

Novel monophosphite ligands having a *tert*-butyloxycarbonyl group

The invention relates to novel monophosphite ligands having a *tert*-butyloxycarbonyl group (BOC group), to use thereof as ligands in hydroformylation and to the hydroformylation process.

The reactions between olefin compounds, carbon monoxide and hydrogen in the presence of a catalyst to give the aldehydes comprising one additional carbon atom are known as hydroformylation or oxo synthesis. The catalysts used in these reactions are frequently compounds of the transition metals of group VIII of the Periodic Table of the Elements. Known ligands are, for example, compounds from the classes of the phosphines, phosphites and phosphonites, each with trivalent phosphorus P^{III}. A good overview of the state of the hydroformylation of olefins can be found in B. CORNILS, W. A. HERRMANN, "Applied Homogeneous Catalysis with Organometallic Compounds", vol. 1 & 2, VCH, Weinheim, New York, 1996 or R. Franke, D. Selent, A. Börner, "Applied Hydroformylation", Chem. Rev., 2012, DOI:10.1021/cr3001803.

Every catalytically active composition has its specific benefits. According to the feedstock and target product, therefore, different catalytically active compositions are used.

The disadvantage of bi- and polydentate phosphine ligands is a relatively high level of complexity necessary for preparation thereof. It is therefore often unfeasible to use such systems in industrial operations. An additional factor is comparatively low activity, which has to be compensated for by chemical engineering, through high residence times. This in turn leads to unwanted side reactions of the products.

In Angew. Chem. Int. Ed. 2000, 39, No. 9, p. 1639-1641, Börner et al. describe ligands having one P-C bond and two P-O bonds; these are thus phosphonites. The phosphonites described therein, when used in hydroformylation, have *n*/*iso* selectivities (*n*/*iso* = the ratio of linear aldehyde (= *n*) to branched (= *iso*) aldehyde) of 0.61 to 1.57.

The phosphonite ligands described in DE 199 54 721 have a good *n*/*iso* selectivity. However, in-house studies have shown that the compound II-c (in DE 199 54 721; page 6) has a tendency to photochemically induced breakdown, and should therefore not be used on the industrial scale.

One disadvantage of the ligands having a phosphonite structure is that their preparation is very complex. However, the possibility of a favourable and simple synthesis is crucial for the use of ligands in an industrial scale process.

5

Ease of availability and the associated good possibility of industrial scale use is an important criterion, since the preparation complexity and the associated production costs for the ligand may only be so high that the viability of the overall process in which the ligand is to be used at a later stage is still assured.

10

Rhodium-monophosphite complexes in catalytically active compositions are suitable for the hydroformylation of branched olefins having internal double bonds.

Since the 1970s, there have been descriptions of the use of "bulky phosphites" in hydroformylation (see, inter alia, van Leeuwen et al., Journal of Catalysis, 2013, 298, 198-205).

15

These feature good activity, but the n/i selectivity for terminally hydroformylated compounds is in need of improvement.

EP 0 155 508 discloses the use of bisarylene-substituted monophosphites in the rhodium-catalysed hydroformylation of sterically hindered olefins, e.g. isobutene. However, rhodium concentrations used here are sometimes very high (one being 250 ppm), which is unacceptable for an industrial scale process in view of the current cost of rhodium and has to be improved.

20

For hydroformylation reactions, tris(2,4-di-tert-butylphenyl)phosphite (TDTBPP) is currently one of the best-performing monophosphite ligands commercially available, and is available under the Alkanox 240 trade name (see also R. Franke, D. Selent, A. Börner, "Applied Hydroformylation", Chem. Rev., 2012, 112, p. 5681, chapter 3.4.2).

25

The technical object that formed the basis of the present invention is that of providing a novel monophosphite ligand which does not have the above-detailed disadvantages from the prior art in the hydroformylation of unsaturated compounds.

30

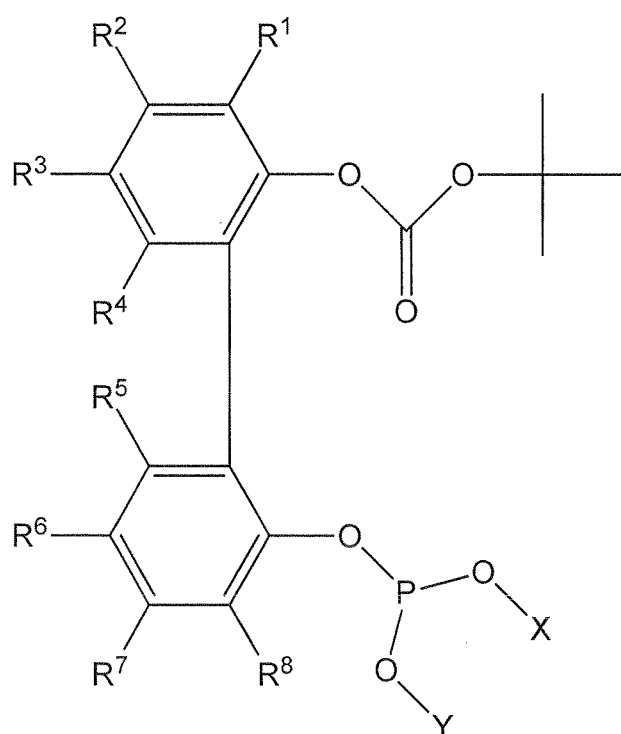
Firstly, the preparation complexity should be lower than for the above-described phosphonite ligands; secondly, a good n selectivity should be achieved in relation to the hydroformylation.

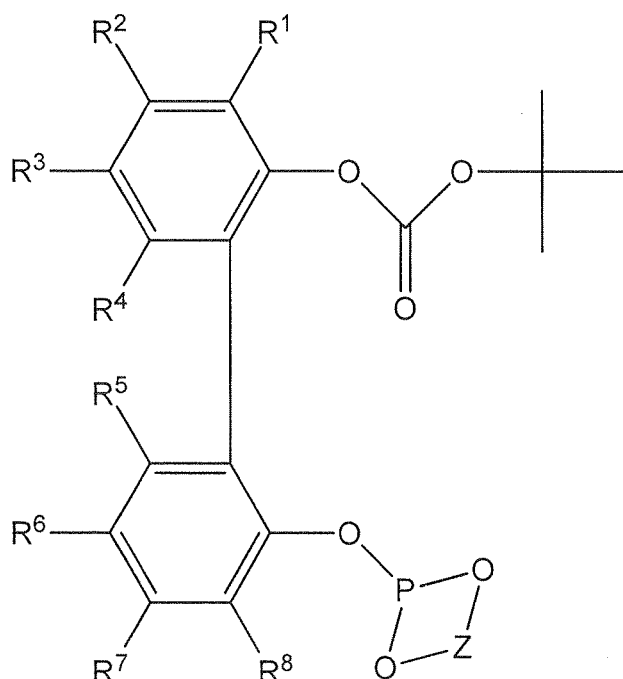
More particularly, the novel monophosphite ligands should also be suitable for hydroformylation of

industrial olefin mixtures containing mainly branched olefins having internal double bonds. In the hydroformylation, at the same time, a high proportion of desired terminally hydroformylated products should be obtained.

- 5 The object is achieved by a ligand according to Claim 1.

Ligand having one of the two general structures I and II:





II

5 where

$R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8$ are each independently selected from: -H, $-(C_1-C_{12})$ -alkyl, $-O-(C_1-C_{12})$ -alkyl, $-O-(C_6-C_{20})$ -aryl, $-(C_6-C_{20})$ -aryl, halogen (such as Cl, F, Br, I), $COO-(C_1-C_{12})$ -alkyl, $CONH-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CON[(C_1-C_{12})$ -alkyl] $_2$, $-CO-(C_1-C_{12})$ -alkyl, $-CO-(C_6-C_{20})$ -aryl, $-COOH$, $-OH$, $-SO_3H$, $-SO_3Na$, $-NO_2$, $-CN$, $-NH_2$, $-N[(C_1-C_{12})$ -alkyl] $_2$;

10 X and Y are each independently selected from:

$-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl, $-(C_6-C_{20})$ -aryl- (C_1-C_{12}) -alkyl, $-(C_6-C_{20})$ -aryl- $O-(C_1-C_{12})$ -alkyl, $-(C_1-C_{12})$ -alkyl- (C_6-C_{20}) -aryl, $-(C_6-C_{20})$ -aryl- $COO-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CONH-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CON[(C_1-C_{12})$ -alkyl] $_2$, $-(C_4-C_{20})$ -heteroaryl, $-(C_4-C_{20})$ -heteroaryl- (C_1-C_{12}) -alkyl, $-(C_5-C_8)$ -cycloalkyl, $-(C_6-C_{20})$ -aryl- $CO-(C_6-C_{20})$ -aryl,

15 Z is selected from:

$-(C_1-C_{12})$ -alkyl-, $-(C_6-C_{20})$ -aryl-, $-(C_6-C_{20})$ -aryl- (C_1-C_{12}) -alkyl-, $-(C_1-C_{12})$ -alkyl- (C_6-C_{20}) -aryl-, $-(C_4-C_{20})$ -heteroaryl-, $-(C_6-C_{20})$ -aryl- $CO-(C_6-C_{20})$ -aryl-, $-(C_6-C_{20})$ -aryl- (C_6-C_{20}) -aryl-;

where the alkyl, heteroalkyl, cycloalkyl, heterocycloalkyl, aryl and heteroaryl groups mentioned may be substituted.

(C₁-C₁₂)-Alkyl and O-(C₁-C₁₂)-alkyl may each be unsubstituted or substituted by one or more identical or different radicals selected from (C₃-C₁₂)-cycloalkyl, (C₃-C₁₂)-heterocycloalkyl, (C₆-C₂₀)-aryl, fluorine, chlorine, cyano, formyl, acyl and alkoxycarbonyl.

5 (C₃-C₁₂)-Cycloalkyl and (C₃-C₁₂)-heterocycloalkyl may each be unsubstituted or substituted by one or more identical or different radicals selected from (C₁-C₁₂)-alkyl, (C₁-C₁₂)-alkoxy, (C₃-C₁₂)-cycloalkyl, (C₃-C₁₂)-heterocycloalkyl, (C₆-C₂₀)-aryl, fluorine, chlorine, cyano, formyl, acyl and alkoxycarbonyl.

10 (C₆-C₂₀)-Aryl and -(C₆-C₂₀)-aryl-(C₆-C₂₀)-aryl- may each be unsubstituted or substituted by one or more identical or different radicals selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -halogen (such as Cl, F, Br, I), -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -SO₃Na, -NO₂, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.

15 In the context of the invention, the expression -(C₁-C₁₂)-alkyl encompasses straight-chain and branched alkyl groups. Preferably, these groups are unsubstituted straight-chain or branched -(C₁-C₈)-alkyl groups and most preferably -(C₁-C₆)-alkyl groups. Examples of (C₁-C₁₂)-alkyl groups are especially methyl, ethyl, propyl, isopropyl, n-butyl, isobutyl, sec-butyl, tert-butyl, n-pentyl, 2-pentyl, 2-methylbutyl, 3-methylbutyl, 1,2-dimethylpropyl, 1,1-dimethylpropyl, 2,2-dimethylpropyl, 1-ethylpropyl, n-hexyl, 2-hexyl, 2-methylpentyl, 3-methylpentyl, 4-methylpentyl, 1,1-dimethylbutyl, 1,2-dimethylbutyl, 2,2-dimethylbutyl, 1,3-dimethylbutyl, 2,3-dimethylbutyl, 3,3-dimethylbutyl, 1,1,2-trimethylpropyl, 1,2,2-trimethylpropyl, 1-ethylbutyl, 1-ethyl-2-methylpropyl, n-heptyl, 2-heptyl, 3-heptyl, 2-ethylpentyl, 1-propylbutyl, n-octyl, 2-ethylhexyl, 2-propylheptyl, 25 nonyl, decyl.

The elucidations relating to the expression -(C₁-C₁₂)-alkyl also apply to the alkyl groups in -O-(C₁-C₁₂)-alkyl, i.e. in -(C₁-C₁₂)-alkoxy. Preferably, these groups are unsubstituted straight-chain or branched -(C₁-C₆)-alkoxy groups.

30 Substituted -(C₁-C₁₂)-alkyl groups and substituted -(C₁-C₁₂)-alkoxy groups may have one or more substituents, depending on their chain length. The substituents are preferably each independently selected from -(C₃-C₁₂)-cycloalkyl, -(C₃-C₁₂)-heterocycloalkyl, -(C₆-C₂₀)-aryl, fluorine, chlorine, cyano, formyl, acyl or alkoxycarbonyl.

The expression " $-(C_3-C_{12})$ -cycloalkyl", in the context of the present invention, encompasses mono-, bi- or tricyclic hydrocarbyl radicals having 3 to 12, especially 5 to 12, carbon atoms. These include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, cyclooctyl, cyclododecyl, cyclopentadecyl, norbornyl and adamantyl.

The expression " $-(C_3-C_{12})$ -heterocycloalkyl groups", in the context of the present invention, encompasses nonaromatic saturated or partly unsaturated cycloaliphatic groups having 3 to 12, especially 5 to 12, carbon atoms. The $-(C_3-C_{12})$ -heterocycloalkyl groups have preferably 3 to 8, more preferably 5 or 6, ring atoms. In the heterocycloalkyl groups, as opposed to the cycloalkyl groups, 1, 2, 3 or 4 of the ring carbon atoms are replaced by heteroatoms or heteroatom-containing groups. The heteroatoms or the heteroatom-containing groups are preferably selected from -O-, -S-, -N-, -N(=O)-, -C(=O)- and -S(=O)-. Examples of $-(C_3-C_{12})$ -heterocycloalkyl groups are tetrahydrothiophenyl, tetrahydrofuryl, tetrahydropyranyl and dioxanyl.

Substituted $-(C_3-C_{12})$ -cycloalkyl groups and substituted $-(C_3-C_{12})$ -heterocycloalkyl groups may have one or more (e.g. 1, 2, 3, 4 or 5) further substituents, depending on their ring size. These substituents are preferably each independently selected from $-(C_1-C_{12})$ -alkyl, $-(C_1-C_{12})$ -alkoxy, $-(C_3-C_{12})$ -cycloalkyl, $-(C_3-C_{12})$ -heterocycloalkyl, $-(C_6-C_{20})$ -aryl, fluorine, chlorine, cyano, formyl, acyl or alkoxycarbonyl. Substituted $-(C_3-C_{12})$ -cycloalkyl groups preferably bear one or more $-(C_1-C_6)$ -alkyl groups. Substituted $-(C_3-C_{12})$ -heterocycloalkyl groups preferably bear one or more $-(C_1-C_6)$ -alkyl groups.

In the context of the present invention, the expression $-(C_6-C_{20})$ -aryl and $-(C_6-C_{20})$ -aryl- $-(C_6-C_{20})$ -aryl- encompasses mono- or polycyclic aromatic hydrocarbyl radicals. These have 6 to 20 ring atoms, more preferably 6 to 14 ring atoms, especially 6 to 10 ring atoms. Aryl is preferably $-(C_6-C_{10})$ -aryl and $-(C_6-C_{10})$ -aryl- $-(C_6-C_{10})$ -aryl-. Aryl is especially phenyl, naphthyl, indenyl, fluorenyl, anthracenyl, phenanthrenyl, naphthacenyl, chrysenyl, pyrenyl, coronenyl. More particularly, aryl is phenyl, naphthyl and anthracenyl.

Substituted $-(C_6-C_{20})$ -aryl groups and $-(C_6-C_{20})$ -aryl- $-(C_6-C_{20})$ -aryl groups may have one or more (e.g. 1, 2, 3, 4 or 5) substituents, depending on their ring size. These substituents are preferably each independently selected from -H-, $-(C_1-C_{12})$ -alkyl, -O- $-(C_1-C_{12})$ -alkyl, -O- $-(C_6-C_{20})$ -aryl, $-(C_6-$

C₂₀)-aryl, -halogen (such as Cl, F, Br, I), -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -SO₃Na, -NO₂, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.

- 5 Substituted -(C₆-C₂₀)-aryl groups and -(C₆-C₂₀)-aryl-(C₆-C₂₀)-aryl groups are preferably substituted -(C₆-C₁₀)-aryl groups and -(C₆-C₁₀)-aryl-(C₆-C₁₀)-aryl groups, especially substituted phenyl or substituted naphthyl or substituted anthracenyl. Substituted-(C₆-C₂₀)-aryl groups preferably bear one or more, for example 1, 2, 3, 4 or 5, substituents selected from -(C₁-C₁₂)-alkyl groups, -(C₁-C₁₂)-alkoxy groups.

10

In one embodiment, X and Y are each independently selected from:

-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-COO-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -(C₄-C₂₀)-heteroaryl, -(C₄-C₂₀)-heteroaryl-(C₁-C₁₂)-alkyl.

15

In one embodiment, X and Y are each independently selected from:

-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-COO-(C₁-C₁₂)-alkyl.

- 20 In one embodiment, X and Y are each independently selected from:

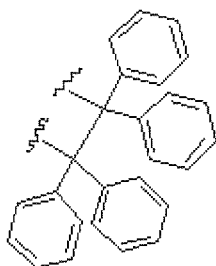
-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-O-(C₁-C₁₂)-alkyl.

In one embodiment, Z is selected from:

-(C₁-C₁₂)-alkyl-, -(C₆-C₂₀)-aryl-, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl-, -(C₆-C₂₀)-aryl-CO-(C₆-C₂₀)-aryl-,

- 25 -(C₁-C₁₂)-alkyl-(C₆-C₂₀)-aryl-, -(C₆-C₂₀)-aryl-(C₆-C₂₀)-aryl-.

In one embodiment, Z is:



In one embodiment, Z is:

-(C₆-C₂₀)-aryl-(C₆-C₂₀)-aryl-

In one embodiment, R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸ are each independently selected from:

- 5 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.

In one embodiment, R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸ are each independently selected from:

- 10 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -COO-(C₁-C₁₂)-alkyl, -N[(C₁-C₁₂)-alkyl]₂.

In one embodiment, R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸ are each independently selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl.

15

In one embodiment, X and Y are the same radicals.

In one embodiment, R³ and R⁶ are each -O-(C₁-C₁₂)-alkyl.

- 20 In one embodiment, R³ and R⁶ are each -OMe.

In one embodiment, R¹ and R⁸ are each -(C₁-C₁₂)-alkyl.

In one embodiment, R¹ and R⁸ are each *tert*-butyl.

25

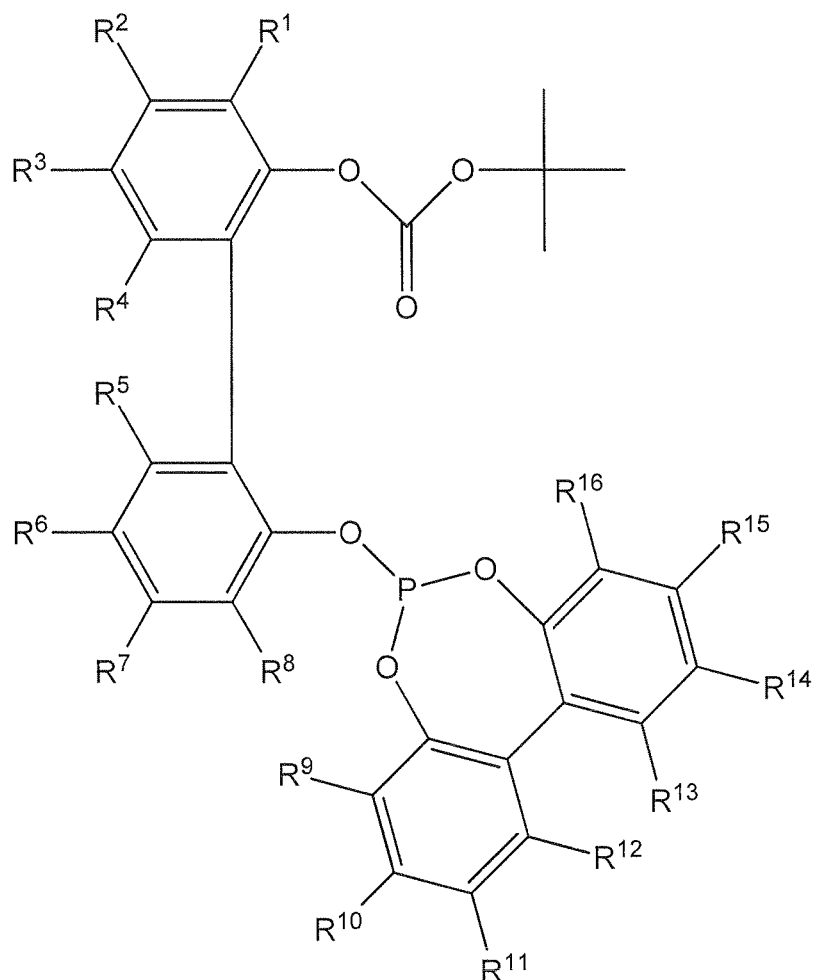
In one embodiment, R¹, R³, R⁶ and R⁸ are each -(C₁-C₁₂)-alkyl.

In one embodiment, R¹, R³, R⁶ and R⁸ are each methyl.

- 30 In one embodiment, R¹, R³, R⁶ and R⁸ are each *tert*-butyl.

In one embodiment, R¹, R², R³, R⁴, R⁵, R⁶, R⁷ and R⁸ are each -H.

In one embodiment, the ligand has the general structure III:



III

- 5 where R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} are each independently selected from:
 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -halogen (such as Cl, F, Br, I), -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -SO₃Na, -NO₂, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.
- 10 In one embodiment, R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} are each independently selected from:
 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.
- 15 In one embodiment, R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} are each independently selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -COO-(C₁-C₁₂)-alkyl, -N[(C₁-C₁₂)-alkyl]₂.

In one embodiment, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, R¹⁵, R¹⁶ are each independently selected from:

5 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl,

where alkyl comprises 1-12 carbon atoms, preferably 1-10 carbon atoms, for example primary, secondary or tertiary alkyl groups such as methyl, ethyl, n-propyl, isopropyl, butyl, sec-butyl, t-butyl, t-butylethyl, t-butylpropyl, n-hexyl, amyl, sec-amyl, t-amyl, isooctyl, 2-ethylhexyl, decyl, dodecyl and octadecyl groups.

10

In one embodiment, R¹¹ and R¹⁴ are each -O-(C₁-C₁₂)-alkyl.

In one embodiment, R¹¹ and R¹⁴ are each -OMe.

15 In one embodiment, R⁹ and R¹⁶ are each -(C₁-C₁₂)-alkyl.

In one embodiment, R⁹ and R¹⁶ are each *tert*-butyl.

In one embodiment, R⁹, R¹¹, R¹⁴ and R¹⁶ are each -(C₁-C₁₂)-alkyl.

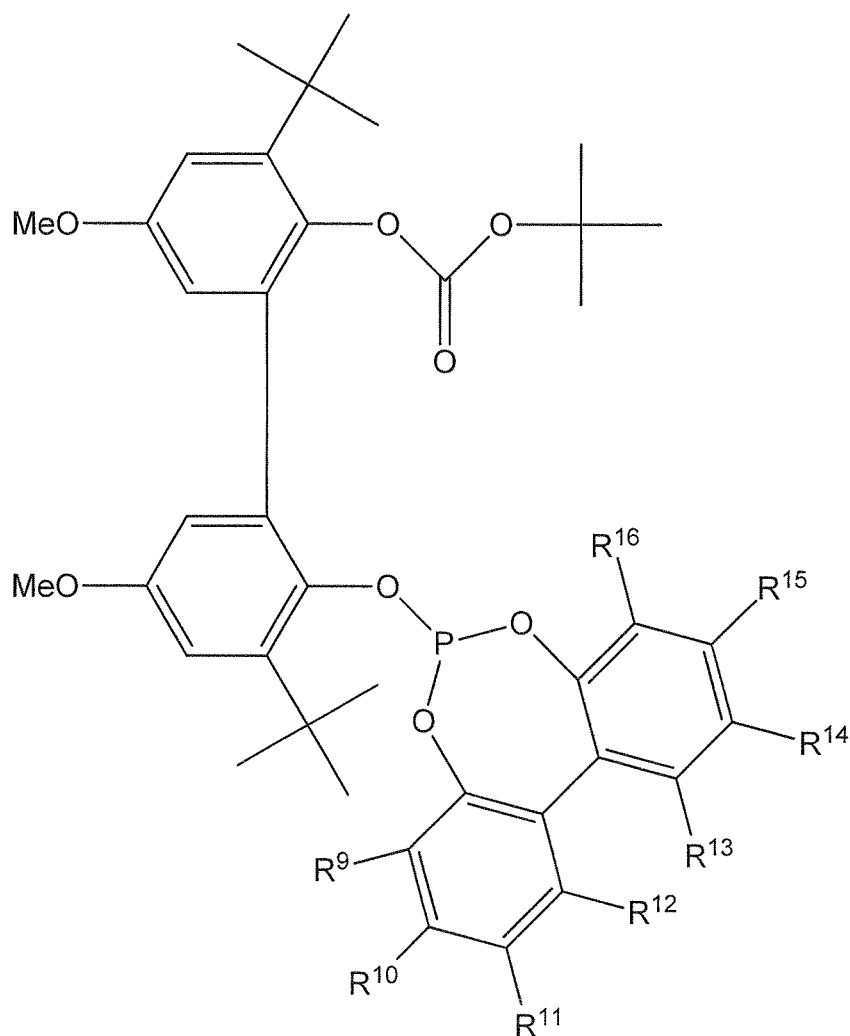
20

In one embodiment, R⁹, R¹¹, R¹⁴ and R¹⁶ are each methyl.

In one embodiment, R⁹, R¹¹, R¹⁴ and R¹⁶ are each *tert*-butyl.

25 In one embodiment, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, R¹⁵ and R¹⁶ are each -H.

In one embodiment, the ligand has the general structure **IV**:



where $R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}$ are each independently selected from:

-H, $-(C_1-C_{12})$ -alkyl, $-O-(C_1-C_{12})$ -alkyl, $-O-(C_6-C_{20})$ -aryl, $-(C_6-C_{20})$ -aryl, -halogen (such as Cl, F, Br, I), $-COO-(C_1-C_{12})$ -alkyl, $-CONH-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CON[(C_1-C_{12})$ -alkyl] $_2$, $-CO-(C_1-C_{12})$ -alkyl, $-CO-(C_6-C_{20})$ -aryl, $-COOH$, $-OH$, $-SO_3H$, $-SO_3Na$, $-NO_2$, $-CN$, $-NH_2$, $-N[(C_1-C_{12})$ -alkyl] $_2$.

In one embodiment, $R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}$ are each independently selected from:

-H, $-(C_1-C_{12})$ -alkyl, $-O-(C_1-C_{12})$ -alkyl, $-O-(C_6-C_{20})$ -aryl, $-(C_6-C_{20})$ -aryl, $-COO-(C_1-C_{12})$ -alkyl, $-CONH-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CON[(C_1-C_{12})$ -alkyl] $_2$, $-CO-(C_1-C_{12})$ -alkyl, $-CO-(C_6-C_{20})$ -aryl, $-COOH$, $-OH$, $-NH_2$, $-N[(C_1-C_{12})$ -alkyl] $_2$.

In one embodiment, $R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}$ are each independently selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -COO-(C₁-C₁₂)-alkyl, -N[(C₁-C₁₂)-alkyl]₂.

In one embodiment, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, R¹⁵, R¹⁶ are each independently selected from:

5 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl;

where alkyl comprises 1-18 carbon atoms, preferably 1-10 carbon atoms, for example primary, secondary or tertiary alkyl groups such as methyl, ethyl, n-propyl, isopropyl, butyl, sec-butyl, t-butyl, t-butylethyl, t-butylpropyl, n-hexyl, amyl, sec-amyl, t-amyl, isooctyl, 2-ethylhexyl, decyl, dodecyl and octadecyl groups.

10

In one embodiment, R¹¹ and R¹⁴ are each -O-(C₁-C₁₂)-alkyl.

In one embodiment, R¹¹ and R¹⁴ are each -OMe.

15 In one embodiment, R⁹ and R¹⁶ are each -(C₁-C₁₂)-alkyl.

In one embodiment, R⁹ and R¹⁶ are each *tert*-butyl.

In one embodiment, R⁹, R¹¹, R¹⁴ and R¹⁶ are each -(C₁-C₁₂)-alkyl.

20

In one embodiment, R⁹, R¹¹, R¹⁴ and R¹⁶ are each methyl.

In one embodiment, R⁹, R¹¹, R¹⁴ and R¹⁶ are each *tert*-butyl.

25 In one embodiment, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, R¹⁵ and R¹⁶ are each -H.

As well as the ligands, also claimed is a complex comprising these ligands.

Complex comprising:

- 30 - an above-described ligand,
- a metal atom selected from: Rh, Ru, Co, Ir.

In a preferred embodiment, the metal is Rh.

In this regard, see R. Franke, D. Selent, A. Börner, "Applied Hydroformylation", Chem. Rev., 2012, DOI:10.1021/cr3001803; p. 5688, Scheme 12 "General Method for the Preparation of a P-Modified Rh precatalyst" and references cited therein, and also P. W. N. M. van Leeuwen, in Rhodium Catalyzed Hydroformylation, P. W. N. M. van Leeuwen, C. Claver (eds.), Kluwer, Dordrecht, 2000, inter alia p. 48 ff, p. 233 ff. and references cited therein, and also K.D. Wiese and D. Obst in Top. Organomet. Chem. 2006, 18, 1-13; Springer Verlag Berlin Heidelberg 2006 p. 6 ff and references cited therein.

Additionally claimed is the use of the ligand as ligand in a ligand-metal complex for catalysis of a hydroformylation reaction.

Use of an above-described ligand in a ligand-metal complex for catalysis of a hydroformylation reaction.

The process in which the ligand is used as ligand in a ligand-metal complex for conversion of an olefin to an aldehyde is likewise claimed.

Process comprising the process steps of:

- a) initially charging an olefin,
- b) adding an above-described complex,
or an above-described ligand and a compound including a metal atom selected from: Rh, Ru, Co, Ir,
- c) feeding in H₂ and CO,
- d) heating the reaction mixture, with conversion of the olefin to an aldehyde.

In this process, process steps a) to d) can be effected in any desired sequence.

The reaction is conducted under customary conditions.

Preference is given to a temperature of 80°C to 160°C and a pressure of 1 to 300 bar. Particular preference is given to a temperature of 100°C to 160°C and a pressure of 15 to 250 bar.

In a preferred embodiment, the metal is Rh.

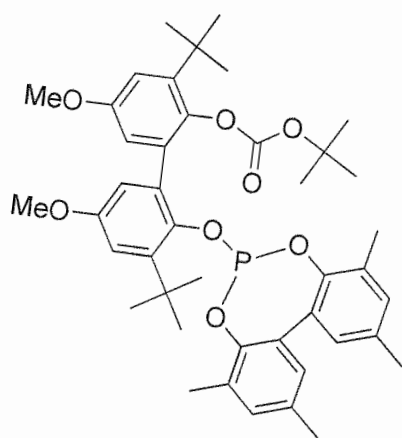
The reactants for the hydroformylation in the process of the invention are olefins or mixtures of olefins, especially monoolefins having 2 to 24, preferably 3 to 16 and more preferably 3 to 12 carbon atoms, having terminal or internal C-C double bonds, for example 1-propene, 1-butene, 2-butene, 1- or 2-pentene, 2-methyl-1-butene, 2-methyl-2-butene, 3-methyl-1-butene, 1-, 2- or 3-hexene, the C₆ olefin mixture obtained in the dimerization of propene (dipropene), heptenes, 2- or 3-methyl-1-hexenes, octenes, 2-methylheptenes, 3-methylheptenes, 5-methyl-2-heptene, 6-methyl-2-heptene, 2-ethyl-1-hexene, the C₈ olefin mixture obtained in the dimerization of butenes (di-n-butene, diisobutene), nonenes, 2- or 3-methyloctenes, the C₉ olefin mixture obtained in the trimerization of propene (tripropene), decenes, 2-ethyl-1-octene, dodecenes, the C₁₂ olefin mixture obtained in the tetramerization of propene or the trimerization of butenes (tetrapropene or tributene), tetradecenes, hexadecenes, the C₁₆ olefin mixture obtained in the tetramerization of butenes (tetrabutene), and olefin mixtures prepared by cooligomerization of olefins having different numbers of carbon atoms (preferably 2 to 4).

The process according to the invention using the ligands according to the invention can be used to hydroformylate α -olefins, terminally branched, internal and internally branched olefins. What is remarkable is the high yield of terminally hydroformylated olefin, even when only a small proportion of olefins having a terminal double bond was present in the reactant.

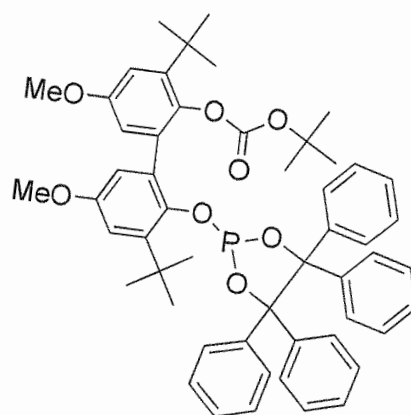
The invention is to be illustrated in detail hereinafter by working examples.

The following seventy structures (1 to 70) show possible working examples of the ligand:

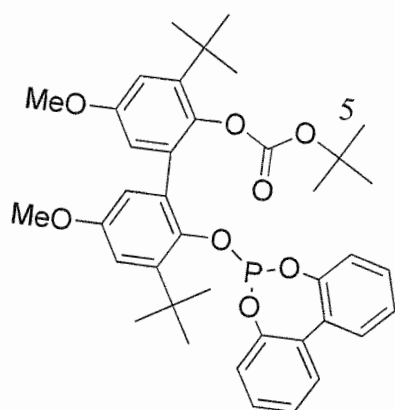
15



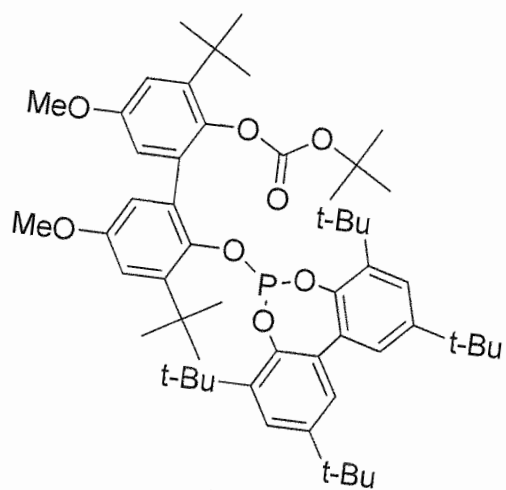
1



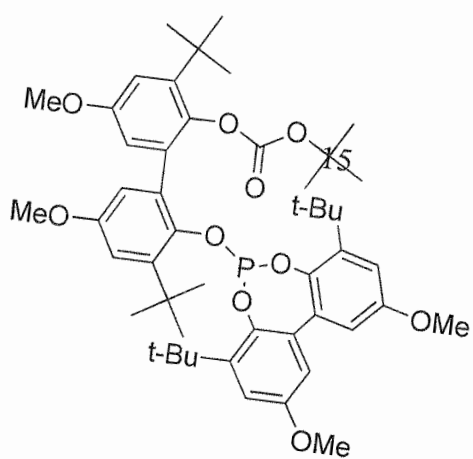
2



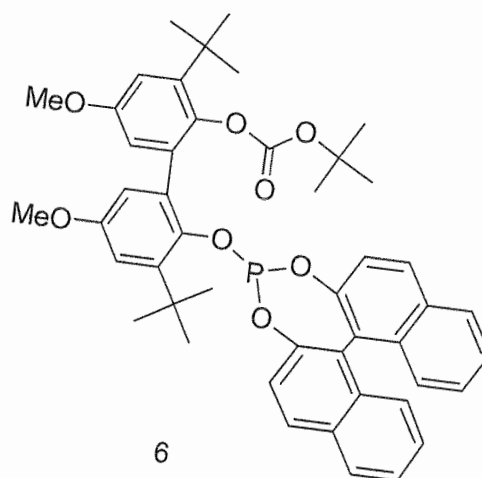
3



4



5



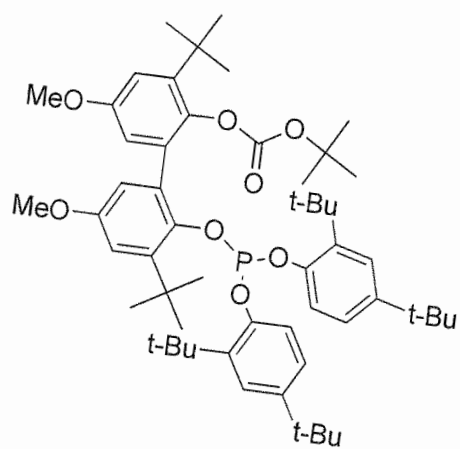
6

10

20

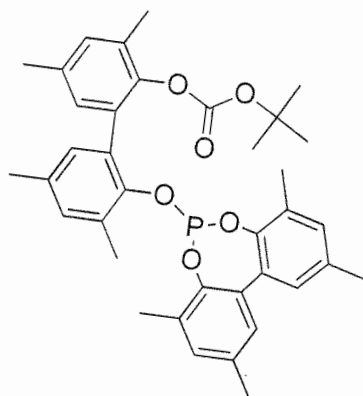
25

5

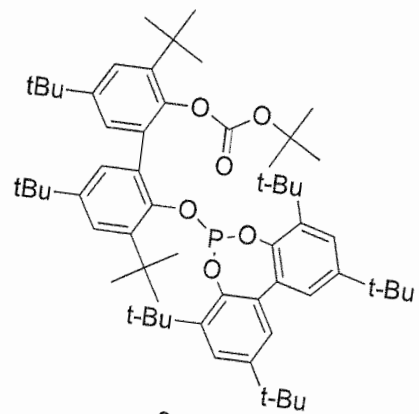


7

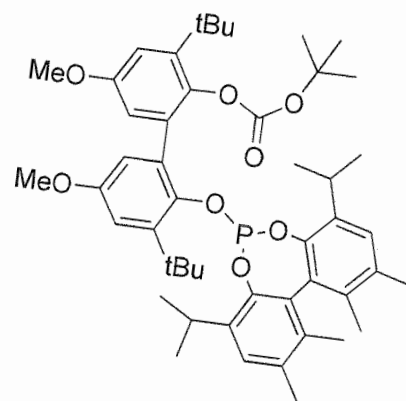
10



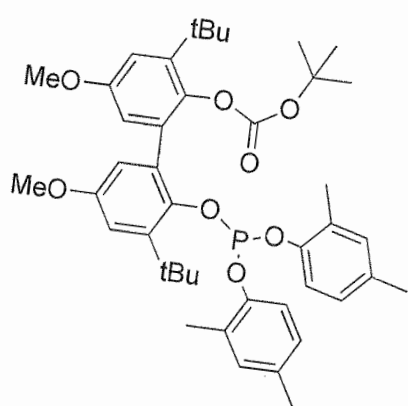
9



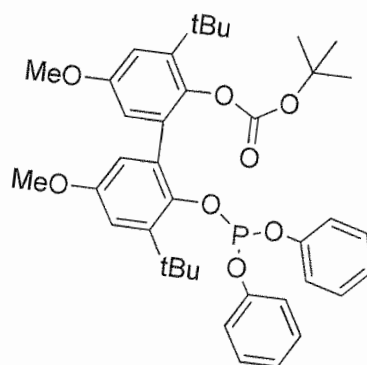
8



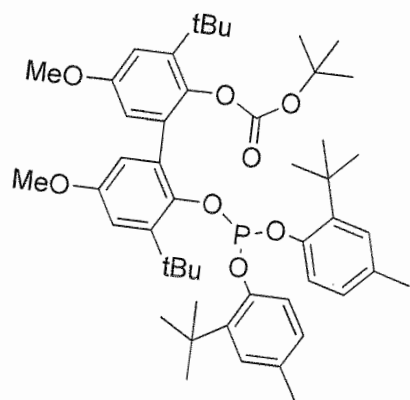
10



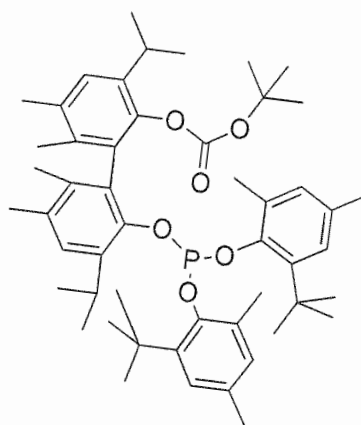
11



12

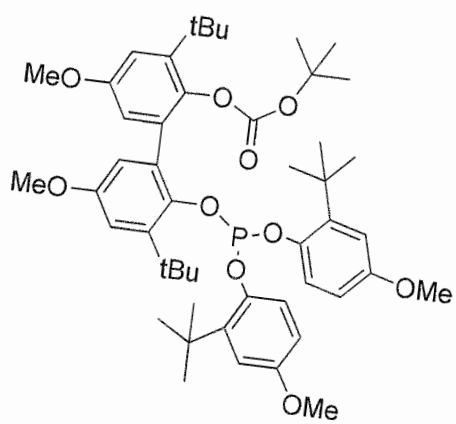


13

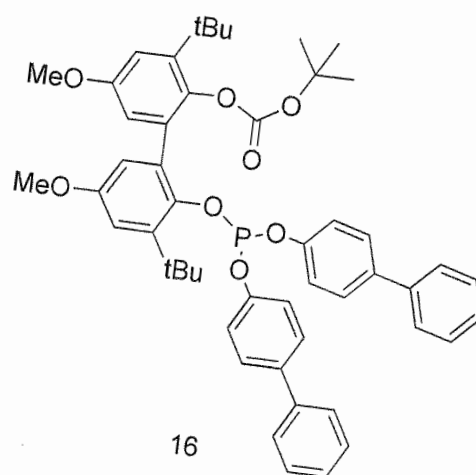


14

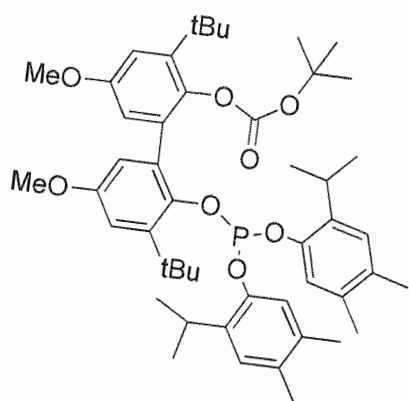
5



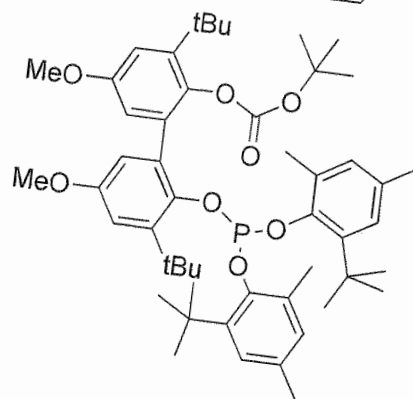
15



16

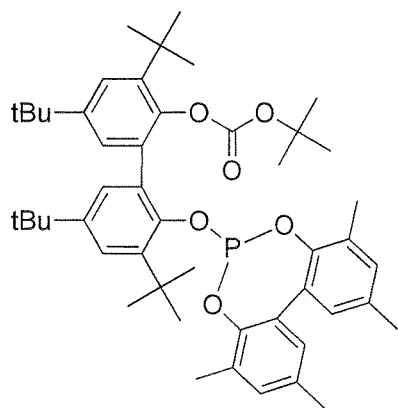


17

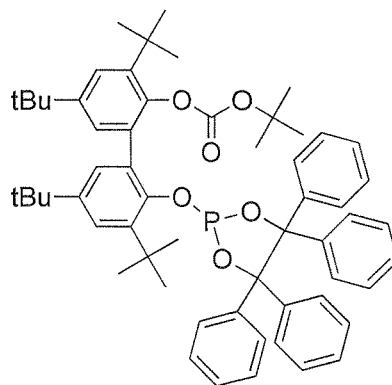


18

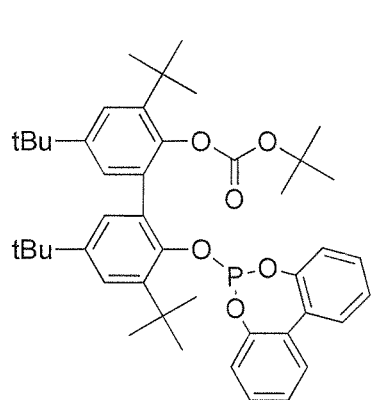
18



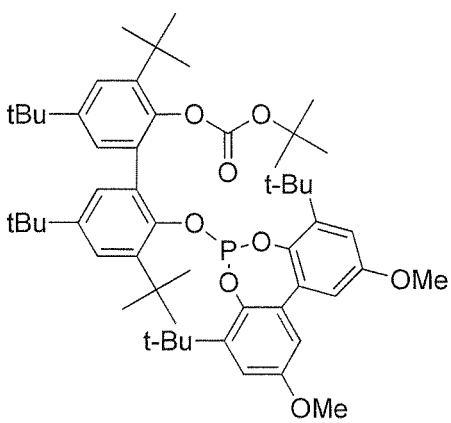
19



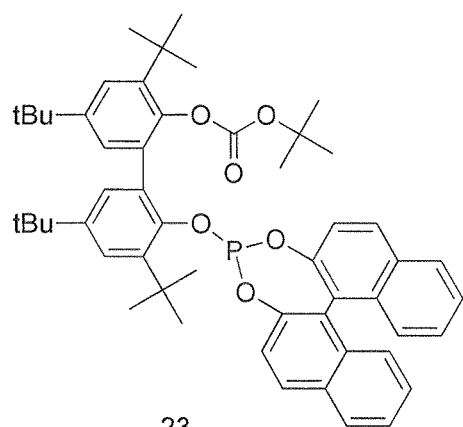
20



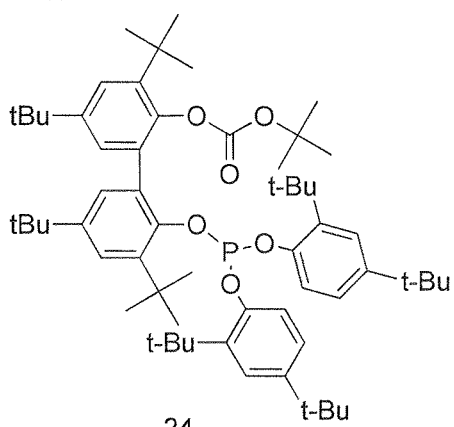
21



22

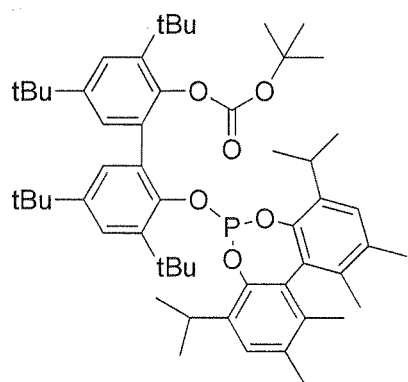


23

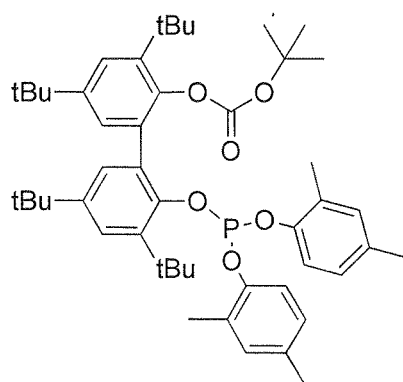


24

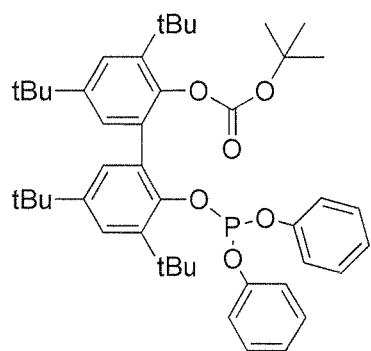
19



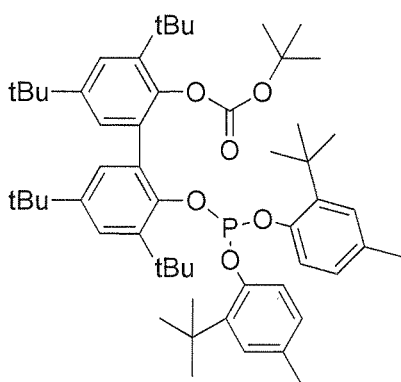
25



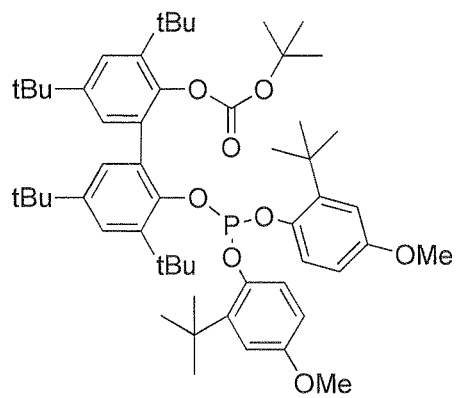
26



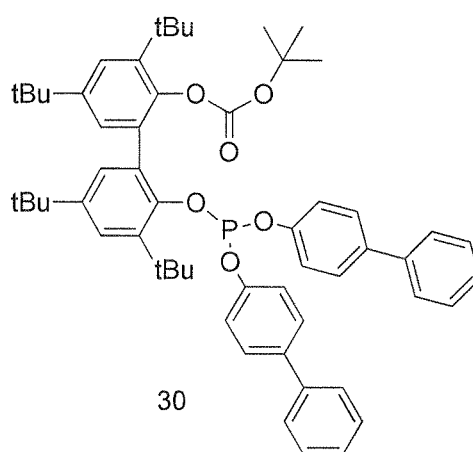
27



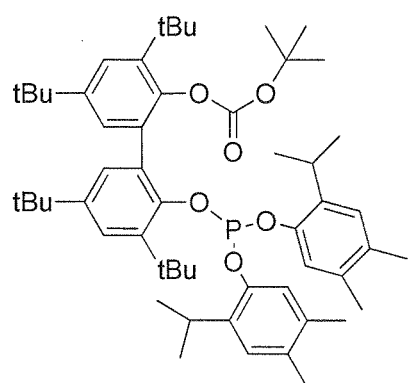
28



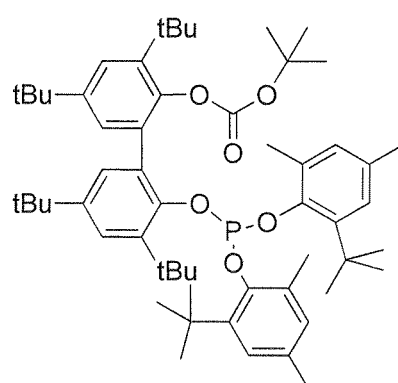
29



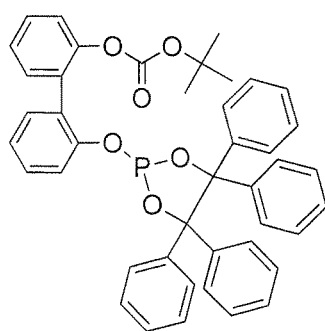
30



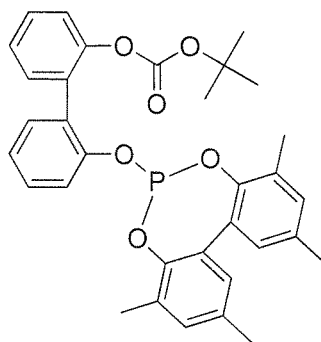
31



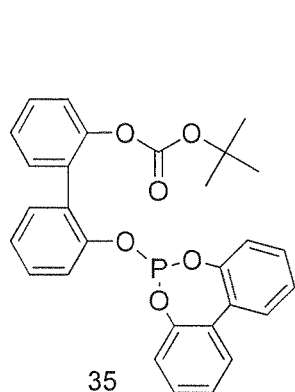
32



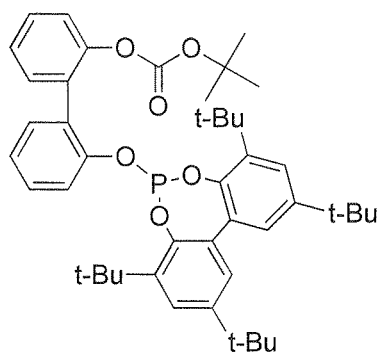
33



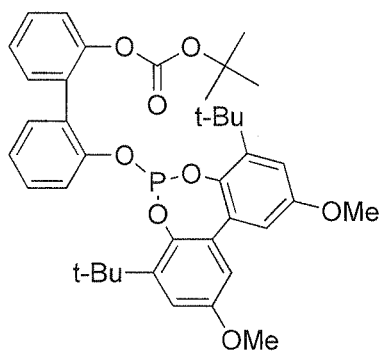
34



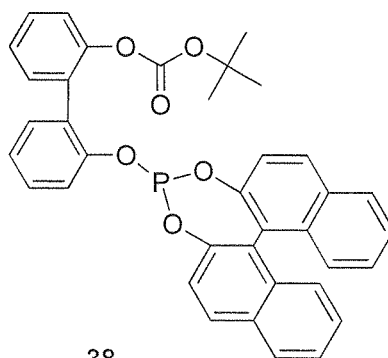
35



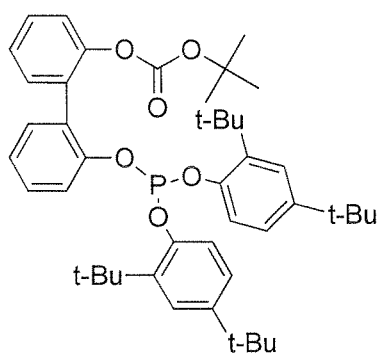
36



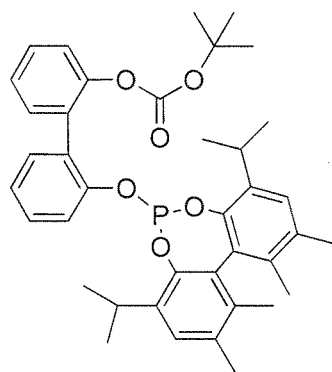
37



38

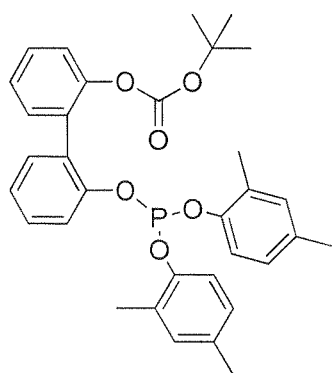


39

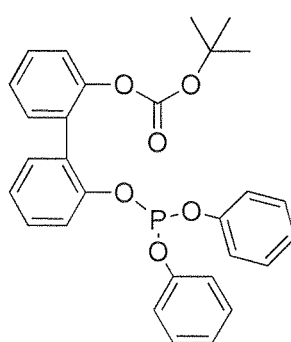


40

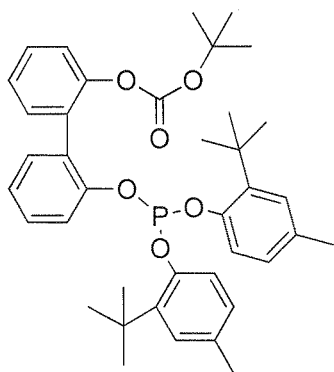
5



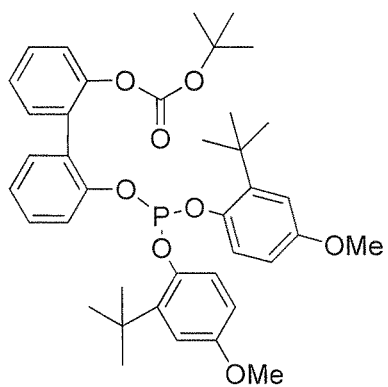
41



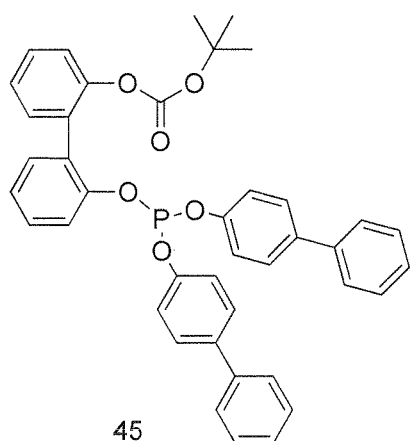
42



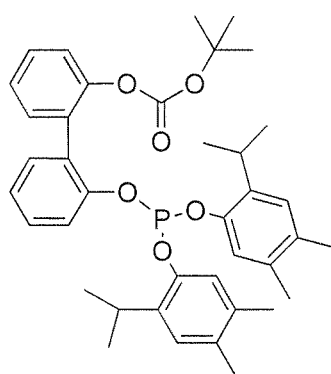
43



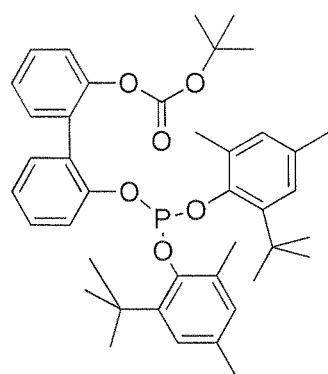
44



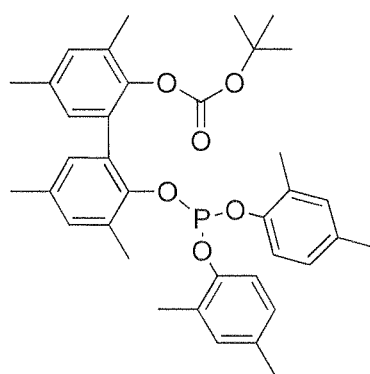
45



46

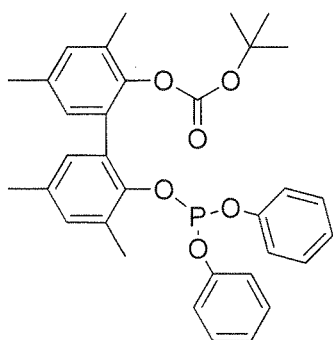


47

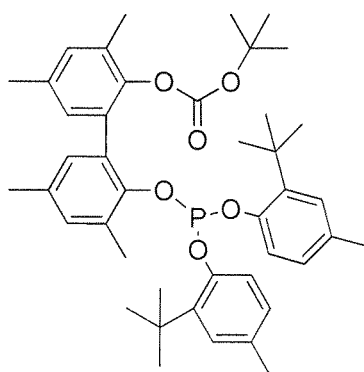


48

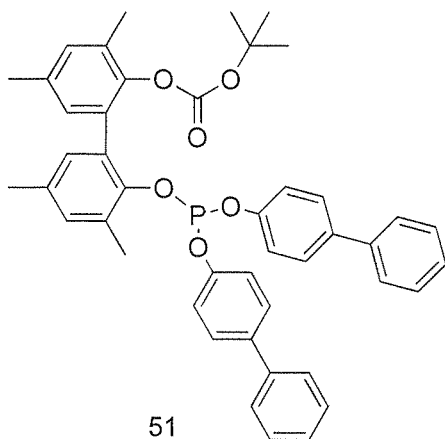
23



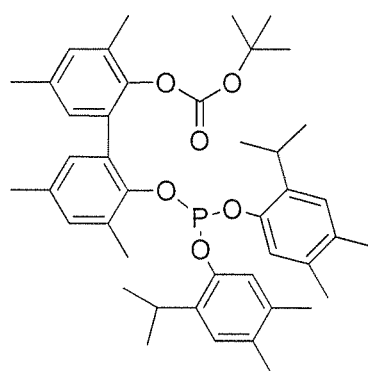
49



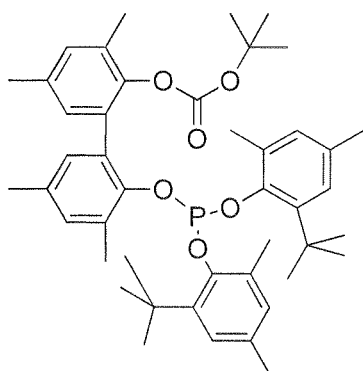
50



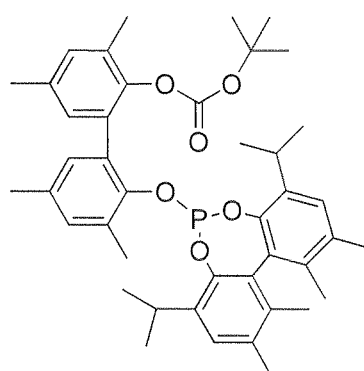
51



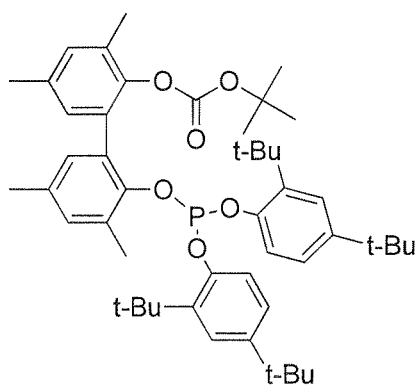
52



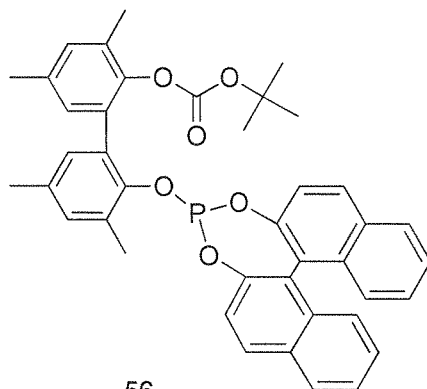
53



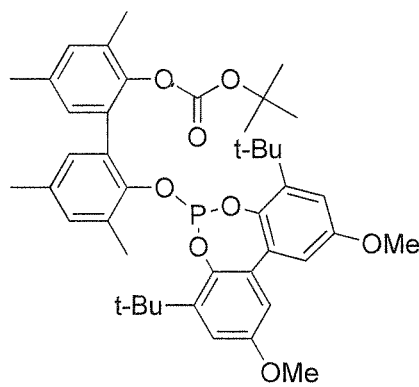
54



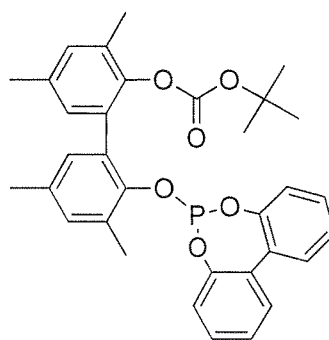
55



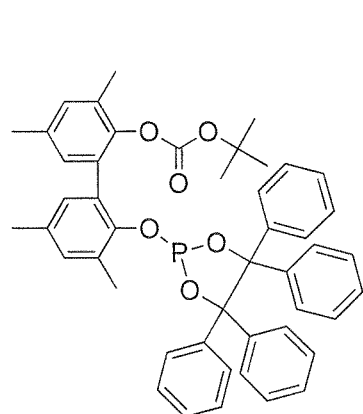
56



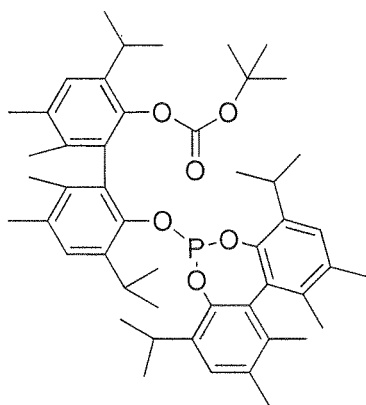
57



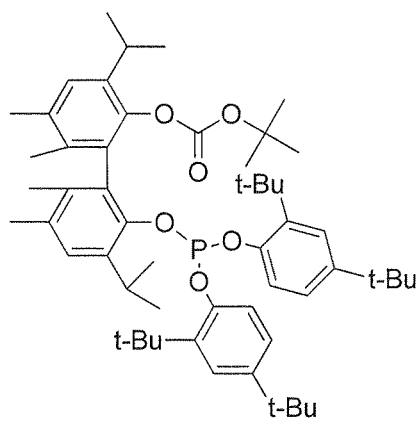
58



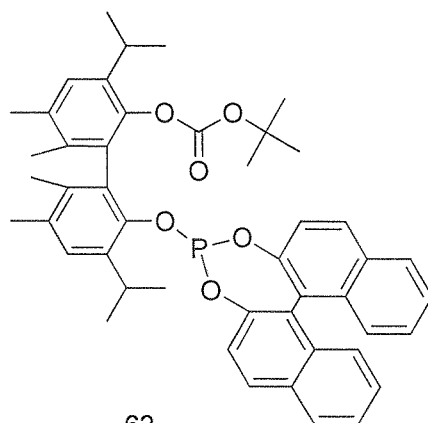
59



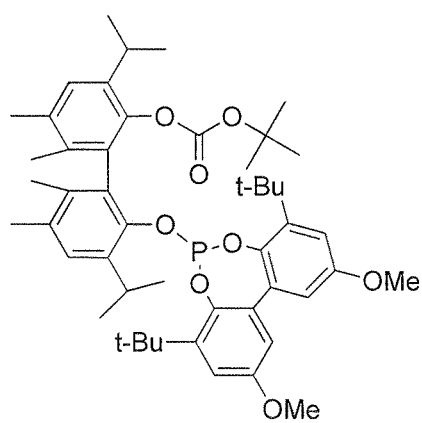
60



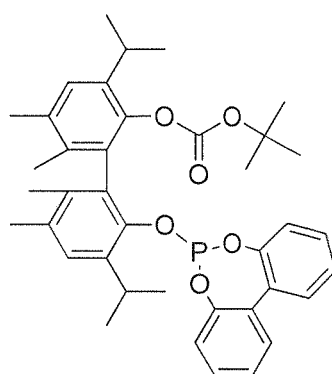
61



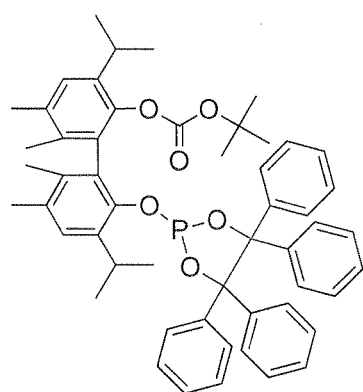
62



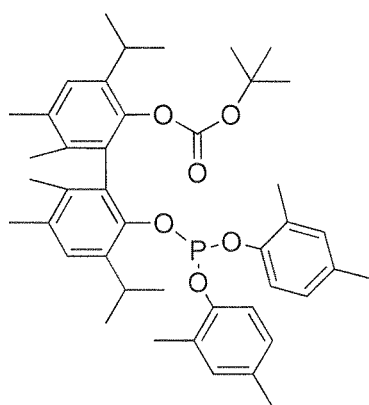
63



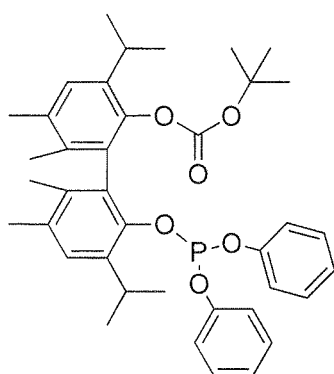
64



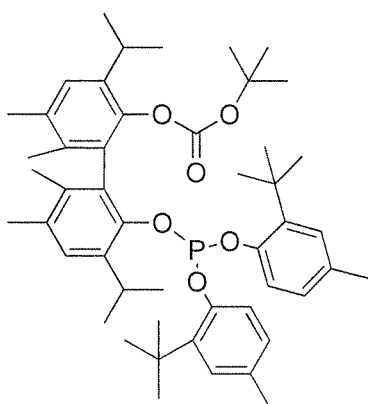
65



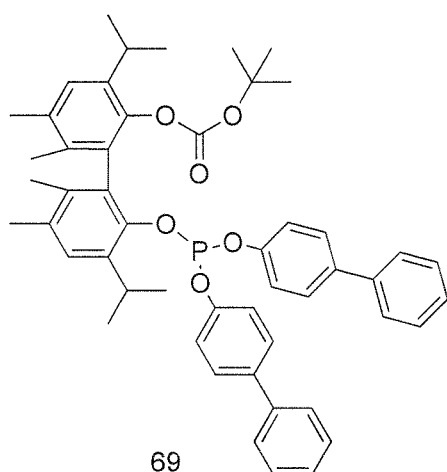
66



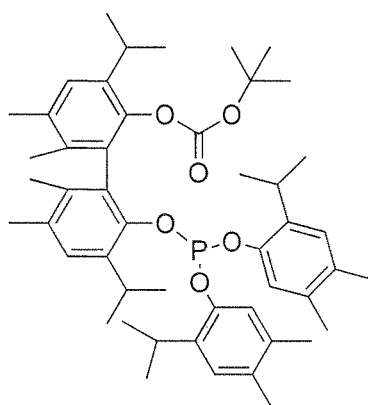
67



68



69



70

5

General operating procedures

10 All the preparations which follow were carried out under protective gas using standard Schlenk techniques. The solvents were dried over suitable desiccants before use (Purification of Laboratory Chemicals, W. L. F. Armarego, Christina Chai, Butterworth Heinemann (Elsevier), 6th edition, Oxford 2009).

15 All preparative operations were effected in baked-out vessels. The products were characterized by means of NMR spectroscopy. Chemical shifts (δ) are reported in ppm. The ^{31}P NMR signals were referenced according to: $\text{SR}_{31\text{P}} = \text{SR}_{1\text{H}} * (\text{BF}_{31\text{P}} / \text{BF}_{1\text{H}}) = \text{SR}_{1\text{H}} * 0.4048$. (Robin K. Harris, Edwin D. Becker, Sonia M. Cabral de Menezes, Robin Goodfellow, and Pierre Granger, Pure Appl. Chem., 2001, 73, 1795 - 1818; Robin K. Harris, Edwin D. Becker, Sonia M. Cabral de

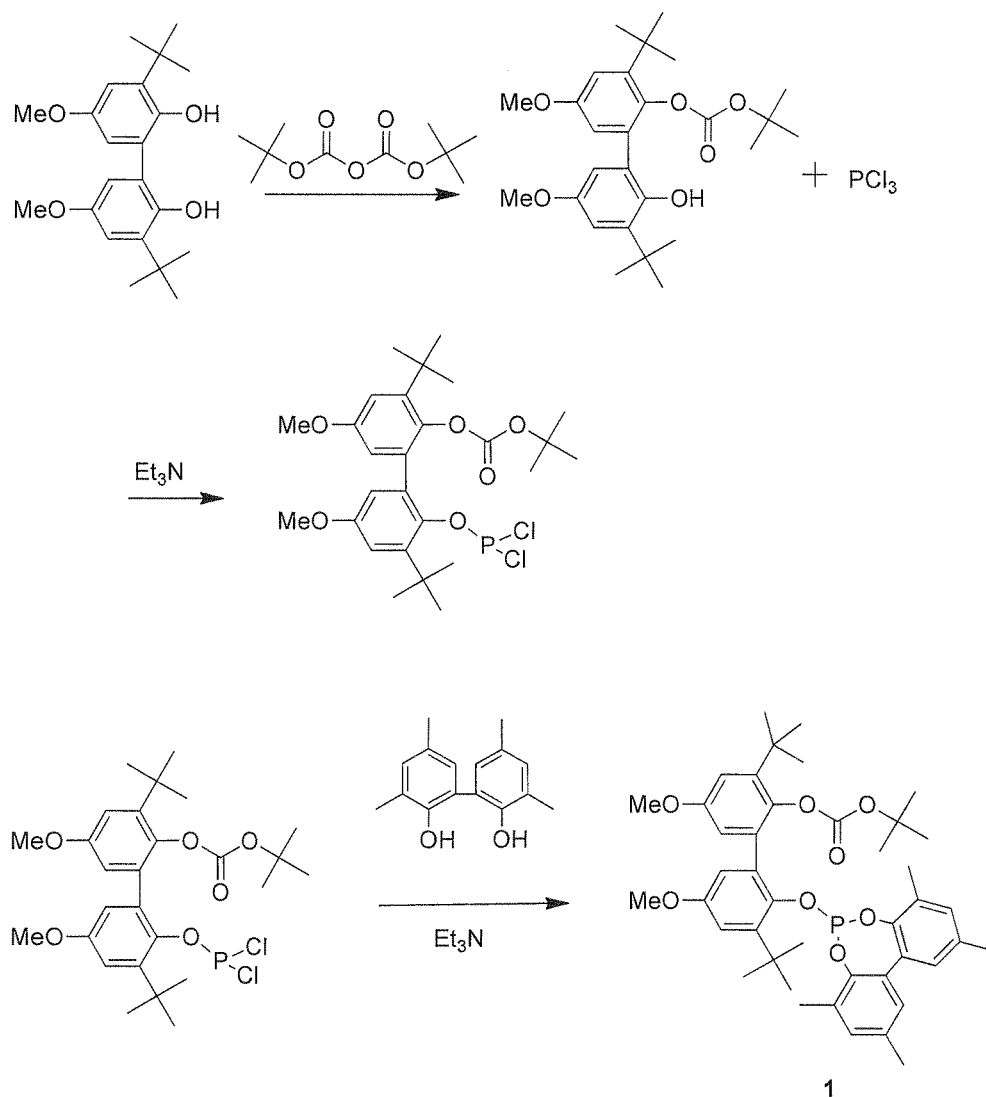
Menezes, Pierre Granger, Roy E. Hoffman and Kurt W. Zilm, Pure Appl. Chem., 2008, 80, 59-84).

Nuclear resonance spectra were recorded by means of a Bruker Avance 300 or Bruker Avance 400; gas chromatography analysis was effected using an Agilent GC 7890A.

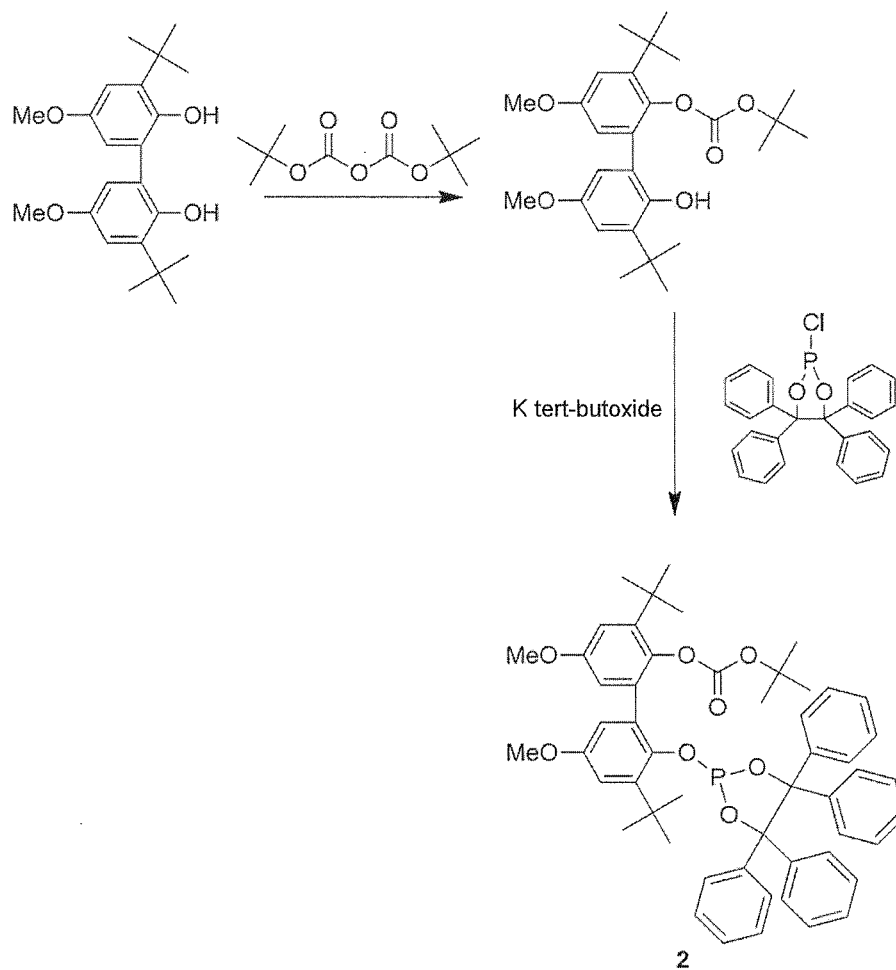
- 5 The ligands according to the invention can be prepared here in various ways. Three possible ways are shown in the schemes which follow (A to C).

The reaction routes shown are merely illustrative and are shown in highly simplified form. Thus, if required, base can be used additionally in all the steps. In addition, the bases specified in the individual synthesis stages may be replaced by other commercially available bases known to
10 those skilled in the art.

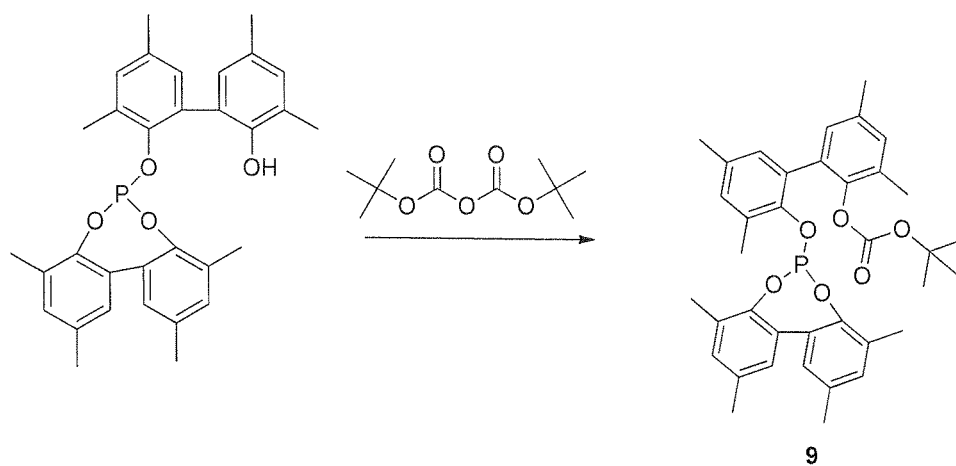
Reaction route A:



Reaction route B:



Reaction route C:

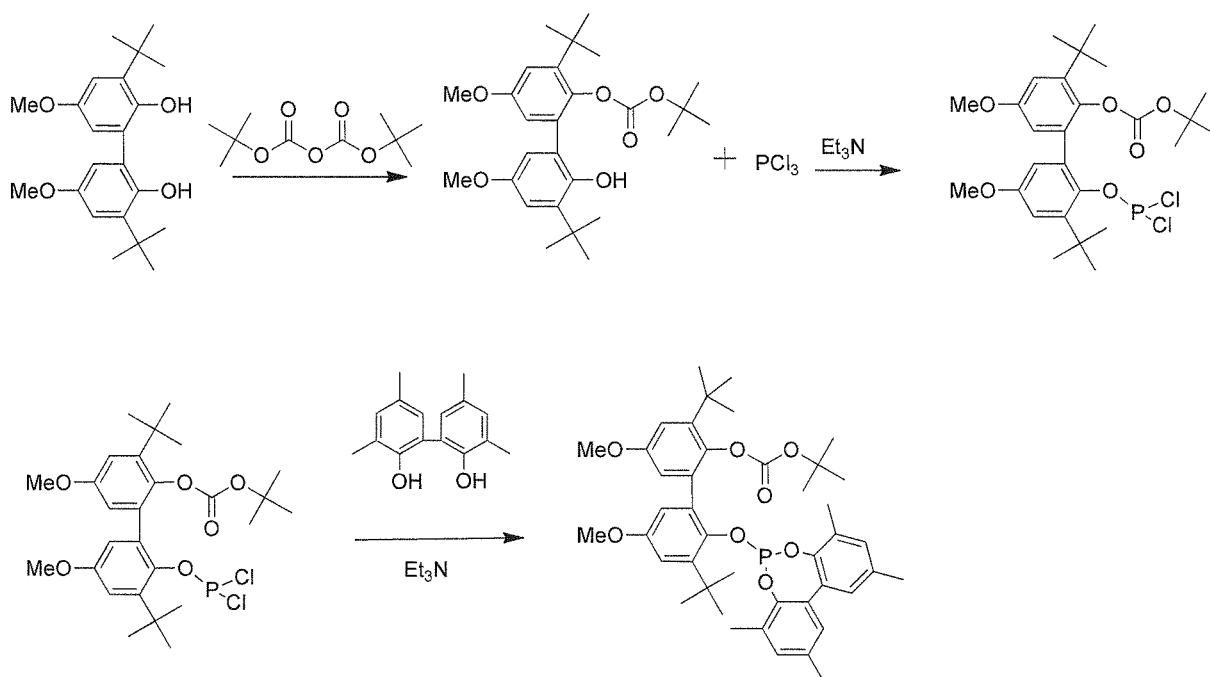


Synthesis of ligand 1

5

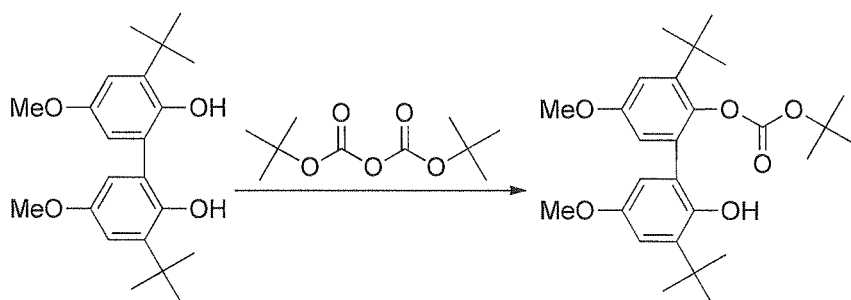
Reaction

scheme:



10

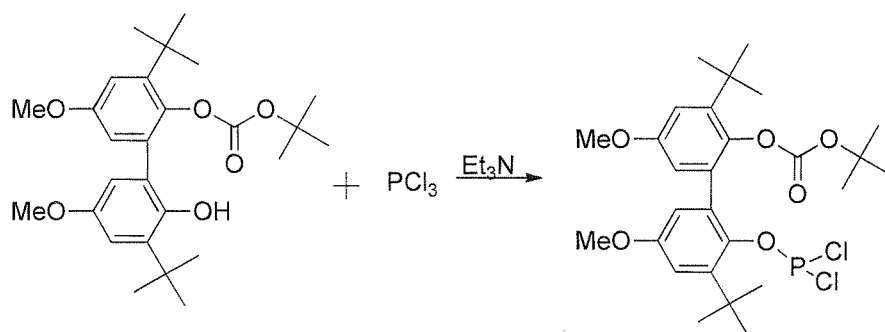
Introduction of the BOC group:



- 15 In a 2 l Schlenk flask, 400 mmol (143.8 g) of 3,3'-di-tert-butyl-5,5'-dimethoxy-[1,1'-biphenyl]-2,2'-diol and 40 mmol (4.8 g) of N,N-dimethylaminopyridine (DMAP) were dissolved in 900 ml of CH_2Cl_2 . Subsequently, at room temperature, 400 mmol (88 g) of di-tert-butyl dicarbonate were

dissolved in 280 ml of CH_2Cl_2 , transferred to a 500 ml dropping funnel and added dropwise to the biphenol/DMAP solution at 32°C within one hour. The solution was stirred at room temperature overnight. The next morning, the solvent was removed under reduced pressure. The slightly waxy, reddish solid was admixed with 800 ml of n-heptane and stirred overnight. This gave a
 5 white residue which was filtered off, washed twice with 50 ml of n-heptane and then dried. The target product was obtained as a white solid (161.6 g, 84%). ^1H NMR (toluene- d_8): 95% and further impurities.

Reaction of tert-butyl (3,3'-di-tert-butyl-2'-hydroxy-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate
 10 with phosphorus trichloride:

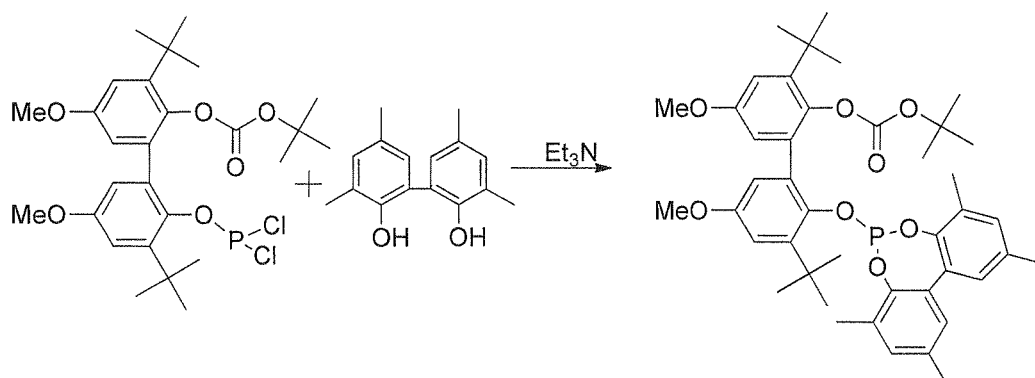


In a 250 ml Schlenk flask which had been repeatedly evacuated and filled with inert gas, 12 g (0.026 mol) of tert-butyl (3,3'-di-tert-butyl-2'-hydroxy-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate
 15 were dissolved by stirring in 120 ml of dried toluene and 12.8 ml (0.091 mol) of triethylamine.

In a second 500 ml Schlenk flask, 100 ml of dried toluene were first stirred together with 8.1 ml (0.091 mol) of phosphorus trichloride. Subsequently, the phosphorus trichloride-toluene solution was added dropwise to the previously prepared carbonate-amine-toluene solution at room temperature within 30 minutes. On completion of addition, the mixture was heated to 80°C for 30
 20 minutes and cooled to room temperature overnight.

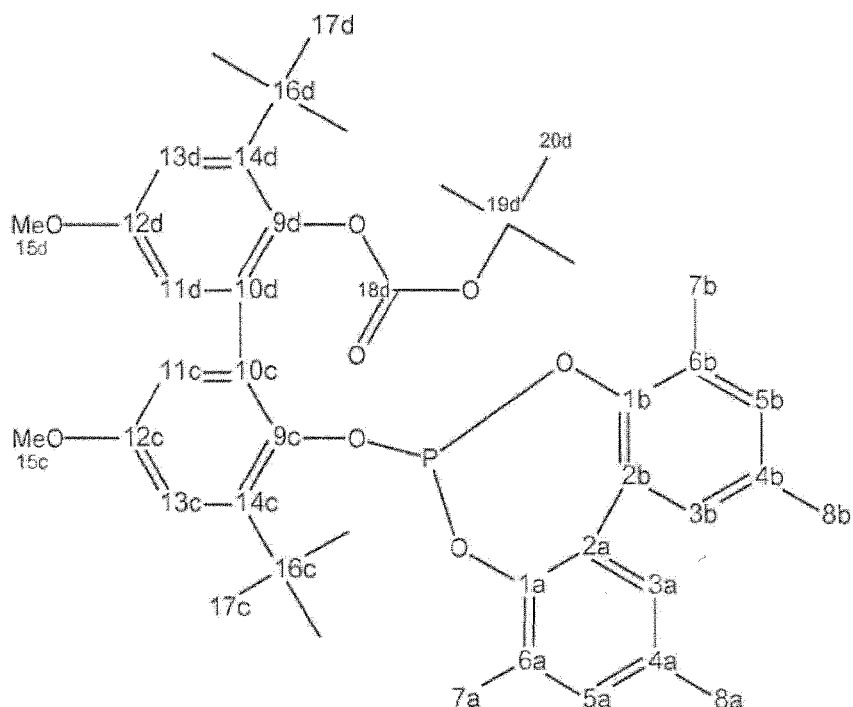
The next morning, the mixture was filtered, the solids were washed with 50 ml of dried toluene, and the filtrate was concentrated to dryness. The target product was obtained as a solid (13.1 g, 89%). ^{31}P NMR (202.4 MHz, toluene- d_8): 203.2 and 203.3 ppm (100%).

Reaction of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate with 3,3',5,5'-tetramethyl-(1,1'-biphenyl)-2,2'-diol



In a 1 l Schlenk flask which had been repeatedly evacuated and filled with inert gas, 24.7 g (0.044 mol) of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate were dissolved in 400 ml of acetonitrile.

- 5 In a second Schlenk flask (1 l) which had been repeatedly evacuated and filled with inert gas, 10.8 g (0.044 mol) of 3,3',5,5'-tetramethyl-(1,1'-biphenyl)-2,2'-diol were dissolved by stirring in 200 ml of acetonitrile and 13.1 ml (0.011 mol) of dried triethylamine. Subsequently, the chlorophosphite solution was slowly added dropwise to the biphenol-triethylamine solution and the mixture was stirred overnight.
- 10 The mixture was then filtered and the residue was washed twice with 15 ml of acetonitrile. The filtrate was concentrated under reduced pressure until a solid precipitated out. The latter was filtered and dried. The target product was obtained as a white solid (28.5 g, 87%). ³¹P NMR (202.4 MHz, toluene-d₈): 139.4 ppm (98.5%).



(1)

Spectrometer: Bruker Avance 500 MHz FT spectrometer

5 Solvent: 1,1,2,2-tetrachloroethane (TCE)

Temperature: 353 K (80°C)

Referencing: ^1H NMR, ^{13}C NMR: TMS = 0

$$^{31}\text{P} \text{ NMR: } \text{SR}_{31\text{P}} = \text{SR}_{1\text{H}} * (\text{BF}_{31\text{P}}/\text{BF}_{1\text{H}}) = \text{SR}_{1\text{H}} * 0.404807$$

10 Table 1: Assignment of ^1H chemical shifts of 1

δ / ppm	Intensity	Multiplicity	Assignment
1.13	9H	s	17d (tert-butyl)
1.20	9H	s	20d (O-tert-butyl)
1.35	9H	s	17c (tert-butyl)
2.02	3H	broad s	7b (methyl)
2.28	3H	s	8b (methyl)
2.31/2.32	6H	broad s	7a (methyl) / 8a (methyl)
3.75	3H	s	15c (O-methyl)

3.78	3H	s	15d (O-methyl)
6.68	1H	d	11d
6.83	1H	d	11c
6.88	2H (1+1)	m	5b, 13d
6.94	1H	d	13c
6.96	1H	s	5a
6.99	2H (1+1)	s	3a + 3b

s: singlet

d: doublet

t: triplet

5 q: quartet

m: multiplet

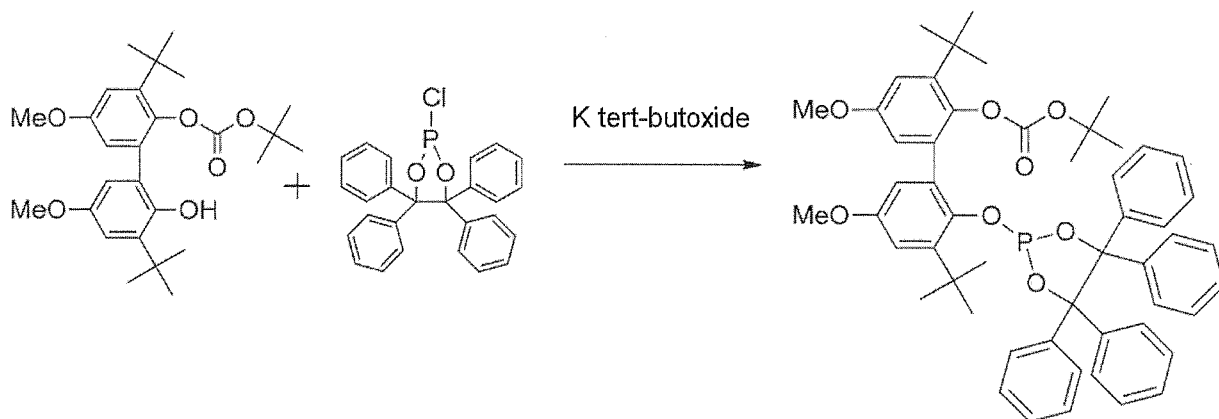
Table 2: Assignment of ^{13}C chemical shifts of 1

δ / ppm	Intensity	Group	Assignment
16.35	1	CH_3	7b
16.61	1	CH_3	7a
20.66	1	CH_3	8b
20.71	1	CH_3	8a
27.38	3	CH_3	20d
30.27	3	CH_3	17d
30.41	3	CH_3	17c
34.85	1	C_q	16c
35.02	1	C_q	16d
55.67	1	CH_3	15d
55.79	1	CH_3	15c
81.67	1	C_q	19d
113.86	1	CH	11c
114.01	1	CH	11d
114.14	1	CH	13c
114.60	1	CH	13d
127.65	1	CH	3b

127.88	1	CH	3a
128.72	1	C _q	10d
130.01	1	C _q	6b
130.77	1	C _q	6a
130.86	1	CH	5b
130.92	1	CH	5a
131.37	1	C _q	2b
131.50	1	C _q	2a
133.49	1	C _q	4b
133.65	1	C _q	4a
135.68	1	C _q	10c
142.09	1	C _q	9d
142.37	1	C _q	14d
143.60	1	C _q	9c
144.05	1	C _q	14c
145.88	1	C _q	1b
146.00	1	C _q	1a
151.27	1	C _q	18d
154.18	1	C _q	12d
157.19	1	C _q	12c

Synthesis of ligand 2

- 5 Reaction of tert-butyl (3,3'-di-tert-butyl-2'-hydroxy-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate with 2-chloro-4,4,5,5-tetraphenyl-1,3,2-dioxaphospholane

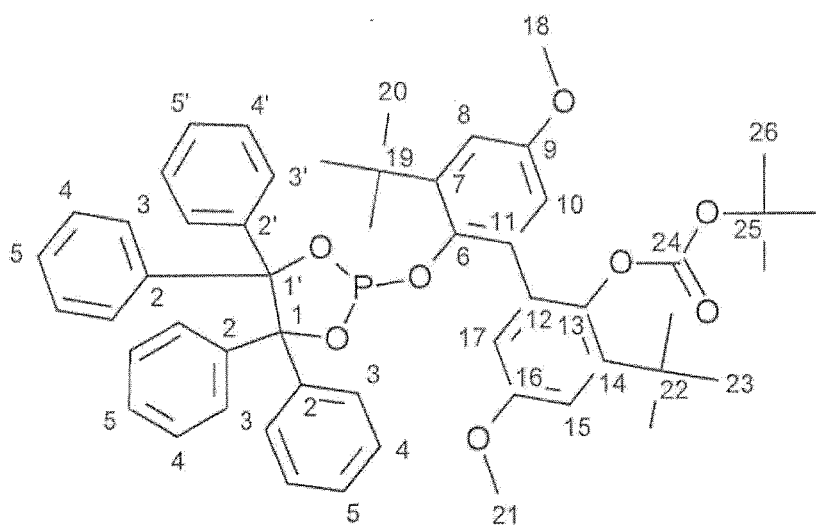


In a 250 ml Schlenk flask which had been repeatedly evacuated and filled with inert gas, 9.1 g (0.021 mol) of 2-chloro-4,4,5,5-tetraphenyl-1,3,2-dioxaphospholane were dissolved in 75 ml of dried toluene.

In a second Schlenk flask (250 ml), 9.2 g (0.02 mol) of tert-butyl (3,3'-di-tert-butyl-2'-hydroxy-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate and 2.3 g (0.02 mol) of potassium tert-butoxide were dissolved in 75 ml of dried toluene while stirring.

Subsequently, the carbonate/potassium tert-butoxide/toluene mixture was slowly added dropwise at room temperature to the chlorophosphite solution, and the mixture was stirred at room temperature overnight.

Thereafter, the solvent was removed under reduced pressure. The resultant residue was stirred in 75 ml of dried acetonitrile for 5 hours. The solids were filtered, washed with dried acetonitrile and dried. The target product was obtained as a white solid (15.3 g, 90%). ^{31}P NMR (202.4 MHz, toluene- d_8): 147.0 ppm (99%).



(2)

Referencing:

 $^1\text{H NMR}$: TMS = 0 ppm, $^{31}\text{P NMR}$: $\text{SR}_{31\text{P}} = \text{SR}_{1\text{H}} * (\text{BF}_{31\text{P}} / \text{BF}_{1\text{H}}) = \text{SR}_{1\text{H}} * 0.404807$

5

Table 3: Assignment of the ^{13}C chemical shifts of **2**

δ [ppm]	Intensity	Group	Assignment
157.31	1 x C	C_q	C9
155.29	1 x C	C_q	C16
152.22	1 x C	C_q	C24
143.68	1 x C	C_q	C13
143.66/143.54	2 x C	C_q	C7, C14
143.35	1 x C	C_q	C6
142.99/142.80 142.72/142.49	4 x C	C_q	C2
135.65	1 x C	C_q	C11
132.78	1 x C	C	C12
131.30/130.45 129.66/129.04	8 x C	CH	(c4)
127.40-126.90	12 x C	CH	C3, C5
115.17	1 x C	CH	C10
114.89	1 x C	CH	C8
114.83	1 x C	CH	C15
114.10	1 x C	CH	C17
95.64/94.85	2 x C	C_q	C1, C1'
81.32	1 x C	C_q	C25
55.08	1 x C	CH_3	C21
55.04	1 x C	CH_3	C18
35.25	1 x C	C_q	C19
35.09	1 x C	C_q	C22
30.77	3 x C	CH_3	C20

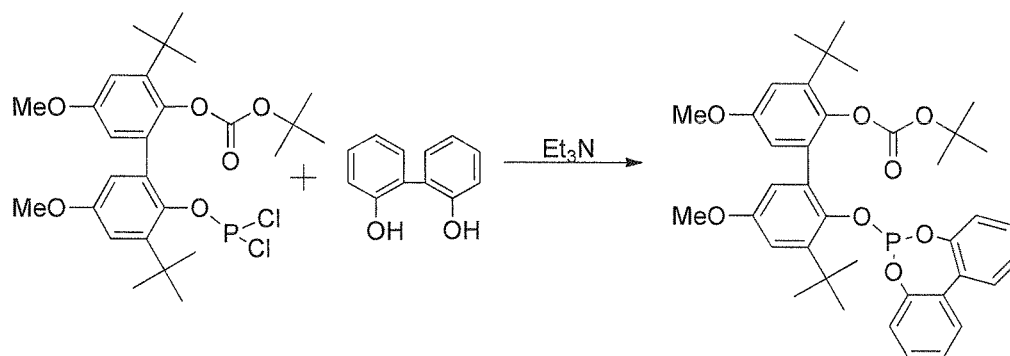
30.64	3 x C	CH ₃	C23
27.56	3 x C	CH ₃	C26

Table 4: Assignment of the ¹H chemical shifts of **2**

δ [ppm]	Intensity	Multiplicity	Assignment
7.54	4H	m	H3,H4,H5 H8, H10 H15, H17
7.21	3H	m	
7.09	5H	m	
6.99-6.89	6H	m	
6.83	6H	m	
3.50	3H	s	H19
3.41	3H	s	H22
1.39	9H	s	H20
1.31	9H	s	H23
1.21	9H	s	H26

5 Synthesis of ligand 3

Reaction of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate with 2,2'-biphenol

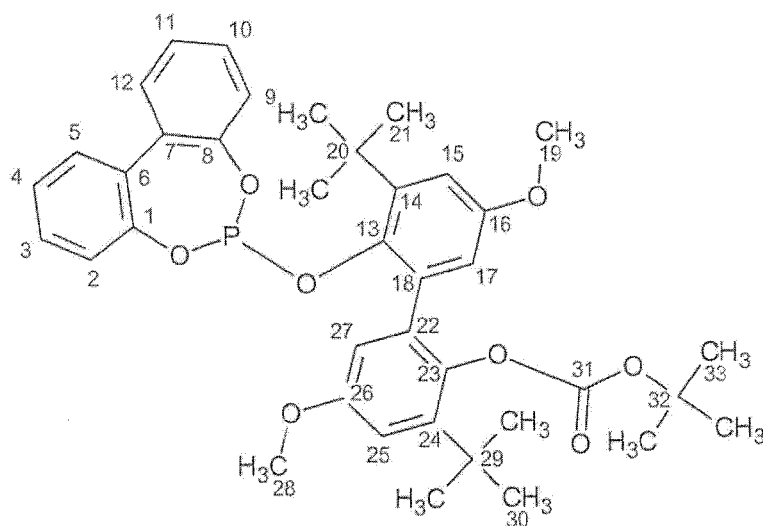


10

In a 250 ml Schlenk flask which had been repeatedly evacuated and filled with inert gas, 10.5 g (0.019 mol) of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate were dissolved in 50 ml of degassed acetonitrile while stirring.

In a second Schlenk flask (250 ml) which had been repeatedly evacuated and filled with inert gas, 3.6 g (0.019 mol) of 2,2'-biphenol were dissolved in 40 ml of degassed acetonitrile and 6.3 ml (0.045 mol) of dried triethylamine while stirring. Subsequently, the chlorophosphite mixture was slowly added dropwise at room temperature to the biphenol/triethylamine solution, and the mixture was stirred at room temperature overnight. The resultant solids were filtered and dried. The target product was obtained as a white solid (11.5 g, 90%). ³¹P NMR (202.4 MHz, toluene-d₈): 146.2 ppm (100%).

20



(3)

5 Table 5: Assignment of the ^{13}C chemical shifts of 3

δ [ppm]	Intensity	Group	Assignment
157.46	1 x C	C_q	C16
155.51	1 x C	C_q	C26
151.76	1 x C	C_q	C31
150.51/149.92	each 1 x C	C_q	C1 + C8
144.07	1 x C	C_q	C24
143.62	1 x C	C_q	C13
142.70	1 x C	C_q	C23
142.67	1 x C	C_q	C14
135.75	1 x C	C_q	C18
132.13/131.73	1 x C	C_q	C6 + C7
131.30	1 x C	C_q	C22
129.87/128.94	each 1 x C	CH	C5 + C12
128.98/128.91	each 1 x C	CH	C3 + C10
125.16/124.98	each 1 x C	CH	C4 + C11
123.54/122.40	each 1 x C	CH	C2 + C9
115.14	1 x C	CH	C25
114.93	1 x C	CH	C15
114.85	1 x C	CH	C27
114.72	1 x C	CH	C17
81.36	1 x C	C_q	C32
55.14	1 x C	CH_3	C28
55.10	1 x C	CH_3	C19
35.57	1 x C	C_q	C29
35.22	1 x C	C_q	C20

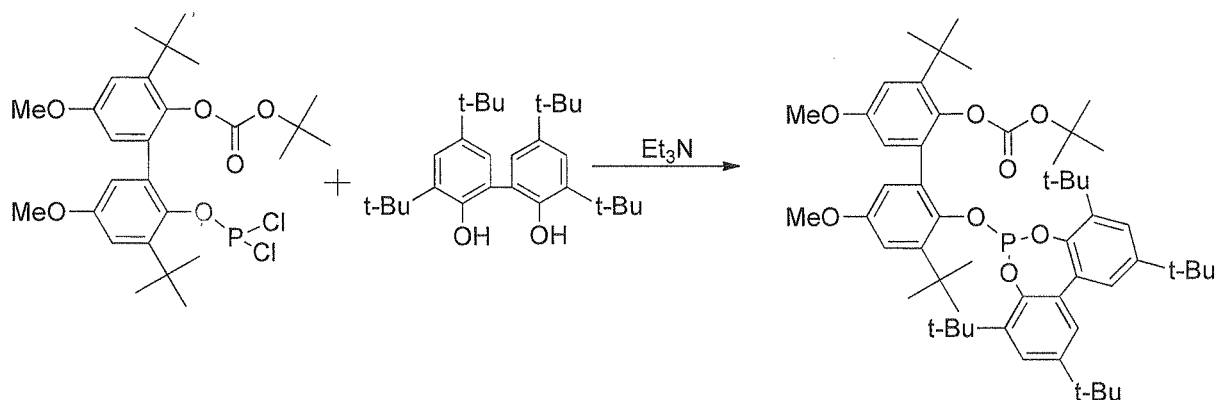
30.78	3 x C	CH ₃	C30
30.62	3 x C	CH ₃	C21
27.45	3 x C	CH ₃	C33

Table 6: Assignment of the ¹H chemical shifts of **3**

δ [ppm]	Intensity	Multiplicity	Assignment
7.26	1H	d (J = 7.7 Hz)	H2,H9,H3,H10 H5,H12,H15,H25
7.15-7.09	6H	m	
7.02	1H	t (J = 7.7 Hz)	
6.95/6.91	2 x 1H	2 x t (J ~ 7.5 Hz)	H4/H11
6.93	1H	d (J=3 Hz)	H17
6.87	1H	d (J=3 Hz)	H27
3.48	3H	s	H19
3.42	3H	s	H29
1.50	9H	s	H20
1.35	9H	s	H21
1.16	9H	s	H33

5 Synthesis of ligand 4

Reaction of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate with 3,3',5,5'-tetra-tert-butylbiphenol



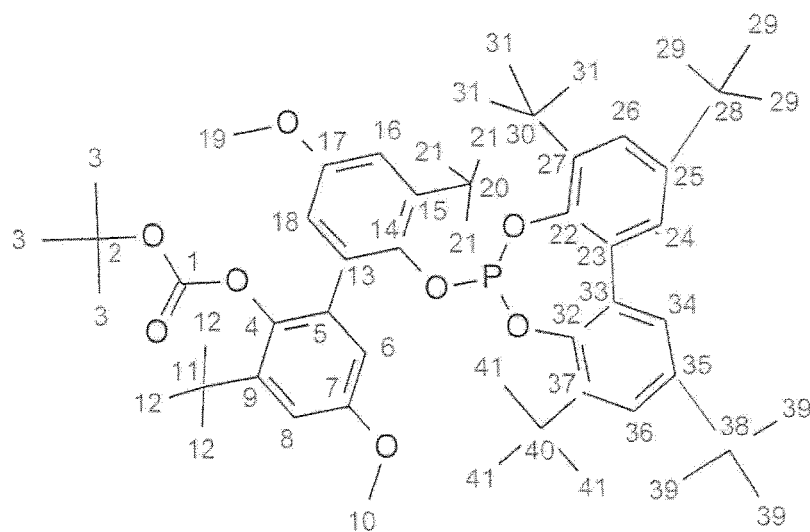
10

In a 250 ml Schlenk flask which had been repeatedly evacuated and filled with inert gas, 7.0 g (0.0125 mol) of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate were dissolved in 100 ml of dried acetonitrile.

- 15 In a second Schlenk flask (100 ml) which had been repeatedly evacuated and filled with inert gas, 5.1 g (0.0125 mol) of 3,3',5,5'-tetra-tert-butylbiphenol were dissolved in 60 ml of dried acetonitrile and 4.2 ml (0.03 mol) of dried triethylamine while stirring. Subsequently, the biphenol-

triethylamine solution was slowly added dropwise at room temperature to the chlorophosphite solution and the mixture was stirred overnight. A portion of the solvent was removed under reduced pressure. The precipitated solids were filtered off and dried. The target product was obtained as a white solid (10.2 g, 91%). ^{31}P NMR (202.4 MHz, toluene- d_8): 142.7 ppm (100%).

5



(4)

Table 7: Assignment of the chemical shifts of 4

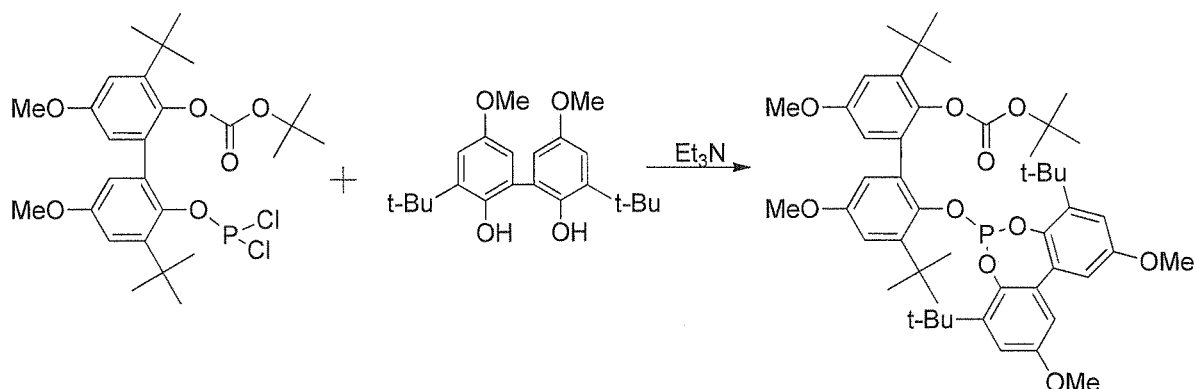
10

Number	$\delta\text{-}^1\text{H}$ / ppm	$\delta\text{-}^{13}\text{C}$ / ppm
<u>1</u>	=	<u>151.6</u>
<u>2</u>	=	<u>81.5</u>
<u>3</u>	<u>1.18</u>	<u>27.3</u>
<u>4</u>	=	<u>142.3</u>
<u>5</u>	=	<u>129.9</u>
<u>6</u> <u>18</u>	<u>6.76</u> <u>6.67</u>	<u>114.7</u> <u>114.1</u>
<u>7</u> <u>17</u>	=	<u>154.4</u> <u>156.8</u>
<u>8</u> <u>16</u>	<u>6.93</u> <u>6.88</u>	<u>113.5</u> <u>115.4</u>
<u>9</u>	=	<u>143.6</u>

<u>10</u> <u>19</u>	<u>3.78</u> <u>3.74</u>	<u>55.4</u> <u>55.7</u>
<u>11</u>	=	<u>35.0</u>
<u>12</u>	<u>1.39</u>	<u>30.6</u>
<u>21</u> <u>29</u> <u>31</u> <u>39</u> <u>41</u>	<u>1.03</u> <u>1.24</u> <u>1.29</u> <u>1.34</u> <u>1.39</u> <u>1.48</u>	<u>31.2</u> <u>31.0</u> <u>31.4</u> <u>31.5</u> <u>30.7</u> <u>31.3</u>
<u>13</u>	=	<u>136.4</u>
<u>14</u>	=	<u>142.1</u>
<u>15</u>	=	<u>140.1</u>
<u>20</u>	=	<u>34.6</u>
<u>22</u> <u>32</u>	=	<u>146.0</u> <u>146.9</u>
<u>24</u> <u>34</u>	<u>7.06</u> <u>7.30</u>	<u>126.6</u> <u>123.8</u>
<u>25</u> <u>35</u>	=	<u>145.1</u> <u>146.3</u>
<u>26</u> <u>36</u>	<u>7.08</u> <u>7.42</u>	<u>126.3</u> <u>124.1</u>
<u>28</u> <u>38</u>	=	<u>35.1</u> <u>35.2</u>
<u>30</u> <u>40</u>	=	<u>34.6</u> <u>35.4</u>
<u>23</u> <u>33</u>	=	<u>135.5</u> <u>132.6</u>
<u>27</u> <u>37</u>	=	<u>140.0</u> <u>141.9</u>

Synthesis of ligand 5

Reaction of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate with 3,3-di-tert-butyl-5,5-dimethoxybiphenol



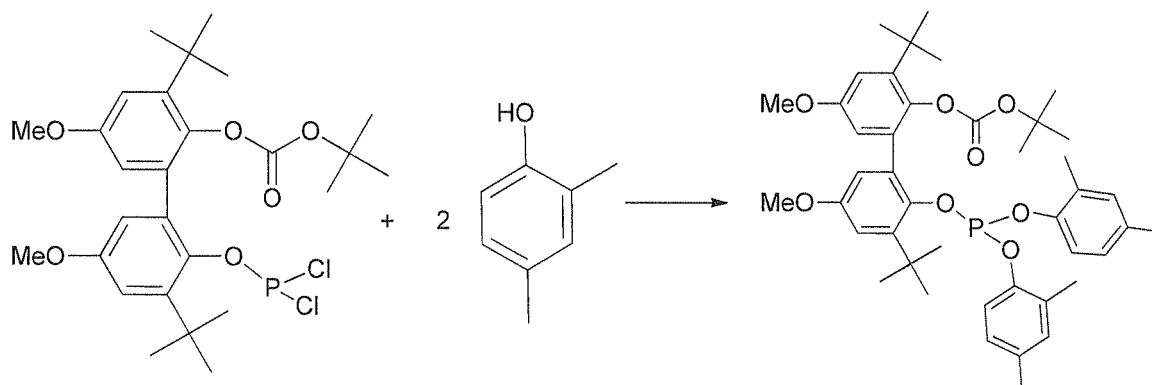
5 In a 250 ml Schlenk flask which had been repeatedly evacuated and filled with inert gas, 7 g (0.0125 mol) of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate were dissolved in 100 ml of dried acetonitrile.

In a second Schlenk flask (100 ml) which had been repeatedly evacuated and filled with inert gas, 4.5 g (0.0125 mol) of 3,3-di-tert-butyl-5,5-dimethoxybiphenol were dissolved in 60 ml of dried
10 acetonitrile and 4.2 ml (0.03 mol) of degassed triethylamine. Subsequently, the biphenol-triethylamine solution was slowly added dropwise at room temperature to the chlorophosphite solution and the mixture was stirred at room temperature overnight.

A portion of the solvent was removed under reduced pressure. The precipitated solids were filtered off and dried. The target product was obtained as a white solid (10.5 g, 96%). ³¹P NMR
15 (202.4 MHz, toluene-d₈): 140.9 (95.2%) and further impurities (further impurities = P-H compounds, oxide compounds, as yet incompletely converted chlorophosphite).

Synthesis of ligand 11

20 Reaction of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate with 2,4-dimethylphenol



In a 500 ml Schlenk flask which had been repeatedly evacuated and filled with inert gas, 6.8 g (0.012 mol) of tert-butyl (3,3'-di-tert-butyl-2'-((dichlorophosphino)oxy)-5,5'-dimethoxy-[1,1'-biphenyl]-2-yl)carbonate were dissolved in 100 ml of dried acetonitrile.

- 5 In a second Schlenk flask (250 ml) which had been repeatedly evacuated and filled with inert gas, 6 g (6 ml; 0.048 mol) of 2,4-dimethylphenol were dissolved in 100 ml of dried acetonitrile and 5 g (7 ml; 0.059 mol) of degassed triethylamine. Subsequently, the biphenol-triethylamine solution was slowly added dropwise at room temperature to the chlorophosphite solution and the mixture was stirred at room temperature overnight and cooled in an ice bath the next morning.
- 10 A portion of the solvent was removed under reduced pressure. This formed a slime-like solution which solidified after prolonged drying. The target product was obtained as a white solid (11.8 g, 62%). ^{31}P NMR (202.4 MHz, toluene- d_8): 139.1 (92.8%) and further impurities (further impurities = P-H compounds, oxide compounds, as yet incompletely converted chlorophosphite).

15 Procedure for the catalysis experiments

Experiment description - general

- 20 In a 100 ml autoclave from Parr Instruments, various olefins were hydroformylated at various temperatures and synthesis gas pressure 20 or 50 bar ($\text{CO}/\text{H}_2 = 1:1$ (% by vol.)). As precursor, 0.005 g of $\text{Rh}(\text{acac})(\text{CO})_2$ was initially charged for a catalyst concentration of 40 ppm of Rh based on the overall reaction mixture, and correspondingly 0.0123 g of $\text{Rh}(\text{acac})(\text{CO})_2$ for a concentration of 100 ppm of Rh. The solvent used was 40 to 46 g of toluene in each case. Ligand 1 was used in different molar excesses relative to rhodium. In addition, as GC standard, about 0.5
- 25 g of tetraisopropylbenzene (TIPB) was added. About 6 g of reactant were metered in after the reaction temperature envisaged had been attained.

During the reaction, the pressure was kept constant via metered addition of synthesis gas with a

mass flow meter and pressure regulator. The stirrer speed was 1200 min^{-1} . Samples were taken from the reaction mixture after 12 hours. The results of the experiments are summarized in Table 8 (yield = total yield of aldehyde and alcohol; S = selectivity for the linear product).

(acac = acetylacetonate)

5

Table 8:

Entry	Starting material	p in [bar]	cRh in ppm	P: Rh	Yield in %	S (n-aldehyde) in %
1	cis-2-butene	20	40	4	58.0	45.3
2	cis-2-butene	50	40	4	96.5	40.7
3	1-butene	20	40	4	49.2	51.9
4	1-butene	50	40	2	97.4	46.8
5	1-butene	50	92	8	99.5	50.3
6	1-octene	50	40	9	97.1	43.2

Reaction conditions: ligand **1**, reaction temperature: 120°C

10

Lines 1 and 2 list experiments on the rhodium-catalysed hydroformylation of the cis-2-butene reactant with ligand **1**. At a synthesis gas pressure of 20 bar, in experiment 1, 58.0 mol% of pentanal is formed with a pentanal selectivity of 45.3%. The proportion of hydrogenation to the alkane is low at about 1.3% to 1.5%. The formation of pentanol is not observed. An increase in the synthesis gas pressure leads to a rise in the pentanal yield to 95.1 mol%, but the regioselectivity falls to about 40%.

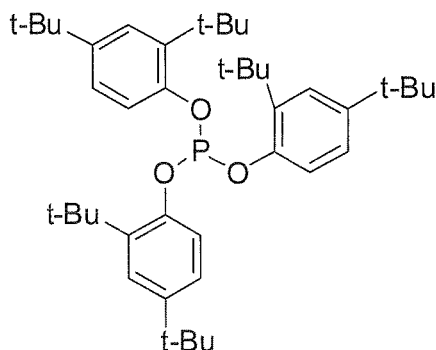
15

Lines 3 to 5 list hydroformylations of 1-butene. At 20 bar (line 3), at a ligand excess of 4:1, a yield

of about 49% and a selectivity for n-pentanal of about 52% are attained. At synthesis gas pressure 50 bar, a n-pentanal selectivity of 50% is obtained with virtually full conversion (lines 4 and 5). Alkane formation is low. In the experiment in line 4, the molar excess of ligand was reduced to about 2:1. The yield rises to 97.4%; the pentanal selectivity falls slightly to 46.8%. In line 5, the Rh concentration was increased to about 100 ppm and the ligand excess was increased to 8:1 relative to rhodium. The aldehyde yield rises to 99.5%; the regioselectivity likewise rises to 50.3%.

It is also possible to hydroformylate longer-chain olefins such as 1-octene with good n selectivity for the product (line 6).

Table 9 contains experiments on the hydroformylation of an n-octene mixture having about 2% 1-octene, 40% 2-octenes, 36% 3-octenes and 23% 4-octenes (yield = total yield of aldehyde and alcohol; S = selectivity for the linear n-pentanal product). In this case, the experiments were conducted both with the inventive ligand **1** and with the comparative TDTBPP ligand.



Tris(2,4-di-tert-butylphenyl)phosphite (TDTBPP)

Table 9:

Entry	T in [°C]	cRh in ppm	P:Rh	Yield in %	S (linear product) in %
1 ^a	80	90	20	99.0	7.2

2 ^a	80	90	5	99.0	11.1
3 ^a	90	90	20	99.2	10.6
4 ^b	90	280	20	97.9	4.7
5 ^a	100	50	20	99.0	15.4
6 ^b	100	90	20	96.4	6.9
7 ^a	110	90	20	99.2	16.5
8 ^b	110	90	20	99.0	9.7
9 ^a	120	90	20	95.2	22.9
10 ^b	120	90	20	99.0	14.4
11 ^a	130	90	20	98.0	30.5
12 ^b	130	76	20	98.8	23.9
13 ^a	140	90	20	97.4	31.6
14 ^b	140	56	20	98.0	23.9
15 ^a	120	90	4	98.9	28.8
16 ^a	120	40	9.5	98.6	29.1

17 ^a	120	40	20	99.1	28.2
-----------------	-----	----	----	------	------

Reaction conditions: 50 bar of synthesis gas (CO/H₂); substrate: n-octenes;

a): ligand **1**; b): ligand TDTBPP.

- 5 Entries 1 to 14 each show results of experiments at a constant temperature in the range from 80°C to 140°C, in each case for the inventive ligand **1** and for the comparative ligand (TDTBPP). As is clearly apparent, the inventive ligand **1** in all cases shows a distinctly higher n selectivity for the desired product combined with very good overall yields. The formation of alkanes and alcohols is insignificant. If entries 13 and 14 are compared, ligand **1** has nearly an 8% increase in
- 10 selectivity compared to the commercially available comparative ligand. Entries 15 to 17 show the use of ligand **1** with different molar excesses relative to rhodium. In all cases, it was possible to achieve very good n selectivities.

- 15 Table 10 gives the results for the hydroformylation of di-n-butene. Di-n-butene is a mixture of isomers of n-octenes (about 16 %), 3-methylheptenes (about 65%) and 3,4-dimethylhexenes (about 19%) (yield = total yield of aldehyde and alcohol; S = selectivity for the linear product) .

Table 10:

Entry	T in [°C]	p in [bar]	cRh in ppm	P:Rh	Yield in %	S (nl) [*] in %
1	120	50	40	10	85.1	30.8
2	120	50	90	7	89.8	28.3
3	120	50	90	7	91.5	30.9
4	120	50	100	5	93.0	36.5

5	120	50	75	20	94.6	29.8
6	130	50	75	20	95.3	32.7
7	110	50	75	20	91.9	24.0
8	120	40	75	20	94.8	29.0

Reaction conditions: ligand **1**; substrate: di-n-butene

* Proportion of the aldehydes formed through terminal hydroformylation (essentially nonanal, 4-methyloctanal, 3-ethylheptanal, 6-methyloctanal, 4,5-dimethylheptanal and 3-ethyl-4-methylhexanal)

The above Table 10 contains experimental results for the rhodium-catalysed hydroformylation of di-n-butene with ligand **1**. Entries 1 to 5 were conducted at 120°C and 50 bar, and entry 8 at 40 bar. Entries 2 and 3 are a double determination with a ligand excess of 7 relative to rhodium and a rhodium concentration based on the overall reaction mixture of 80 ppm; entry 1 was performed at an excess of about 10:1 and an Rh concentration of 40 ppm. Entry 4 describes a reduction in the excess to 5:1 compared to entries 2 and 3. Entries 5 to 8 are experiments with a high ligand excess of about 20:1. Entries 5 to 7 were conducted at different temperatures. Entry 8 differs from entry 5 by the pressure. Analogously to the experiments with the n-octene mixture, high n selectivities between 28 and 36 mol% are found in all of experiments 1 to 6 and 8. At lower temperature (entry 7), the n selectivity is reduced to about 24%. n-Octenes are converted virtually quantitatively within the experimental duration of 12 hours; the conversion of the 3-methylheptenes is > 96%. The 3,4-dimethylhexenes are converted to an extent of 73%-86%. It was thus possible to show with the aid of the above examples that the novel catalyst system is also suitable for hydroformylation of technical olefin mixtures containing mainly branched olefins containing internal double bonds, and a high proportion of desired terminally hydroformylated products can be obtained.

Table 11 gives the results for the hydroformylation of n-octenes with ligand **3** (yield = total yield of aldehyde and alcohol; S = selectivity for the linear product).

Table 11:

Entry	T in [°C]	Yield in %	S (linear product) in %
1	80	30.0	8.6
2	90	85.9	4.9
3	100	91.3	5.9
4	110	98.5	8.3
5	120	99.0	11.9

Reaction conditions: ligand **3**; 50 bar of synthesis gas; substrate: n-octenes; cRh = 90 ppm; L/Rh
5 = 20.

The above table contains a compilation of the experimental data for the hydroformylation of n-octenes with ligand **3** in the form of a temperature series from 80°C to 120°C at synthesis gas pressure 50 bar, an Rh concentration of about 100 ppm and a ligand excess of about 20:1. The n-nonanal selectivities in this series of experiments are low at 4.9 to 11.9 mol%, but the aldehyde yields at higher temperatures are virtually quantitative and very good. Alkane formation is low at
10 < 1%; hydrogenation to alcohols is not observed.

Table 12 gives the results for the hydroformylation of di-n-butene. Di-n-butene is a mixture of
15 isomers of n-octenes (about 16%), 3-methylheptenes (about 65%) and 3,4-dimethylhexenes (about 19%) (yield = total yield of aldehyde and alcohol; S = selectivity for the linear product) .

Table 12:

Entry	Ligand	T in [°C]	p in [bar]	cRh in ppm	P:Rh	Yield in %
1	4	140	50	100	20:1	38
2	3	140	50	100	10:1	74
3	5	120	50	100	20:1	85
4	5	130	50	100	20:1	86
5	5	140	50	100	20:1	96
6	5	140	50	100	15:1	97
7	5	140	50	100	5:1	97

Reaction conditions: ligand **1**; substrate: di-n-butene

* Proportion of the aldehydes formed through terminal hydroformylation (essentially nonanal, 4-methyloctanal, 3-ethylheptanal, 6-methyloctanal, 4,5-dimethylheptanal and 3-ethyl-4-methylhexanal)

The above Table 12 contains experimental results for the rhodium-catalysed hydroformylation of di-n-butene with ligands **3**, **4** and **5**. While ligand **4** (entry 1) gives a moderate overall yield of aldehydes and alcohols, ligands **3** and **5** are notable for very good yields. Especially ligand **5** shows virtually quantitative yields at elevated temperature (140°C) (entries 5 to 7).

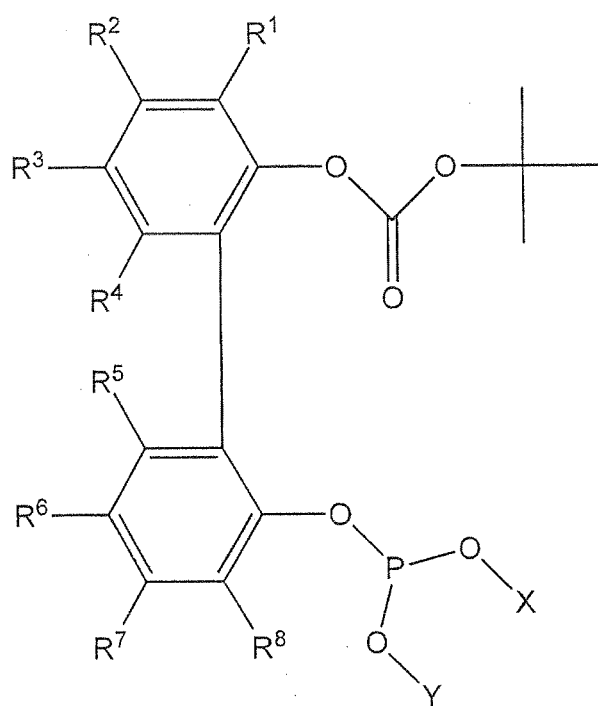
It was thus possible to show with the aid of the above examples that the novel catalyst system is also suitable for hydroformylation of technical olefin mixtures containing mainly branched olefins

containing internal double bonds, and a high proportion of desired hydroformylated products can be obtained.

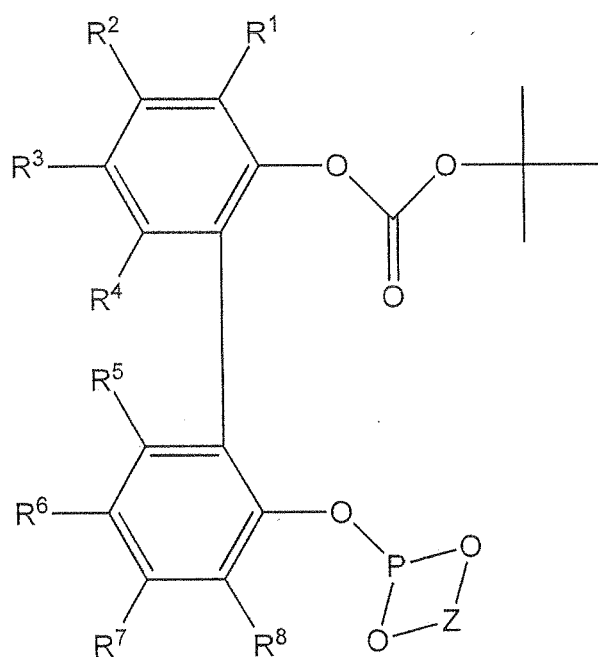
5 The inventive monophosphite ligands have a very good n selectivity in relation to the hydroformylation. Selectivity for the desired linear aldehydes is much greater here than, for example, in the case of the commercially available TDTBPP ligand. The stated objects are therefore achieved by these novel inventive ligands.

Claims

1. Ligand having one of the two general structures I and II:



I



II

where

5 $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8$ are each independently selected from: -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -SO₃Na, -NO₂, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

X and Y are each independently selected from:

10 -(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-O-(C₁-C₁₂)-alkyl, -(C₁-C₁₂)-alkyl-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-COO-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -(C₄-C₂₀)-heteroaryl, -(C₄-C₂₀)-heteroaryl-(C₁-C₁₂)-alkyl, -(C₅-C₈)-cycloalkyl-(C₄-C₂₀)-aryl-CO-(C₆-C₂₀)-aryl,

Z is selected from:

15 -(C₁-C₁₂)-alkyl-, -(C₆-C₂₀)-aryl-, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl-, -(C₁-C₁₂)-alkyl-(C₆-C₂₀)-aryl-, -(C₄-C₂₀)-heteroaryl-, -(C₆-C₂₀)-aryl-CO-(C₆-C₂₀)-aryl-, -(C₆-C₂₀)-aryl-(C₆-C₂₀)-aryl-;
where the alkyl, heteroalkyl, cycloalkyl, heterocycloalkyl, aryl and heteroaryl groups mentioned may be substituted.

2. Ligand according to Claim 1,

where X and Y are each independently selected from:

20 -(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-COO-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -(C₄-C₂₀)-heteroaryl, -(C₄-C₂₀)-heteroaryl-(C₁-C₁₂)-alkyl.

3. Ligand according to either of Claims 1 and 2,

25 where X and Y are each independently selected from:

-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-O-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-COO-(C₁-C₁₂)-alkyl.

4. Ligand according to any of Claims 1 to 3,

30 where Z is selected from:

-(C₁-C₁₂)-alkyl-, -(C₆-C₂₀)-aryl-, -(C₆-C₂₀)-aryl-(C₁-C₁₂)-alkyl-, -(C₆-C₂₀)-aryl-CO-(C₆-C₂₀)-aryl-, -(C₁-C₁₂)-alkyl-(C₆-C₂₀)-aryl-, -(C₆-C₂₀)-aryl-(C₆-C₂₀)-aryl-.

5. Ligand according to any of Claims 1 to 4,

where R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 are each independently selected from: -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.

6. Ligand according to any of Claims 1 to 5,

where X and Y are the same radicals.

7. Ligand according to any of Claims 1 to 6,

where R^3 and R^6 are each -O-(C₁-C₁₂)-alkyl.

8. Ligand according to any of Claims 1 to 7,

where R^3 and R^6 are each -OMe.

9. Ligand according to any of Claims 1 to 8,

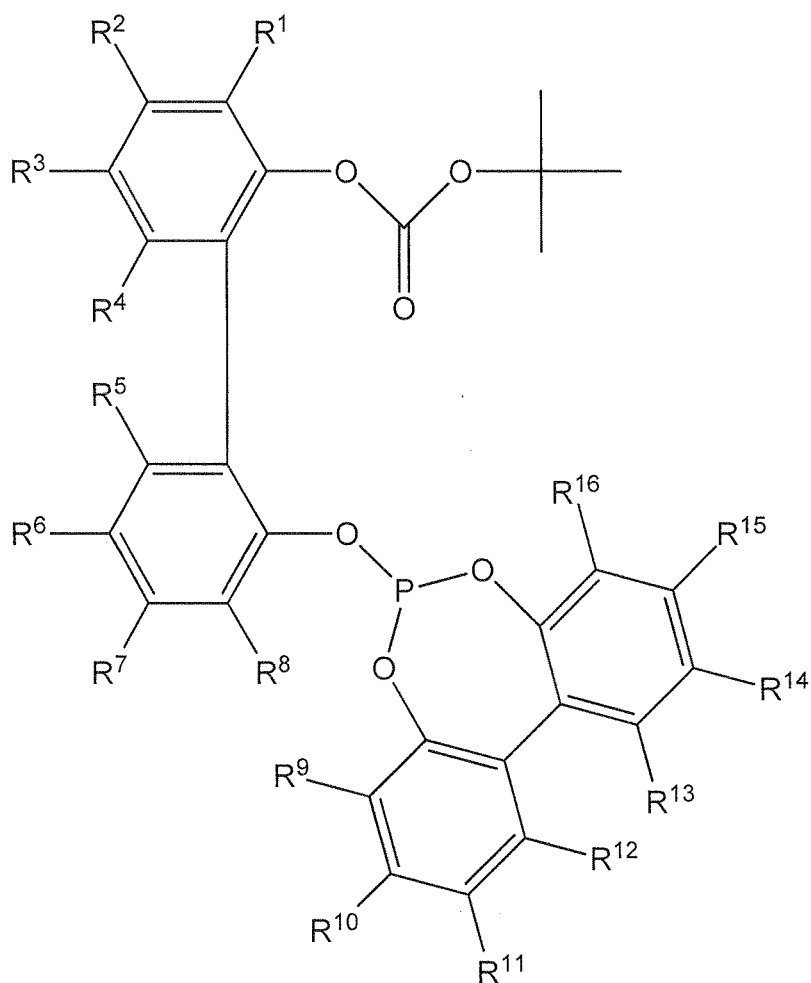
where R^1 and R^8 are each -(C₁-C₁₂)-alkyl.

10. Ligand according to any of Claims 1 to 9,

where R^1 and R^8 are each *tert*-butyl.

11. Ligand according to any of Claims 1 to 10,

having the general structure III:



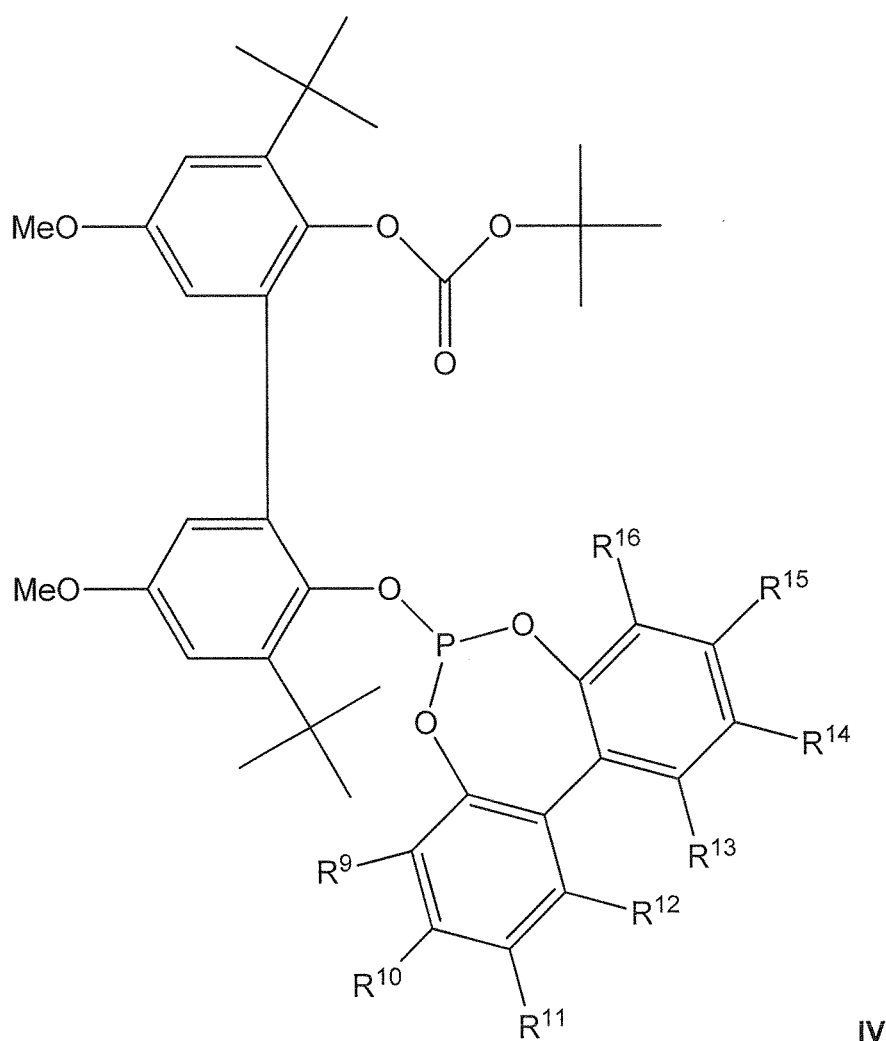
III

where R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} are each independently selected from:

- 5 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -halogen, -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -SO₃Na, -NO₂, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.

12. Ligand according to any of Claims 1 to 11,

10 having the general structure IV:



where R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} are each independently selected from:

- H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -halogen, -COO-(C₁-C₁₂)-alkyl, -CONH-(C₁-C₁₂)-alkyl, -(C₆-C₂₀)-aryl-CON[(C₁-C₁₂)-alkyl]₂, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -SO₃Na, -NO₂, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂.

13. Complex comprising:

- a ligand according to any of Claims 1 to 12,
- a metal atom selected from: Rh, Ru, Co, Ir.

14. Use of a ligand according to any of Claims 1 to 12

in a ligand-metal complex for catalysis of a hydroformylation reaction.

15. Process comprising the process steps of:

a) initially charging an olefin,

b) adding a complex according to Claim 13,

or a ligand according to any of Claims 1 to 12 and a compound including a metal atom selected

5 from: Rh, Ru, Co, Ir,

c) feeding in H_2 and CO,

d) heating the reaction mixture, with conversion of the olefin to an aldehyde.