 7 -

the volume ratio of the volume of the liquid phase to the volume of the gas phase ($V_{\text{liq}}/V_{\text{gas}}$) in process step B) is greater than or equal to 0.25, preferably greater than 0.3, in particular greater than 2, and/or

the ammonia is used in process step B) in a molar ratio based on the hydroxyl groups in the secondary alcohol of at least 5:1, preferably 50:1, particularly preferably 500:1.

In the context of the present invention the term "primary amine" likewise refers to salts thereof and also mixtures of the amine and/or its salts.

In the context of the present invention the term "secondary alcohol" refers to an organic compound which has at least one secondary hydroxy group ($R\text{-CH(OH)-R}'$ where R and R' are not H). To calculate the volume ratio, the "gas phase" is considered to be the internal volume of the apparatus surrounding the reaction minus the volume of the liquid phase.

Possible homogeneous catalysts to be used in the process of the invention are all homogeneous catalysts known to those skilled in the art which are able to activate the CH bond of the carbon atom bearing the OH group to be aminated. Examples of such catalysts encompass alkali metal alkoxides, aluminium alkoxides and lanthanide alkoxides, inorganic compounds of noble metals (e.g. $[\text{RuCl}_3 \cdot n\text{H}_2\text{O}]$, IrCl_3), monometallic or multimetallic, mononuclear or multinuclear coordination compounds of one or more noble metals selected from among the elements ruthenium (e.g. $[\text{RuCl}_2(\text{PPh}_3)_3]$, $[\text{RuH}_2(\text{PPh}_3)_4]$, the Shvo catalyst ($[(\eta^4\text{-C}_4\text{Ph}_4\text{CO})\text{Ru}(\text{CO})_3]_2$), $[\text{Ru}(\text{cod})(\text{cot})]$, $[(\text{PPh}_3)_2\text{Ru}(\text{CH}_3\text{CN})_3\text{Cl}]\text{BPh}_4$, $[\text{Ru}(\text{p-cymene})\text{Cl}_2]_2$, $[\text{Ru}(\text{p-cymene})\text{Cl}_2]_2/\text{DPEphos}$, $[\text{Ru}(\text{PPh}_3)_3(\text{CO})\text{H}_2]$, $[\text{Ru}_3(\text{CO})_{12}]$, $[\text{Ru}_3(\text{CO})_{12}]/\text{N-phenyl-2-(PCl}_2\text{)pyrrole}$, $[\text{RuCl}_2(\text{dmsO})_4]$), rhodium (e.g. the Wilkinson catalyst ($[\text{RhCl}(\text{PPh}_3)_3]$), $[\text{RhH}(\text{PPh}_3)_3]$), iridium (e.g. $[\text{IrCl}_3(\text{dmsO})_3]$, $[\text{Cp}^*\text{IrCl}_2]_2$, $[\text{Ir}(\text{cod})\text{Cl}]_2/(\text{dppp})/\text{Cs}_2\text{CO}_3$, $[\text{IrCl}_2\text{H}(\text{cod})]_2$, KOH-activated phenanthroline-iridium complexes) and palladium ($[\text{Pd}(\text{PPh}_3)_4]$, $[\text{PdCl}_2(\text{dppe})]$, $[\text{Pd}(\text{OAc})_2]$) and also of the other platinum metals and iron.

In a further preferred embodiment of the process of the invention, catalysts which are known to those skilled in the art as catalysts for hydroformylation are used in step B). For this purpose, it is possible to use transition metal-carbonyl compounds of the general formula $\text{H}_x\text{M}_y\text{M}'_z(\text{CO})_z\text{L}_n$, where $n=0$ ("unmodified hydroformylation catalysts") or $n \neq 0$ ("modified hydroformylation catalysts") and x, y and z are integers. y' can be zero when a monometallic catalyst is used, or y' can be a positive integer when a bimetallic catalyst is used. M and M' can be identical or different. As transition metals M and M', it is possible to use rhodium, cobalt, iridium, ruthenium, osmium, platinum, palladium, iron, nickel, chromium, molybdenum or manganese; preference is given to using

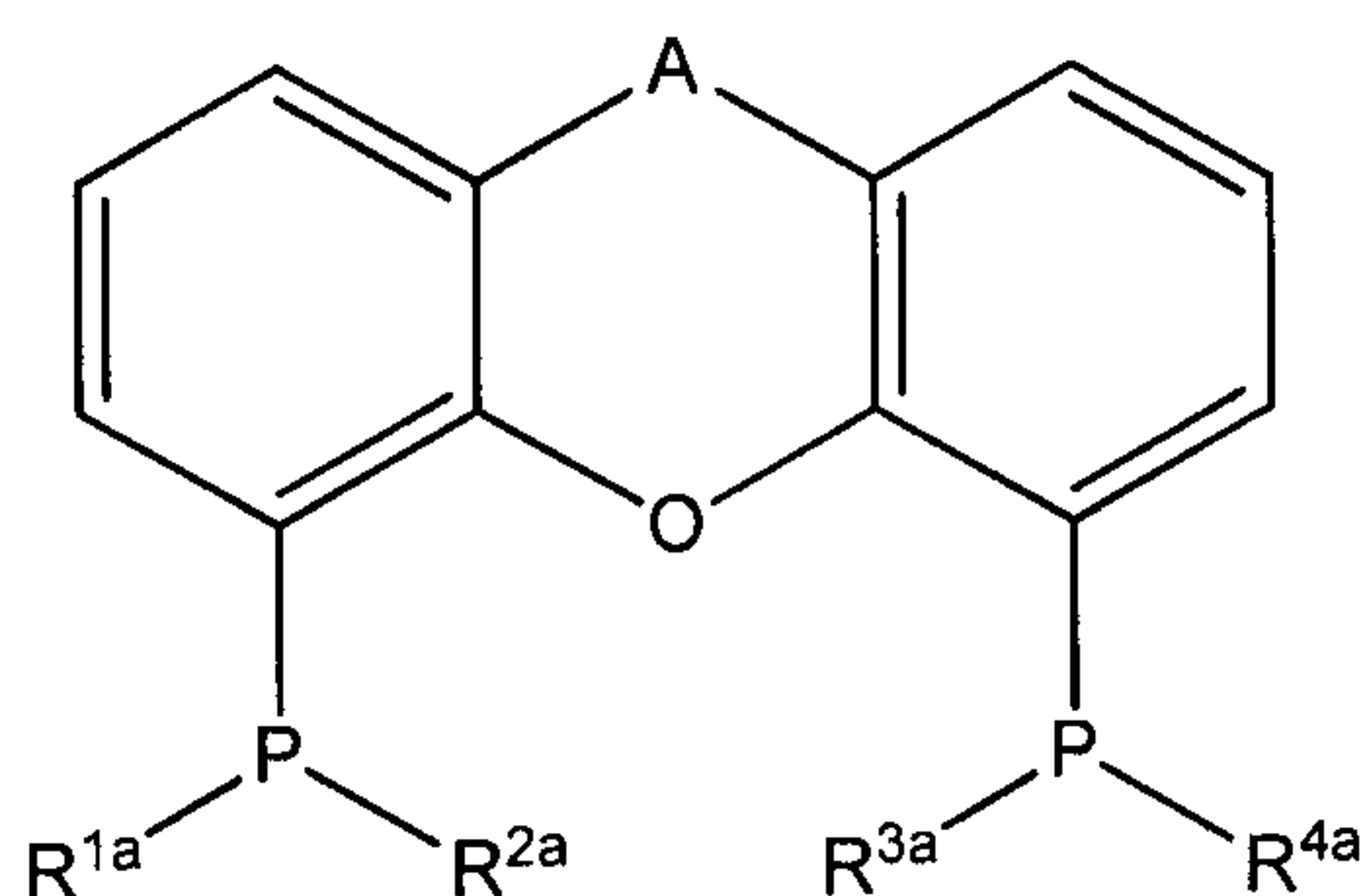
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- 8 -

rhodium, cobalt, iridium, ruthenium, osmium or platinum. The ligand L can be selected from the group consisting of phosphanes, phosphane oxides, phosphites, amines, amides, isonitriles, arsanes or stibanes; examples are triphenylphosphane, triphenylphosphane oxide, triphenylphosphanetrissulphonic acid sodium salt, triphenylamine or triphenylarsane. Examples of hydroformylation catalysts are selected from the group consisting of $\text{HCo}(\text{CO})_4$, $\text{HCo}(\text{CO})_3\text{PBU}_3$, $\text{HRh}(\text{CO})(\text{PR}_3)_3$, $\text{Rh}_4(\text{CO})_{12}$, $\text{Rh}_6(\text{CO})_{16}$, $\text{Rh}_2(\text{CO})_4\text{Cl}_2$, $\text{CoRh}(\text{CO})_7$, $\text{Co}_2\text{Rh}_2(\text{CO})_{12}$, $\text{HRh}(\text{CO})_3$.

A hydroformylation catalyst which is preferred in this context is a catalyst system containing at least one xantphos ligand of the general formula 1 and a transition metal compound.

In the context of the present invention, the term "xantphos ligand" refers to a compound of the general formula 1,



General formula 1

where

R^{1a}, R^{2a}, R^{3a} and R^{4a} are identical or different and are selected independently from the group containing, preferably consisting of, phenyl, tert-butyl and isopropyl, and A is selected from the group containing, preferably consisting of, $-\text{C}(\text{CH}_3)_2-$, $-\text{CH}_2\text{CH}_2-$, $-\text{Si}(\text{CH}_3)_2-$, $-\text{S}-$, $-\text{O}-$, $-\text{C}(\text{C}(\text{CH}_3)_2)-$.

Preference is given to using xantphos ligands in which $\text{R}^{1a} = \text{R}^{2a} = \text{R}^{3a} = \text{R}^{4a} = \text{phenyl}$ and $\text{A} = -\text{C}(\text{CH}_3)_2-$.

The transition metal is preferably selected from the group containing, preferably consisting of, ruthenium, cobalt, rhodium, iridium, nickel, palladium and platinum and also the other platinum metals and iron. The transition metal is particularly preferably selected from the group consisting of ruthenium, iridium and palladium; particularly preferably from the group consisting of ruthenium and iridium, in particular ruthenium.

It may be mentioned that, depending on the selected combination of the above-described elements forming the catalyst, this can have an electric charge and be used in the form of a salt formed with

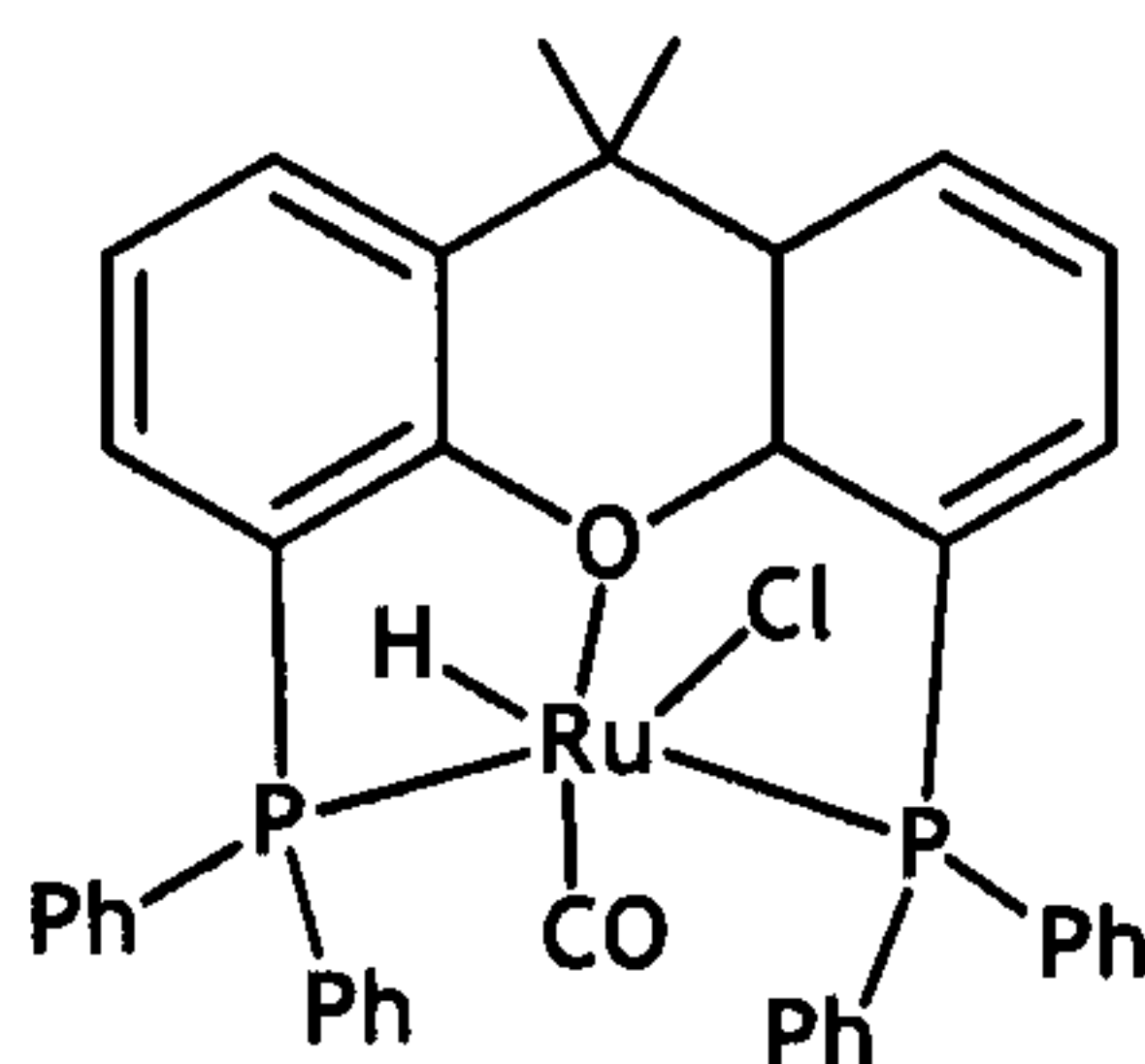
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- 9 -

the aid of suitable counterions.

In a particularly preferred embodiment, the catalyst is the xanthene-based coordination compound carbonylchlorohydrido[9,9-dimethyl-4,5-bis(diphenylphosphino)xantheno]ruthenium(II):

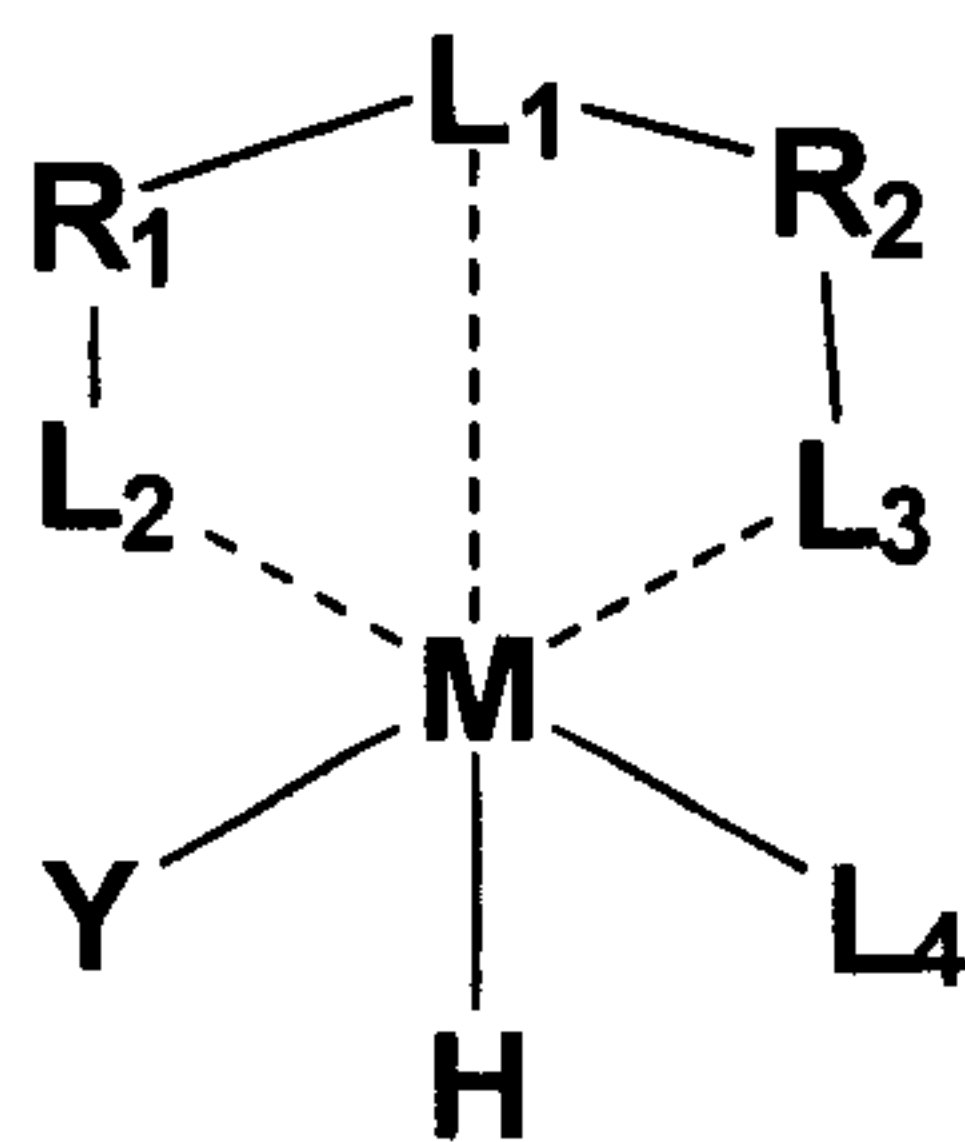
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Carbonylchlorohydrido[9,9-dimethyl-4,5-bis(diphenylphosphino)xantheno]ruthenium(II)

10 In a further preferred embodiment of the process of the invention, pincer catalysts are used in step B).

As pincer catalysts used in process step B), it is possible to use coordination compounds of transition metals having the general structure A)



15

General structure A)

Here, in particular catalysts in which L_1 is a carbon atom or heteroatom, preferably nitrogen, serving as ligator for the central atom M , where M is a transition metal, to which further ligators L_2 and L_3 are covalently bound via the two divalent organic radicals R_1 and R_2 , are advantageous for the process of the invention.

The central metal M is preferably selected from the group containing ruthenium, cobalt, rhodium,

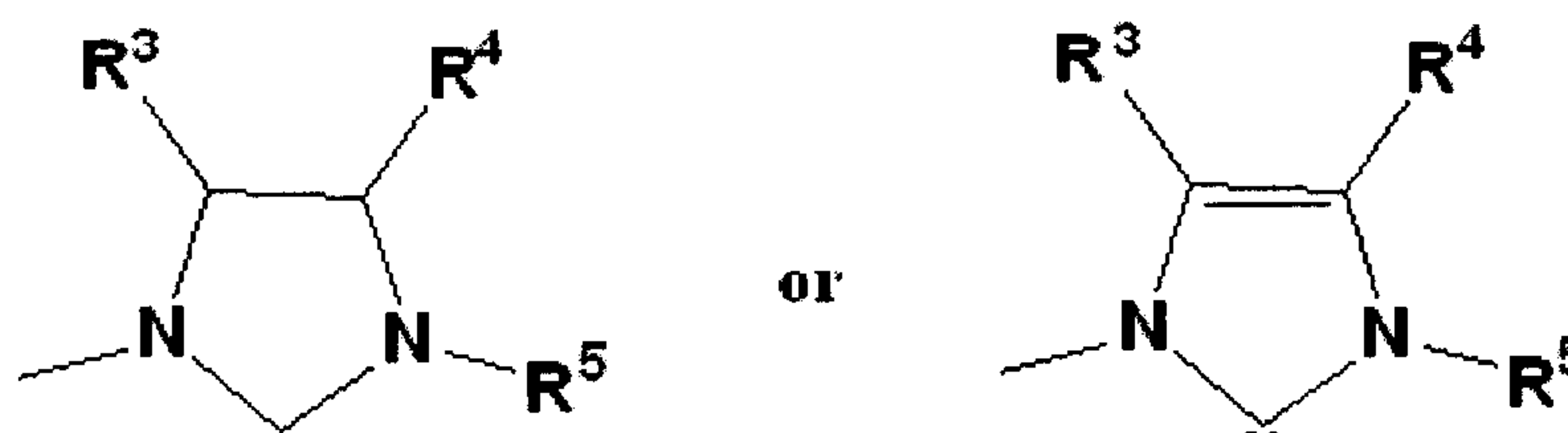
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- 10 -

iridium, nickel, palladium and platinum. The central metal is particularly preferably selected from the group consisting of ruthenium, iridium and palladium; particularly preferably from the group consisting of ruthenium and iridium.

- 5 The divalent organic radicals R_1 and R_2 can, independently of one another, optionally contain further substituted aliphatic, alicyclic or aromatic structures which, together with the ligator L_1 , optionally give a molecular unit whose configuration and conformation are fixed. The ligator L_1 is preferably part of a heterocyclic structure to which the radicals R_1 and R_2 are bound. L_1 is particularly preferably the nitrogen atom of an acridinyl or quinolinyl structure. This acridinyl or quinolinyl structure can bear one, two, three, four, five, six or seven substituents in any position, which together with the organic radicals R_1 and/or R_2 form a further aromatic unit fused onto the acridinyl or quinolinyl structure and can be selected from the group consisting of hydrogen, alkyl, cycloalkyl, aryl, heterocyclyl, heteroaryl, alkylcycloalkyl, alkylaryl, alkylheterocyclyl, alkylheteroaryl, halogen, nitro, ester, amide, cyano, alkoxy, alkylamino and arylamino radicals. In a preferred
10
15 embodiment, R_1 , R_2 and L_1 are constituents of a 4,5-dimethyleneacridine radical.

- The ligators L_2 and L_3 covalently bound to the above-described unit formed by R_1 , R_2 and L_1 are each further heteroatoms present in molecular radicals selected independently from the group comprising phosphine (PR^aR^b), amine (NR^aR^b), imine, sulphide (SR^a), thiol (SH), sulphoxide
20 ($S(=O)R^a$), heteroaryl containing at least one atom selected from among nitrogen or sulphur, arsine (AsR^aR^b), stibine (SbR^aR^b) and N-heterocyclic carbene represented by the structures



- 25 The ligator L_4 coordinated to the central metal described is a heteroatom present in a monodentate two-electron donor selected from the group CO, $PR^aR^bR^c$, NO^+ , $AsR^aR^bR^c$, $SbR^aR^bR^c$, SR^aR^b , nitrile (R^aCN), isonitrile (R^aNC), N_2 , PF_3 , CS, heteroaryl (e.g. pyridine, thiophene), tetrahydrothiophene or N-heterocyclic carbene.

- Y is a monoanionic ligand selected from the group halogen, carboxylate, trifluoroacetate,
30 sulphonate, trifluoromethanesulphonate, cyanide, hydroxide, alkoxide, imide; or else an uncharged

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- 11 -

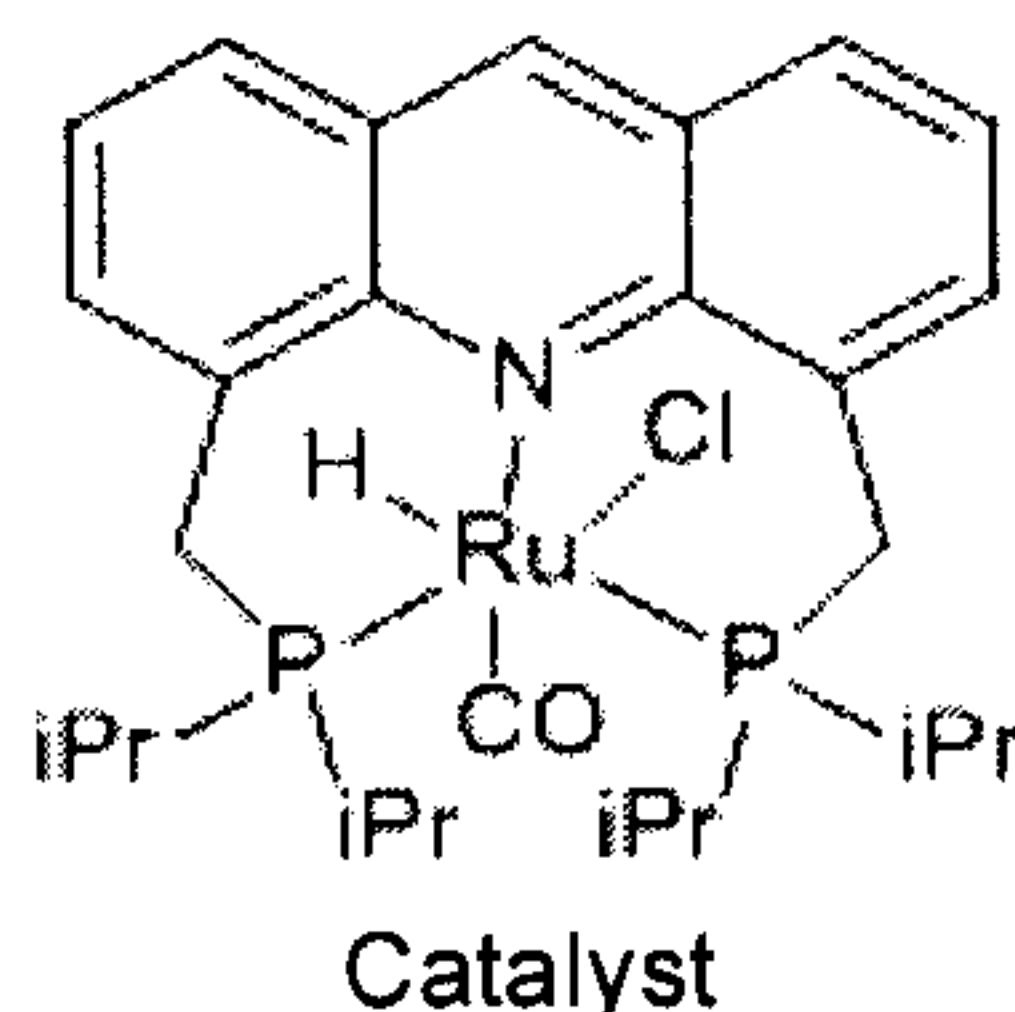
solvate molecule such as NH_3 , $\text{NR}^a\text{R}^b\text{R}^c$, $\text{R}^a\text{R}^b\text{NSO}_2\text{R}^c$. Y is preferably selected from the group halide, acetone, dialkylacetone (e.g. 2-butanone), cyclic ketone (e.g. cyclohexanone), THF, anisole, DMSO, acetonitrile, dichloromethane, toluene, water, pyridine.

- 5 The radicals R^3 , R^4 , R^5 , R^a , R^b and R^c are identical or different and are selected independently from the group alkyl, cycloalkyl, aryl, heterocyclyl, heteroaryl, alkylcycloalkyl, alkylaryl, alkylheterocyclyl and alkylheteroalkyl. The radicals R^3 , R^4 , R^5 , R^a , R^b and R^c are preferably each selected independently from among methyl, ethyl, isopropyl, ¹butyl, cyclohexyl, cyclopentyl, phenyl and mesityl.

10

It may be mentioned that, depending on the selected combination of the above-described elements forming the catalyst, this can have an electric charge and be used in the form of a salt formed with the aid of suitable counterions.

- 15 In a particularly preferred embodiment, the catalyst is the acridine-based coordination compound carbonylchlorohydrido[4,5-(di-*i*-propylphosphino)methylacridino]ruthenium(II):



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Carbonylchlorohydrido[4,5-(di-*i*-propylphosphino)methylacridino]ruthenium(II)]

- The process of the invention can be utilized for the direct amination of secondary alcohols by means of ammonia to form primary amines. Alcohols which are preferably used in process step A) have at least two secondary hydroxy groups. These polyols are preferably characterized in that they can be vaporized only unsatisfactorily without decomposition, if at all, and are therefore not suitable for a gas-phase reaction; in particular these alcohols have a cyclic, preferably polycyclic, carbon skeleton. Such alcohols are, for example, carbohydrates, sugars, sugar alcohols or the derivatives which can be derived therefrom by means of chemical reactions (e.g. dehydrations), for example amino sugars, desoxy sugars, glycols, glycitols, and C- or O-glycosides.
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- 12 -

Alcohols which are particularly preferably used in process step A) are selected from the group consisting of 2-dodecanol, cyclododecanol, 4-phenyl-2-butanol, isosorbide, isomannide, isoidite, polypropylene glycol, mannitol, sorbitol, galactitol and alkyl glycosides, with particular preference being given to using isomannide, 2-dodecanol, cyclododecanol and 4-phenyl-2-butanol.

- 5 Figure 1 shows the range of intermediates and products resulting from the process of the invention when starting out from the three isomers of 1,4:3,6-dianhydrohexitol, which represents secondary alcohols which are very particularly preferably used in the process of the invention.

The process of the invention can likewise be used advantageously for secondary alcohols which
10 have a carboxy group or ester group, in particular a carboxy group.

Preferred secondary alcohols containing carboxy groups are, in particular, alpha-hydroxycarboxylic acids and OH-modified, natural fatty acids, where the OH-modified, natural fatty acids are selected, in particular, from the group derived from the fractions of coconut oil, kernel oils and castor oil. Examples of such alcohols bearing a carboxy group are 2-hydroxypropionic acid (lactic acid),
15 2-hydroxy-3-methylbutanoic acid, 2-hydroxy-4-methylmercaptobutanoic acid, 2-hydroxy-4-methylpentanoic acid, 2-hydroxy-3-methylpentanoic acid, 2-hydroxy-3-(3-indyl)propionic acid, 2-hydroxy-3-phenylpropionic acid, 2-hydroxy-6-aminohexanoic acid, 2-hydroxy-5-guanidinopentanoic acid, 2-hydroxy-3-(1H-imidazol-4-yl)propanoic acid, 2-hydroxy-3-(4-hydroxyphenyl)propanoic acid, 2-hydroxy-4-aminocarbonylbutanoic acid, 2,3-dihydroxybutanoic
20 acid, 2-hydroxypentanedioic acid, glycolic acid, 2,3-dihydroxypropanoic acid, 2-hydroxy-3-mercaptopropanoic acid, 2-hydroxy-3-aminocarbonylpropanoic acid and 2-hydroxysuccinic acid. Preferred secondary alcohols containing ester groups are, in particular, selected from the group of alkyl esters, in particular the methyl esters, ethyl esters, n-propyl esters and isopropyl esters, of the hydroxycarboxylic acids.

25

In particular, the alcohols are selected from the group of the esters of OH-modified natural fatty acids and the esters of alpha-hydroxycarboxylic acids. Examples of this class of compounds are the methyl esters, ethyl esters, n-propyl esters and isopropyl esters of 2-hydroxypropionic acid (lactic acid), 2-hydroxy-3-methylbutanoic acid, 2-hydroxy-4-methylmercaptobutanoic acid, 2-hydroxy-4-methylpentanoic acid, 2-hydroxy-3-methylpentanoic acid, 2-hydroxy-3-(3-indyl)propionic acid,
30 2-hydroxy-3-phenylpropionic acid, 2-hydroxy-6-aminohexanoic acid, 2-hydroxy-5-guanidinopentanoic acid, 2-hydroxy-3-(1H-imidazol-4-yl)propanoic acid, 2-hydroxy-3-(4-hydroxyphenyl)propanoic acid, 2-hydroxy-4-aminocarbonylbutanoic acid, 2,3-dihydroxybutanoic acid, 2-hydroxypentanedioic acid, glycolic acid, 2,3-dihydroxypropanoic acid, 2-hydroxy-3-

201000282

- 13 -

mercaptopropanoic acid, 2-hydroxy-3-aminocarbonylpropanoic acid and 2-hydroxysuccinic acid.

Illustrative alcohol concentrations used in the process of the invention are in the range from 0.1 to 10 000 mmol/l, preferably from 0.1 to 1000 mmol/l and particularly preferably from 1 to 100 mmol/l.

5

The fluid phase used in process step A) can be formed by a solvent or a gas which is present in liquefied or supercritical form under the process conditions, in particular ammonia, or mixtures of the components mentioned.

10 In this context, water or organic solvents or mixtures thereof can be used as solvent; these mixtures can be a homogeneous solution or else an emulsion. Particular preference is given to using at least one organic solvent. A nonlimiting selection of suitable organic solvents encompasses benzene, toluene, the xylene isomers, mesitylene, dioxane, THF, dimethoxyethane, anisole and cyclohexane.

15

In the context of the present invention, the ammonia or ammonia-releasing compounds used in process step B) also include, in particular, liquid or supercritical ammonia and/or a solution of ammonium salts in a solvent (e.g. ammonium hydroxide in water).

Gaseous or liquefied ammonia is preferably used as free ammonia in process step B).

20

In a preferred embodiment, process step B) is carried out under superatmospheric pressure.

Illustrative pressures in the process of the invention are in the range from 1 to 1000 bar, preferably from 5 to 500 bar, particularly preferably from 5 to 100 bar and very particularly preferably from 20 to 50 bar. The pressure can be built up by injection of the ammonia and/or a further gas, in

25 particular an inert gas such as nitrogen or argon, with the pressure preferably being built up by means of gas mixtures of the two.

The temperatures in process step B) of the process of the invention are in a range which keeps to a minimum the decomposition reactions of secondary alcohol, primary amine and all further

30 intermediates occurring during the course of the process which, owing to thermal stress, lead to the formation of by-products. For example, the temperatures are in the range from 80 to 220°C, preferably from 100 to 200°C and particularly preferably from 120 to 170°C, measured in the fluid phase.

201000282

- 14 -

According to the invention, the process is preferably carried out in the absence of hydrogen, where “absence of hydrogen” means that no hydrogen is additionally introduced into the reaction; any traces of hydrogen present in the air or the hydrogen formed from the substrate under the reaction conditions are not considered to be “in the absence of hydrogen” for the purposes of the present invention.

Brief description of the figures

Figure 1: Scheme for the direct amination of dianhydrohexitols

10 Examples

Example 1: Direct single-stage amination of isomannide by means of ammonia over heterogeneous catalysts, comparative example

1.45 g of isomannide (10 mmol) and 2.78 g of a catalyst based on Ni/Al₂O₃ are placed in a high-pressure reactor provided with propeller stirrer and internal cooling coil and flushed with nitrogen at room temperature in the closed and gastight reactor. 250 ml of liquid ammonia (10 mol) are then metered in over a period of 25 minutes and the reaction mixture is heated in stages firstly to 150°C (140 bar), then to 185°C (260 bar). After a reaction time of 90 minutes, the reactor is cooled, vented, the reaction mixture is taken up in ethanol and filtered. No conversion of isomannide can be observed when using a catalyst based on elemental nickel.

Example 2: Direct single-stage amination of isomannide by means of ammonia over coordination compounds of monodentate ligands ($V_{\text{liq}}/V_{\text{gas}} = 0.35$, example according to the invention)

Under an argon atmosphere, 1.461 g (10 mmol) of isomannide, 0.1 mmol of [Ru(p-cym)Cl₂]₂/K₂CO₃ and 25 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times and again pressurized with 15 bar of argon. 235.2 mmol of ammonia are then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.35$). The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to 140°C and maintained at this temperature for 24 hours. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr

201000282

- 15 -

and the filtrate is evaporated under reduced pressure on a rotary evaporator to remove the solvent. The formation of the corresponding monoamino alcohol was confirmed.

Example 3: Direct single-stage amination of 2-dodecanol by means of ammonia over a ruthenium-pincer complex ($V_{\text{liq}}/V_{\text{gas}} = 0.3$, according to the invention)

5 Under an argon atmosphere, 1.863 g (10 mmol) of 2-dodecanol, 0.030 g (0.05 mmol) of carbonylchlorohydrido[4,5-(di-*i*-propylphosphinomethylacridino)ruthenium(II)] as catalyst and 25 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times
10 and again pressurized with 15 bar of argon. 2 g (117.6 mmol) of liquid ammonia are then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.3$). The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal temperature of 170°C and maintained at this temperature for 48 hours. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon
15 three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr and the filtrate is evaporated under reduced pressure on a rotary evaporator to remove the solvent. The crude product obtained is purified by bulb tube distillation under reduced pressure. This gives 1.241 g of 2-dodecylamine (yield: 67% of theory; boiling range: 170-180°C air bath temperature at 11 mbar).

20

Example 4: Direct single-stage amination of cyclododecanol by means of ammonia over a ruthenium-pincer complex ($V_{\text{liq}}/V_{\text{gas}} = 0.3$, according to the invention)

Under an argon atmosphere, 1.843 g (10 mmol) of cyclododecanol, 0.030 g (0.05 mmol) of carbonylchlorohydrido[4,5-(di-*i*-propylphosphinomethylacridino)ruthenium(II)] as catalyst and
25 25 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times and again pressurized with 15 bar of argon. 2 g (117.6 mmol) of liquid ammonia are then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.3$). The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal
30 temperature of 170°C and maintained at this temperature for 48 hours. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr and the filtrate is evaporated under reduced pressure on a rotary evaporator to remove the solvent. The crude product obtained is purified by bulb tube distillation under

201000282

- 16 -

reduced pressure. This gives 1.427 g of cyclododecylamine (yield: 78% of theory; boiling range: 175-180°C air bath temperature at 6 mbar).

Example 5: Direct single-stage amination of 4-phenyl-2-butanol by means of ammonia over an

5 Ru-pincer complex ($V_{\text{liq}}/V_{\text{gas}} = 0.3$, according to the invention)

Under an argon atmosphere, 1.502 g (10 mmol) of 4-phenyl-2-butanol, 0.030 g (0.05 mmol) of carbonylchlorohydrido[4,5-(di-*i*-propylphosphinomethylacridino)ruthenium(II)] as catalyst and 25 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times
10 and again pressurized with 15 bar of argon. 2 g (117.6 mmol) of liquid ammonia are then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.3$). The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal temperature of 170°C and maintained at this temperature for 48 hours. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon
15 three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr and the filtrate is evaporated under reduced pressure on a rotary evaporator to remove the solvent. The crude product obtained is purified by bulb tube distillation under reduced pressure. This gives 0.945 g of 4-phenyl-2-butylamine (yield: 63% of theory, boiling range: 135-140°C air bath temperature at 8 mbar).

20

Example 6: Direct single-stage amination of isomannide by means of ammonia over an

Ru-pincer complex, (according to the invention, $V_{\text{liq}}/V_{\text{gas}} = 0.35$)

Under an argon atmosphere, 1.461 g (10 mmol) of isomannide, 0.061 g (0.1 mmol) of
25 carbonylchlorohydrido[4,5-(di-*i*-propylphosphinomethylacridino)ruthenium(II)] as catalyst and 25 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times and again pressurized with 15 bar of argon. 4 g (235.2 mmol) of liquid ammonia are then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.35$). The reaction mixture is stirred for
30 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal temperature of 170°C and maintained at this temperature for 48 hours. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr and the filtrate is evaporated under reduced pressure on a rotary evaporator

201000282

- 17 -

to remove the solvent. The crude product obtained is purified by bulb tube distillation under reduced pressure. This gives 1.290 g of a mixture of the diamines diaminoisomannide, diaminoisorbide and diaminoisoidide in a ratio of 50:41:9 (yield: 90% of theory, boiling range 185-190°C air bath temperature at 10 mbar).

5

Example 7: Direct single-stage amination of tripropylene glycol by means of ammonia over a homogeneous ruthenium catalyst (according to the invention; $V_{\text{liq}}/V_{\text{gas}} = 0.3$)

Under an argon atmosphere, 0.961 g (5 mmol) of tripropylene glycol, 0.0305 g (0.05 mmol) of carbonylchlorohydrido[4,5-(di-i-propylphosphinomethylacridino)ruthenium(II)] as catalyst and
10 25 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times and again pressurized with 15 bar of argon. 2 g (2.95 ml; 117 mmol) of liquid ammonia are then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.3$). The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal
15 temperature of 170°C and maintained at this temperature for 48 hours, resulting in a pressure of 45 bar being established. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr and the filtrate is evaporated under reduced pressure on a rotary evaporator to remove the solvent. The crude
20 product obtained is purified by bulb tube distillation under reduced pressure. This gives the diamine of tripropylene glycol in a yield of 91% of theory, boiling range 90-95°C air bath temperature at 10 mbar.

Example 8: Direct single-stage amination of tripropylene glycol over a homogeneous ruthenium
25 catalyst (not according to the invention; $V_{\text{liq}}/V_{\text{gas}} = 0.17$)

Under an argon atmosphere, 0.4805 g (2.5 mmol) of tripropylene glycol, 0.01525 g (0.025 mmol) of carbonylchlorohydrido[4,5-(di-i-propylphosphinomethylacridino)ruthenium(II)] as catalyst and 12.5 ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 100
30 ml Hastelloy autoclave. The autoclave is closed, pressurized with 20 bar of argon and vented three times and again pressurized with 15 bar of argon. 1 g (1.475 ml; 58.8 mmol) of liquid ammonia is then introduced into the autoclave (overall $V_{\text{liq}}/V_{\text{gas}} = 0.17$). The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal temperature of 170°C and maintained at this temperature for 48 hours, resulting in a

201000282

- 18 -

pressure of 45 bar being established. After cooling to room temperature, careful depressurization of the mixture and pressurization with 20 bar of argon three times with subsequent venting, the autoclave is opened, the reaction mixture filtered through kieselguhr and the filtrate is evaporated under reduced pressure on a rotary evaporator to remove the solvent. The crude product obtained is purified by bulb tube distillation under reduced pressure. The diamine of tripropylene glycol is obtained in a yield of 90% of theory.

Example 9: Direct single-stage amination of 2-octanol by means of ammonia over a homogeneous ruthenium catalyst (variation of pressure and V_{liq}/V_{gas})

10

Under an argon atmosphere, m_O g of 2-octanol, m_{Ru} g of [carbonylchlorohydridotris(triphenylphosphane)ruthenium(II)] as catalyst, m_P g of xantphos and V_{LM} ml of 2-methyl-2-butanol as solvent are placed in the glass liner of a 314 ml Hastelloy autoclave. The autoclave is closed, pressurized with 5 bar of nitrogen, vented and cooled to -70°C . m_A g of liquid ammonia are then condensed into the autoclave, the reactor is warmed again to room temperature and pressurized with p bar of nitrogen. The reaction mixture is stirred for 10 minutes at room temperature (600 rpm), subsequently heated while stirring to an internal temperature of 170°C and maintained at this temperature for 48 hours. After cooling to room temperature, careful depressurization of the mixture and pressurization with 5 bar of nitrogen with subsequent depressurization, the autoclave is opened and the reaction mixture is analyzed by means of a gas chromatograph. Reaction parameters and also conversions and selectivities to the desired primary amine 2-octylamine are reported in Tab. 1. The results show that the selectivity to the target product can be increased both by increasing the V_{liq}/V_{gas} ratio and also by increasing the pressure and by simultaneously increasing both parameters.

25

Table 1

No.	m_O [g] ¹	m_{Ru} [g] ²	m_P [g] ³	V_S [ml] ⁴	m_A [g] ⁵	p [bar] ⁶	V_{liq}/V_{gas} [-] ⁷	C [%] ⁸	S [%] ⁹
8.1	3.2	0.7	0.42	24.6	9.8	0	0.14	100	74.6
8.2	3.2	0.7	0.42	24.6	9.8	40	0.14	100	92
8.3	16.3	3.57	2.18	125.2	37.5	0	1.68	65	89
8.4	16.3	3.57	2.18	125.2	37.5	40	1.68	75	83.7

1: mass of 2-octanol; 2: mass of [carbonylchlorohydridotris(triphenylphosphane)ruthenium(II)]; 3: mass of xantphos; 4: volume of solvent; 5: mass of ammonia; 6: nitrogen pressure set before reaction; 7: ratio of

201000282

- 19 -

the liquid phase volume to the gas phase volume; 8: conversion of 2-octanol; 9: selectivity to 2-octylamine.

201000282

- 20 -

Claims

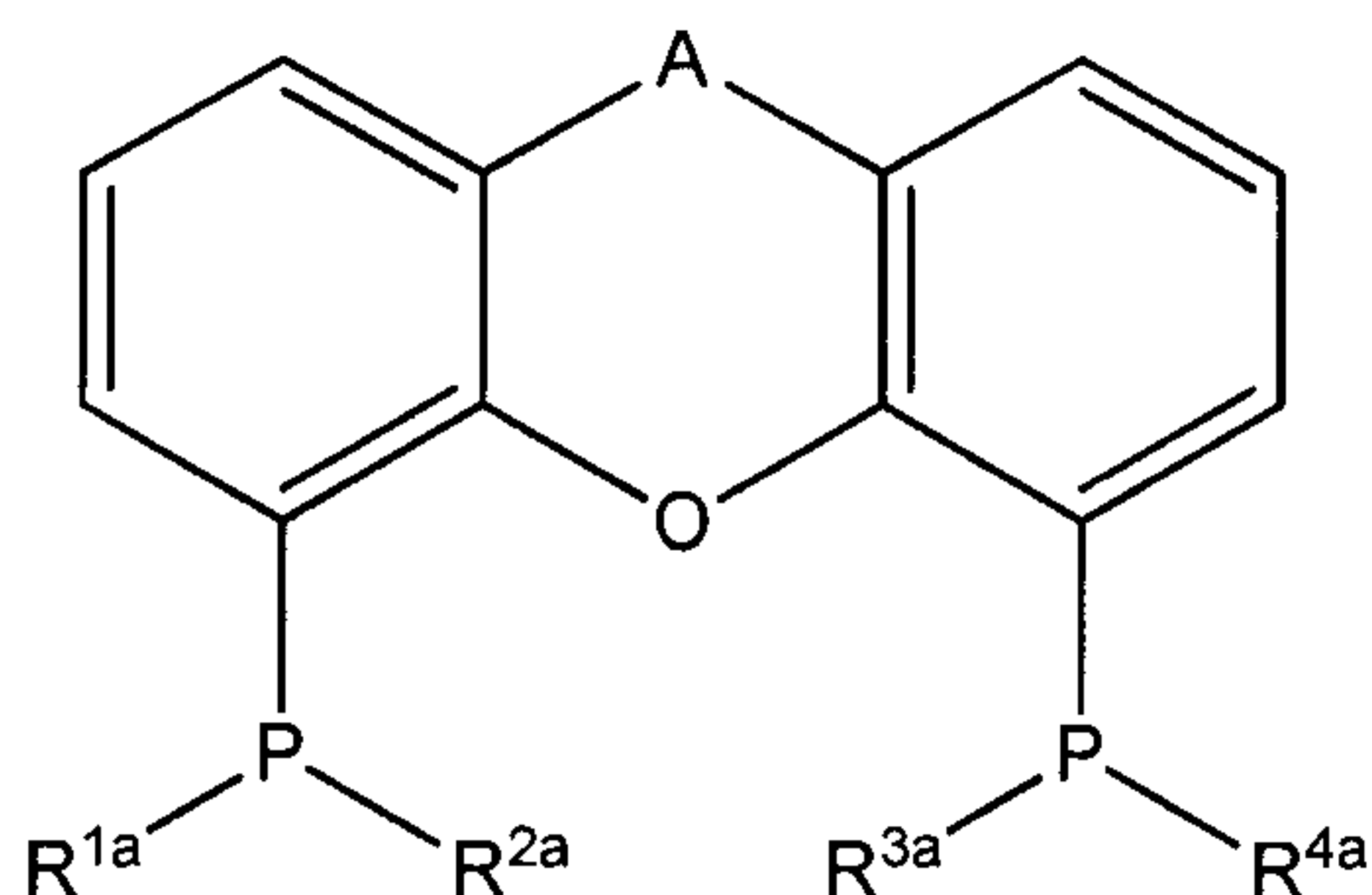
1. Process for preparing primary amines which comprises the process steps
 - A) provision of a solution of a secondary alcohol in a fluid, nongaseous phase,
 - 5 B) contacting of the phase with free ammonia and/or at least one ammonia-releasing compound and a homogeneous catalyst and optionally
 - C) isolation of the primary amine formed in process step B),characterized in that the volume ratio of the volume of the liquid phase to the volume of
10 the gas phase in process step B is greater than or equal to 0.25, and/or the ammonia is used in process step B) in a molar ratio based on the hydroxyl groups in the secondary alcohol of at least 5:1.
2. Process according to Claim 1, characterized in that at least one catalyst selected from
15 among alkali metal alkoxides, aluminium alkoxides and lanthanide alkoxides, inorganic compounds of noble metals and monometallic or multimetallic, mononuclear or multinuclear coordination compounds of one or more noble metals selected from among the elements ruthenium, iridium, rhodium, osmium,
20 palladium, platinum and iron is used as homogeneous catalyst.
3. Process according to Claim 1 or 2, characterized in that
25 the alcohol used in process step A) has at least two secondary hydroxy groups.
4. Process according to at least one of the preceding claims, characterized in that
the alcohol used in process step A) has a cyclic or polycyclic carbon skeleton.
30
5. Process according to at least one of the preceding claims, characterized in that
the alcohol used in process step A) is selected from the group consisting of:

201000282

- 21 -

2-dodecanol, cyclododecanol, 4-phenyl-2-butanol, isosorbide, isomannide, isoidite, polypropylene glycol, mannitol, sorbitol, galactitol and alkyl glycosides.

6. Process according to at least one of the preceding claims,
5 characterized in that
the alcohol used in process step A) is selected from among alpha-hydroxycarboxylic acids and OH-modified, natural fatty acids.
7. Process according to at least one of the preceding claims,
10 characterized in that
liquid or supercritical ammonia and/or a solution of ammonium salts in a solvent is used in process step B).
8. Process according to at least one of the preceding claims,
15 characterized in that
process step B) is carried out under superatmospheric pressure.
9. Process according to at least one of the preceding claims,
characterized in that
20 process step B) is carried out in a temperature range from 80 to 220°C.
10. Process according to at least one of the preceding claims,
characterized in that
a hydroformylation catalyst, in particular a catalyst system containing at least one
25 xantphos ligand of the general formula 1 and a transition metal compound



general formula 1

201000282

- 22 -

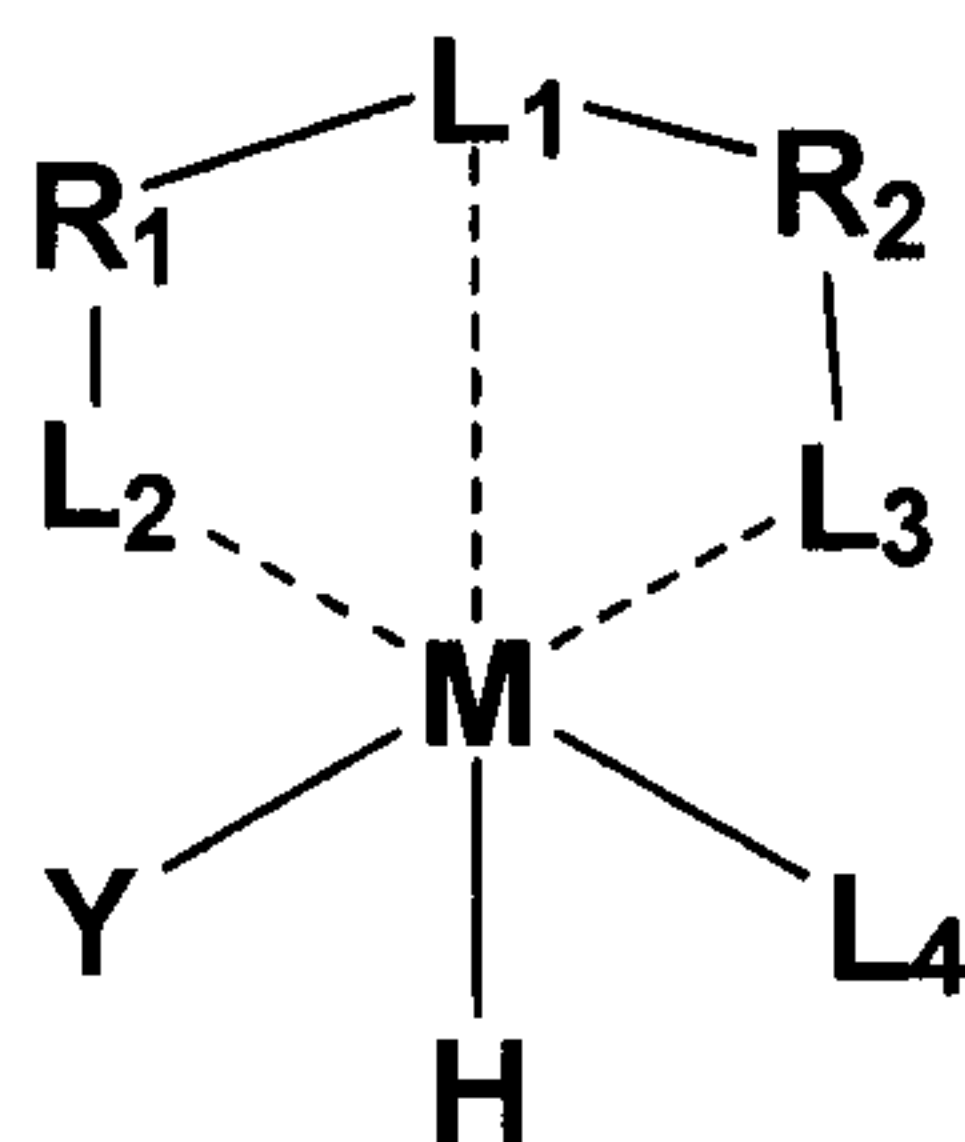
where R^{1a} , R^{2a} , R^{3a} and R^{4a} are identical or different and are selected independently from the group containing phenyl, tert-butyl, isopropyl, and A is selected from the group containing $-C(CH_3)_2-$, $-CH_2CH_2-$, $-Si(CH_3)_2-$, $-S-$, $-O-$, $-C(C(CH_3)_2)-$, is used as homogeneous catalyst.

5

11. Process according to at least one of Claims 1 to 9, characterized in that at least one pincer catalyst is used as homogeneous catalyst.

10

12. Process according to Claim 11, characterized in that at least one coordination compound of transition metals having the general structure A)



15

general structure A)

where

M is a transition metal,

20

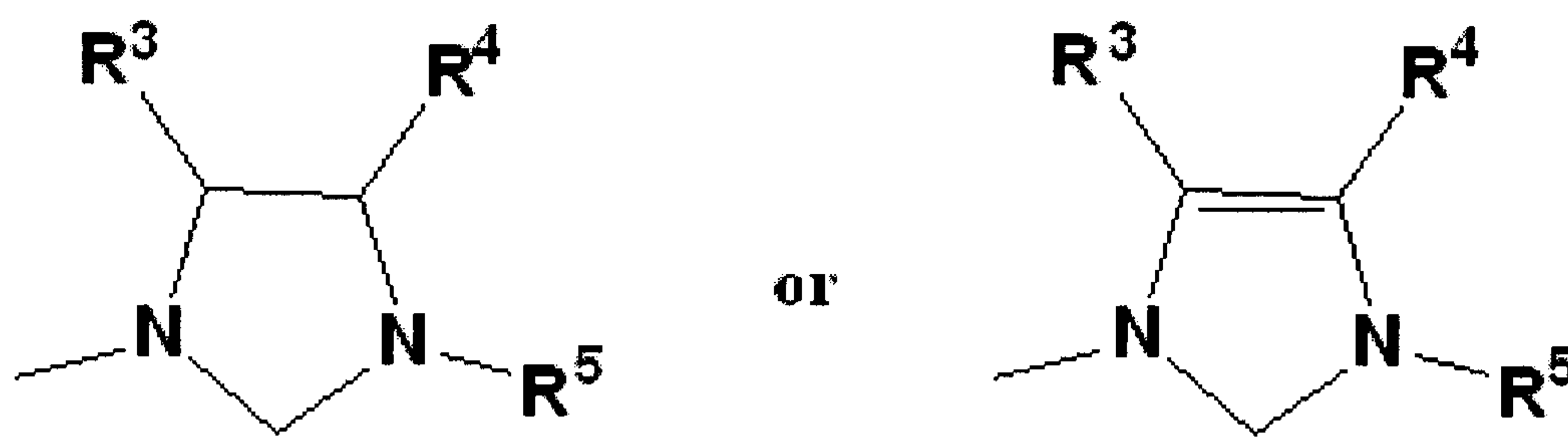
L_1 is a heteroatom serving as ligator for the central atom M,

L_2 and L_3 are each further heteroatoms present in molecular radicals selected independently from the group comprising phosphine (PR^aR^b), amine (NR^aR^b), imine, sulphide (SR^a), thiol (SH), sulphoxide ($S(=O)R^a$), heteroaryl containing at least one atom selected from among nitrogen and sulphur, arsine (AsR^aR^b), stibine (SbR^aR^b) and N-heterocyclic carbene represented by the structures

25

201000282

- 23 -



L_4 is a heteroatom present in a monodentate two-electron donor selected from the group CO, $PR^aR^bR^c$, NO^+ , $AsR^aR^bR^c$, $SbR^aR^bR^c$, SR^aR^b , nitrile (R^aCN), isonitrile (R^aNC), N_2 , PF_3 , CS, heteroaryl (e.g. pyridine, thiophene), tetrahydrothiophene or N-heterocyclic carbene,

Y is a monoanionic ligand selected from the group halogen, carboxylate, trifluoroacetate, sulphonate, trifluoromethanesulphonate, cyanide, hydroxide, alkoxide, imide; or else an uncharged solvate molecule,

R_1 and R_2 are divalent organic radicals and

R^3 , R^4 , R^5 , R^a , R^b and R^c are selected independently from the group alkyl, cycloalkyl, aryl, heterocyclyl, heteroaryl, alkylcycloalkyl, alkylaryl, alkylheterocyclyl and alkylheteroalkyl, is used as homogeneous catalyst.

13. Process according to Claim 11 or 12,
- 15 characterized in that
- carbonylchlorohydrido[4,5-(di-*i*-propylphosphino)methylacridino]ruthenium(II) is used as homogeneous catalyst.

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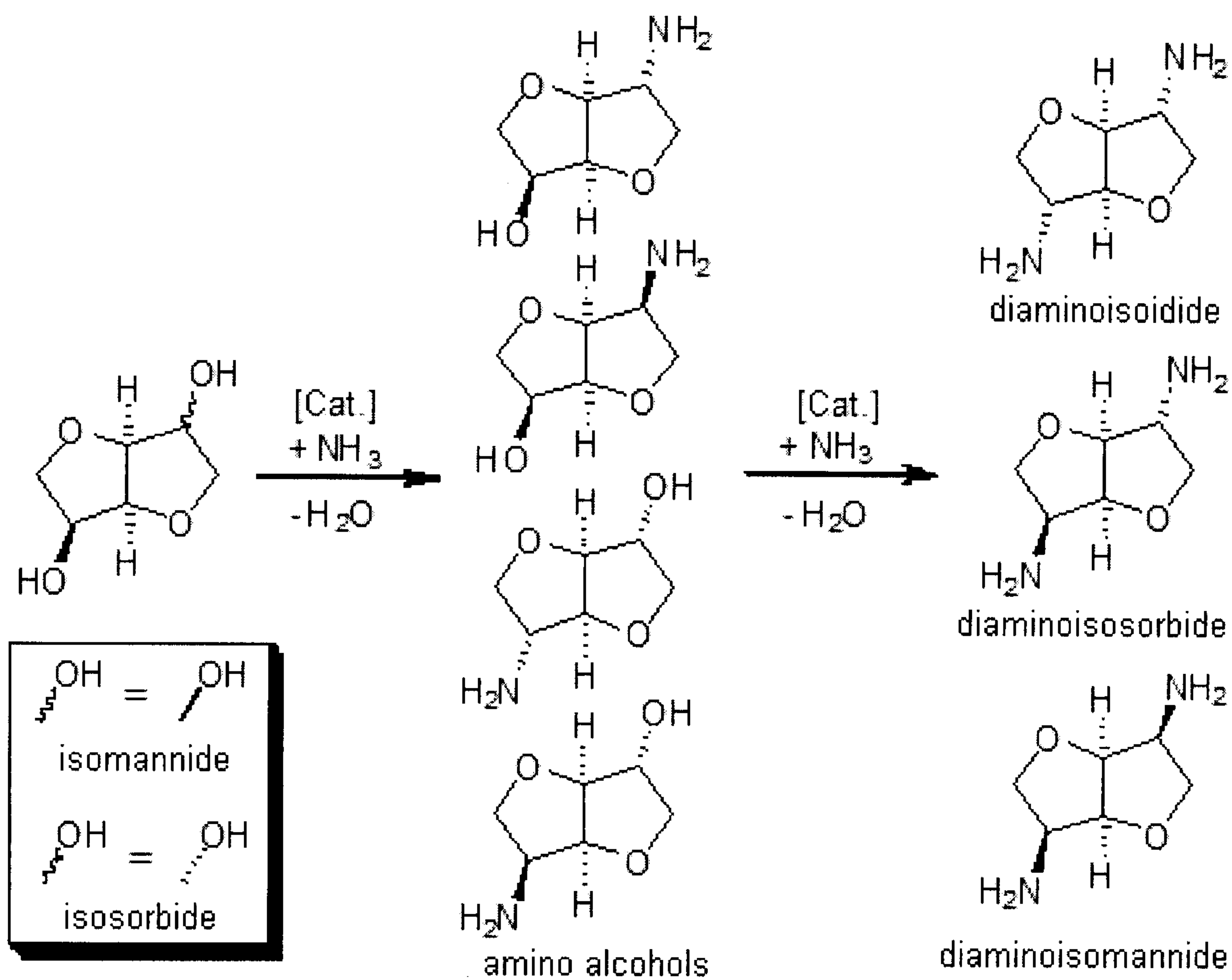


Figure 1