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(54) Titre : UTILISATION D'UN LIGAND CONTENANT DU PHOSPHORE ET D'UN LIGAND ORGANIQUE CYCLIQUE
DANS UN COMPOSE A METAL DE TRANSITION
(54) Title: TRANSITION METAL COMPOUNDS HAVING A CYCLIC PHOSPHORUS-CONTAINING LIGAND AND A
CYCLIC ORGANIC LIGAND FOR USE IN METATHESIS REACTIONS

(57) **Abrégé/Abstract:**

According to the present invention there is provided a compound in the form of a transition metal compound including a transition metal, a phosphorus containing ligand, and a cyclic organic ligand. The phosphorus containing ligand is a heterocyclic organic compound with a ligating phosphorus atom which ligates with the transition metal, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound. The cyclic organic ligand is a cyclic organic compound with a ligating carbon atom in the cyclic ring structure of the cyclic organic compound which ligates with the transition metal by means of a double bond. The invention also relates to a method preparing such a compound and a metathesis reaction wherein such a compound is used as a catalyst.

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(54) Title: TRANSITION METAL COMPOUNDS HAVING A CYCLIC PHOSPHORUS-CONTAINING LIGAND AND A CYCLIC ORGANIC LIGAND FOR USE IN METATHESIS REACTIONS

(57) Abstract: According to the present invention there is provided a compound in the form of a transition metal compound including a transition metal, a phosphorus containing ligand, and a cyclic organic ligand. The phosphorus containing ligand is a heterocyclic organic compound with a ligating phosphorus atom which ligates with the transition metal, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound. The cyclic organic ligand is a cyclic organic compound with a ligating carbon atom in the cyclic ring structure of the cyclic organic compound which ligates with the transition metal by means of a double bond. The invention also relates to a method preparing such a compound and a metathesis reaction wherein such a compound is used as a catalyst.

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TRANSITION METAL COMPOUNDS HAVING A CYCLIC PHOSPHORUS-CONTAINING LIGAND AND A CYCLIC ORGANIC LIGAND FOR USE IN METATHESIS REACTIONS

TECHNICAL FIELD

5

The invention relates to the use of a phosphorus containing ligand and a cyclic organic ligand in a transition metal compound and to the use of a phosphorus containing ligand and cyclic organic ligand in a catalysed reaction, preferably a metathesis reaction. The invention also relates to a compound including such a phosphorus containing ligand and cyclic organic ligand; and to a metathesis reaction using the said catalyst. The invention further relates to a method of preparing such a catalyst.

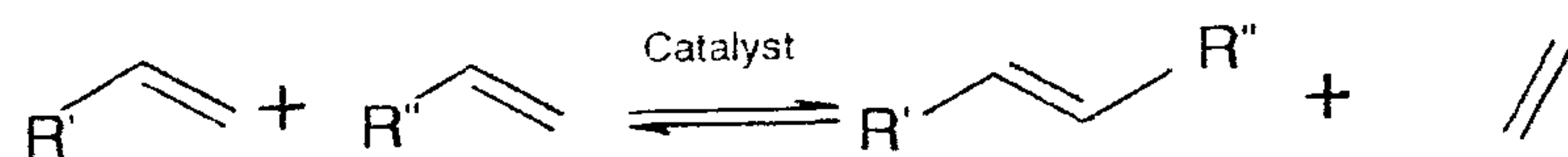
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BACKGROUND TO THE INVENTION

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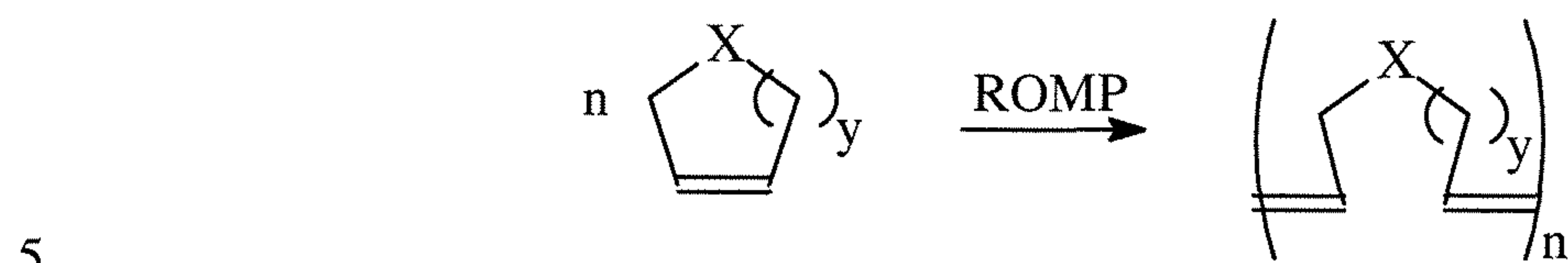
There is considerable interest regarding the formation of carbon-carbon bonds *via* olefin metathesis. Olefin metathesis refers to the metal-catalysed redistribution of carbon-carbon double bonds. Cross metathesis (CM) can be described as a metathesis reaction between two non-cyclic olefins, which may be the same or different, for example:

20

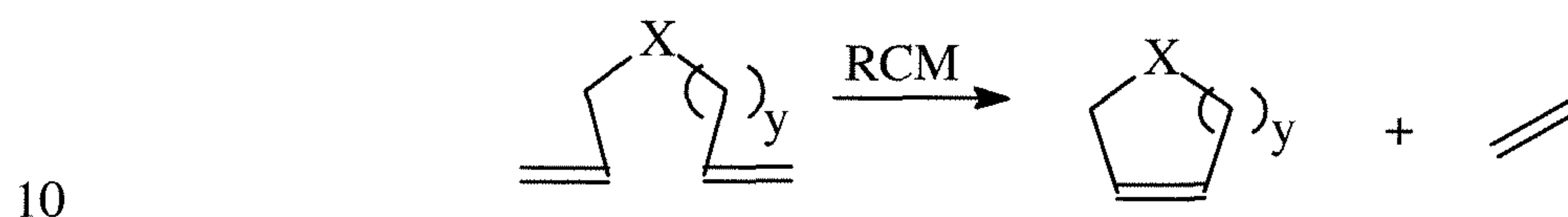


Where the olefins are the same, the reaction is known as self metathesis.

Ring-opening metathesis polymerization (ROMP) is a variant of olefin metathesis reactions wherein cyclic olefins (for example) produce polymers and co-polymers, for example:

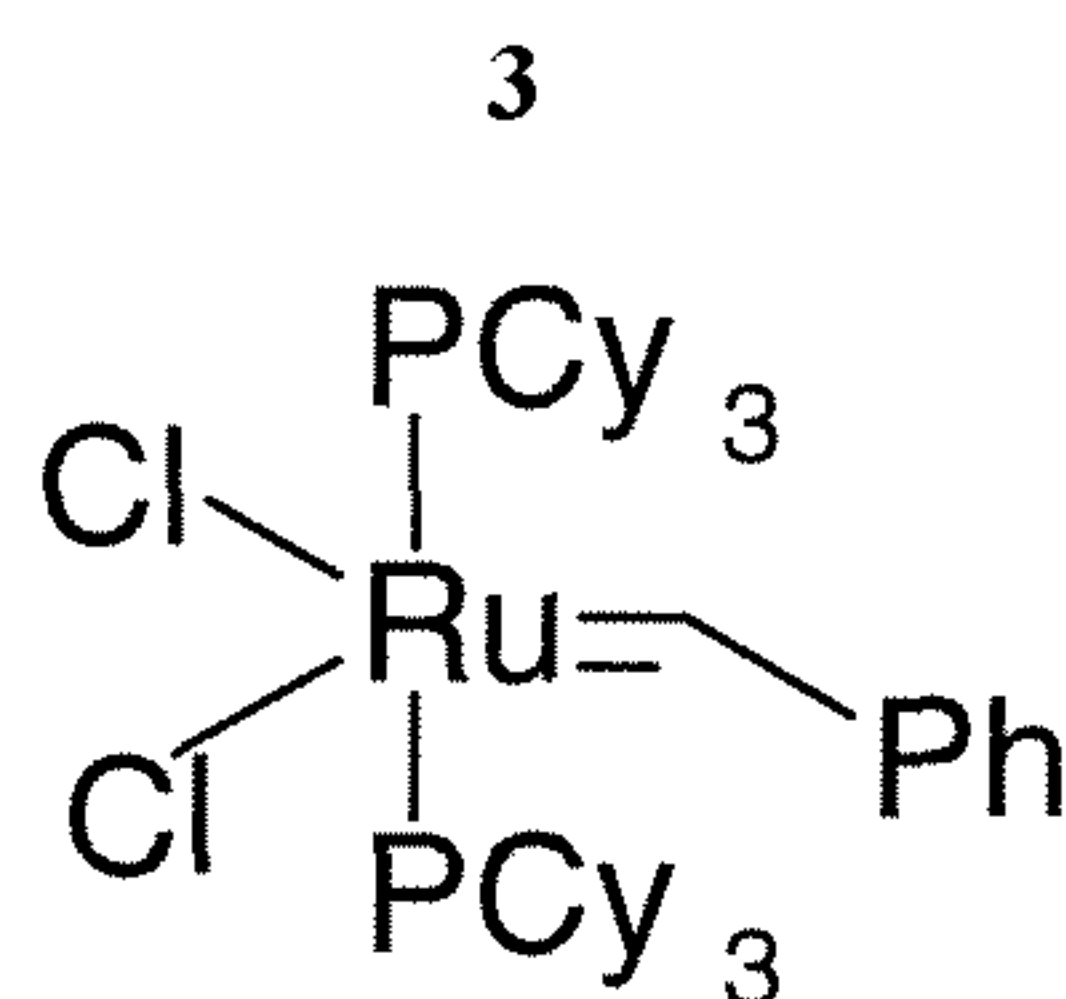


Ring-closing metathesis (RCM) represents a process in which an acyclic diene (for example) is cyclised to produce a cycloalkene, for example;



As indicated above metathesis reactions take place in the presence of a catalyst. A great deal of research has been done in an attempt to synthesise and isolate catalysts which are able to catalyse homogeneous olefin metathesis reactions. More particularly the synthesis of Group VIII transition metal metathesis catalysts has led to catalysts with increased functional group tolerance and stability with respect to conditions such as air, water and acids.

During the 1990's the so-called "1st generation Grubbs catalyst" of formula 1a was developed:



.....(1a)

where Cy is cyclohexyl.

5

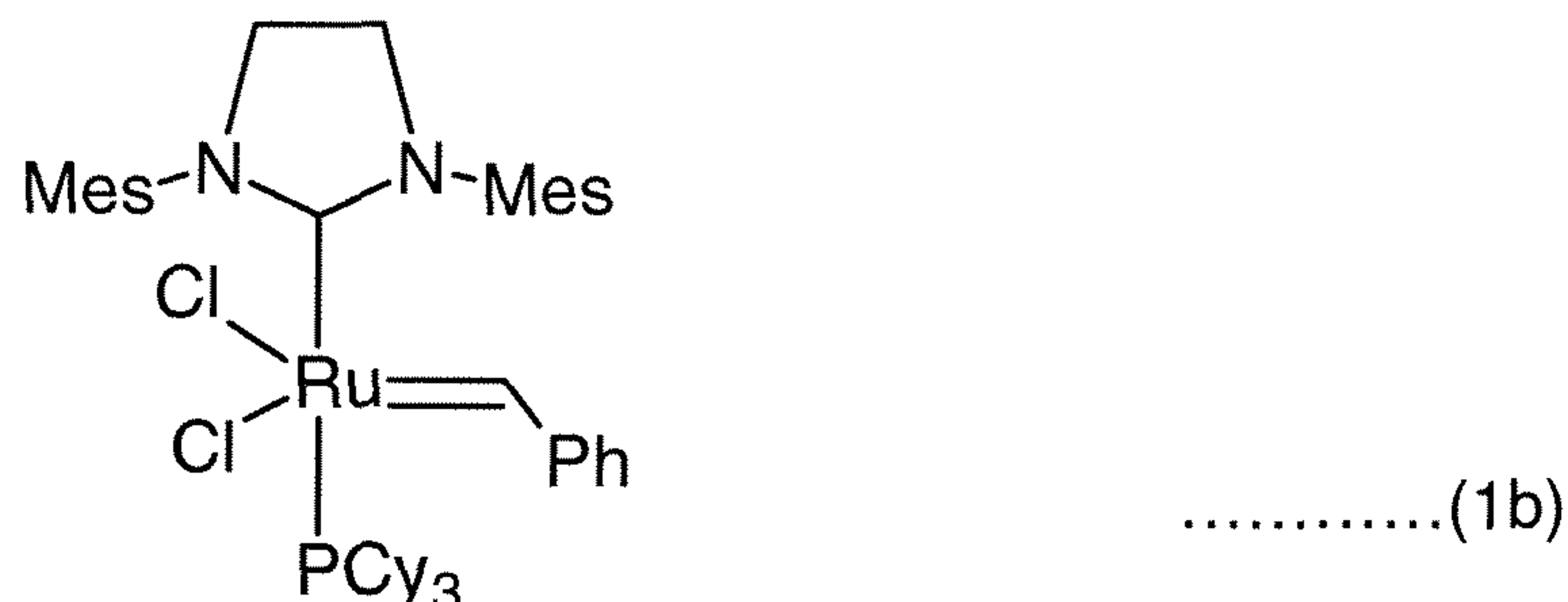
This well defined ruthenium catalyst afforded high selectivities, high reaction rates and good tolerance for oxygenates in feed during homogeneous olefin metathesis reactions, including cross metathesis, ring closing metathesis and ring opening metathesis polymerisation. These processes have many potential commercial applications for the commodities, pharmaceutical and fine chemicals industries as well as in the field of speciality polymers. Several reviews describe the development and applications of Grubbs-type catalysts (for example Acc. Chem. Res. 2001, 34, 18-24; Angew. Chem., Int .Ed., 2000, 39, 3012-3043).

15

Much research has been carried out to investigate the effect of changing the nature of the ligands, (for example J. Am. Chem. Soc. 1997, 119, 3887 – 3897; Tetrahedron Lett. 1999, 40, 2247-2250; Angew. Chem., Int. Ed. 1998, 37, 2490-2493) resulting in the development of second generation Grubbs catalysts. The main thrust of second generation Grubbs catalyst research has related to a move away from the use of phosphine ligands to the use of highly nucleophilic N-heterocyclic carbenes for homogeneous metathesis reactions. Formula 1b shows the structure of the standard second generation Grubbs

20

catalyst. While this catalyst shows greater reactivity compared to catalyst 1a, it is more expensive than the first generation catalyst.



5

where Cy = cyclohexyl, and Mes = mesityl

WO ZA03/00087 discloses the use of a phosphorus containing ligand as a ligand for a metathesis catalyst in a catalysed metathesis reaction wherein the phosphorus containing ligand is a heterocyclic organic compound with a ligating phosphorus atom as an atom in the heterocyclic ring structure of the heterocyclic organic compound.

A major disadvantage of complexes depicted by formula 1a relates to their preparation which requires either reagents which are hazardous (e. g. potentially explosive diazoalkanes), or difficult to prepare (e.g. diphenylcyclopropene), or extremely sensitive.

As a result there exists a need to develop efficient routes to these complexes where

1. The individual components (ligands and alkylidene) are inexpensive, non-hazardous and scaleable

2. The reaction to prepare the Ru-alkylidene-type olefin metathesis catalyst that uses the individual components as reagents is straightforward, non-hazardous and can be performed on the multi-kilogram scale economically.

5

It has now been found that relatively inexpensive phosphorus containing ligands such as phosphabicyclononane ligands, when combined with a specific alkylidene-type moiety such as the indenylidene alkylidene moiety provide a non-hazardous, economical Ru-alkylidene-type olefin metathesis catalysts.

10 These catalysts or catalyst precursors are usually easy to prepare from well accessible, stable and essentially non-toxic starting materials and can usually be isolated and stored. At least some of these catalysts exhibit high catalytic activity, a good compatibility with functional groups, solvents, water and additives, and they need not to be activated by any additive.

15

An indenylidene ruthenium complex was first synthesized by Hill (*J. Chem. Soc., Dalton Trans.* 1999, 285), who incorrectly assigned the structure of the diphenylallenylidene complex. Together with Fürstner the complex was used in various ring-closing metathesis reactions (*Chem. Commun.* 1999, 601-602).

20 Later detailed evaluations showed that the correct structure is the rearranged indenylidene complex (*Organometallics* 1999, 18, 5416-5419, *Chem. Eur. J.* 2001, 7, 4811-4820). Still, this complex was only used in RCM by Fürstner in the synthesis of natural products.

In 2003 F. Verpoort published the use of this complex in the Atom Transfer Radical Addition (ATRA), *New J. Chem.* 2003, 27, 257-262. Several different olefins have been used in the ATRA with carbon tetrachloride in good to nearly quantitative yields. Verpoort also used the complex in the nucleophilic
5 addition of carboxylic acids to terminal alkynes (*Synlett* 2002, 935-941), e.g. formic acid, acetic acid, isovaleric acid, or benzoic acid to t-Butylacetylene, 1,7-octadiyne or 4-pentynoic acid. Here the catalyst showed moderate yields. Blechert (*Synlett* 2001, 3, 430-432) used the catalyst as a precursor for other metathesis catalysts.

10

The indenylidene complexes as described above did not include a phosphorus containing ligand which is a heterocyclic organic compound with a ligating phosphorous atom as an atom in the heterocyclic ring structure of the heterocyclic organic compound.

15

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided the use of a phosphorus containing ligand and a cyclic organic ligand as ligands for a
20 catalyst in the form of a transition metal compound containing a transition metal; wherein the phosphorus containing ligand is a heterocyclic organic compound with a ligating phosphorus atom which ligates with the transition metal, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound; and wherein the cyclic
25 organic ligand is a cyclic organic compound with a ligating carbon atom in the

cyclic ring structure of the cyclic organic compound which ligates with the transition metal by means of a double bond.

Preferably the catalyst is a metathesis catalyst.

5

According to a second aspect of the present invention there is provided the use of a phosphorus containing ligand and a cyclic organic ligand in the preparation of a transition metal compound catalyst including a transition metal, the phosphorus containing ligand and the cyclic organic ligand;
10 wherein the phosphorus containing ligand is a heterocyclic organic compound with a ligating phosphorus atom which ligates with the transition metal, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound; and wherein the cyclic organic ligand is a cyclic organic compound with a ligating carbon atom in the cyclic ring
15 structure of the cyclic organic compound which ligates with the transition metal by means of a double bond.

Preferably the catalyst is for use in a metathesis reaction.

20 According to a third aspect of the present invention there is provided a compound in the form of a transition metal compound including a transition metal, a phosphorus containing ligand, and a cyclic organic ligand; wherein the phosphorus containing ligand is a heterocyclic organic compound with a ligating phosphorus atom which ligates with the transition metal, and which
25 ligating phosphorus atom is an atom in the heterocyclic ring structure of the

heterocyclic organic compound; and wherein the cyclic organic ligand is a cyclic organic compound with a ligating carbon atom in the cyclic ring structure of the cyclic organic compound which ligates with the transition metal by means of a double bond.

5

Preferably the compound is a catalyst, and preferably the catalyst is a metathesis catalyst.

Preferably the metathesis reaction/catalyst is a homogenous metathesis reaction/catalyst, or a reaction with an immobilized preformed catalyst.

10

Preferably the ligating phosphorus atom is also bound to a further moiety which is not part of the heterocyclic ring structure.

Preferably the phosphorus containing ligand comprises a phosphine ligand, preferably a secondary or tertiary phosphine ligand, preferably a tertiary phosphine ligand. The further moiety bound to the ligating phosphorus atom may be an atom, and preferably it is H. In an alternative and preferred embodiment of the invention the said moiety may comprise an organic group, preferably an organyl group. The organyl group may comprise an alkyl, alkenyl, alkynyl, aryl, cycloalkyl, cycloalkenyl, cycloalkynyl and optionally it may be substituted. Preferably it comprises an alkyl, cycloalkyl or aryl.

15
20

Preferably the heterocyclic organic compound has a single heteroatom in the form of the ligating phosphorus atom.

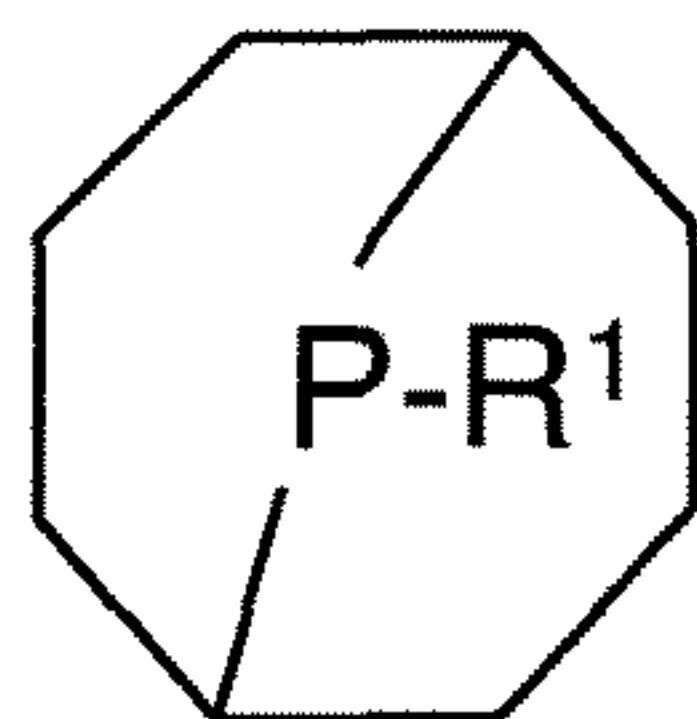
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The heterocyclic organic compound may comprise a bicyclic organic compound. Preferably the heterocyclic organic compound includes no unsaturated carbon to carbon bonds. Preferably the two ring structures have at least 3 shared atoms. Preferably the two ring structures do not have more than 12 ring atoms, preferably they have nine ring atoms.

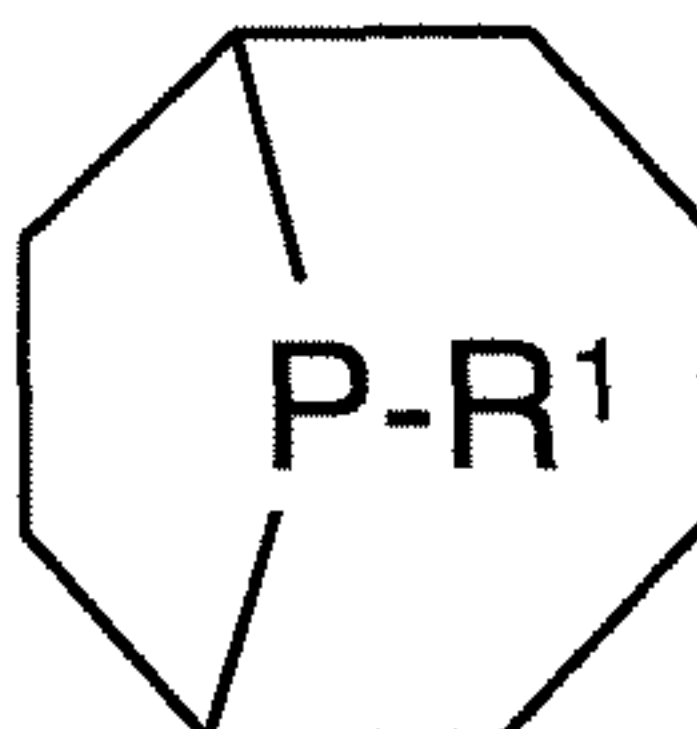
In a preferred embodiment of the invention the phosphine ligand comprises a bicyclic tertiary phosphine having a ligating phosphorus atom which is preferably bound to two first atoms (preferably carbon atoms) in the ring structure with each of said first atoms being bound to two other second atoms (preferably carbon atoms) in the ring structure. Preferably both the second atoms are carbon atoms. It will be appreciated that in this embodiment each first atom is bound to three ring atoms.

In a preferred embodiment of the invention the heterocyclic organic compound comprises a phosphacycloalkane, preferably a phosphabicycloalkane, preferably a phosphabicyclononane, each of which optionally may be substituted. Preferably it comprises a monophosphacycloalkane, preferably a monophosphabicycloalkane, preferably a monophosphabicyclononane. Preferably the compound comprises a tertiary phosphine.

In a preferred embodiment of the invention, the phosphabicyclononane is a 9-phosphabicyclo[3.3.1]nonane of formula 2a or a 9-phosphabicyclo[4.2.1]nonane of formula 2b or mixtures thereof:



..... (2a)



5

..... (2b)

wherein R^1 is H or an organic group (including an organyl group). Preferably R^1 is an optionally substituted alkyl, or optionally substituted aryl, or an optionally substituted cycloalkyl.

10

The phosphabicyclononane may be a compound of formula 2a.

15

In one embodiment of the invention R^1 is alkyl, preferably $-C_{20}H_{41}$ also known as eicosyl. In this instance the ligand is known as eicosyl phoban (that is for both compounds of formula 2a and 2b where R^1 is $-C_{20}H_{41}$).

In one preferred embodiment of the invention R^1 is cyclohexyl. In this instance the ligand is known as cyclohexyl phoban (that is for both compounds of formula 2a and 2b where R^1 is cyclohexyl).

20

The cyclic ring structure of the cyclic organic ligand may be a heterocyclic ring structure, but preferably it is a homocyclic ring structure.

5 The ring structure which includes the ligating carbon atom may be saturated, but preferably it is unsaturated. The ring structure including the ligating carbon atom may be monocyclic, but preferably it is polycyclic and preferably it includes at least two fused ring structures, that is two ring structures that share two adjacent ring atoms.

10 In one embodiment of the invention the ligating carbon atom may form part of a non-aromatic ring structure which is fused to an aromatic (including heteroaromatic) ring structure. The non-aromatic ring structure may include only carbon ring atoms and preferably it has only 5 ring atoms. The non-aromatic ring structure may include at least one (preferably two) unsaturated
15 carbon-carbon bonds. The non-aromatic ring structure may include at least one non-hydrogen moiety bound to a carbon atom of the non-aromatic ring structure which non-hydrogen moiety does not form part of the aromatic ring structure. The non-hydrogen moiety may comprise an organic group, preferably an organyl group, preferably it comprises an aromatic or
20 heteroaromatic group and preferably it is phenyl. The aromatic ring structure fused to the non-aromatic ring structure may contain more ring atoms than the non-aromatic ring structure, and preferably if it has 6 ring atoms. The aromatic ring structure may include only carbon ring atoms.

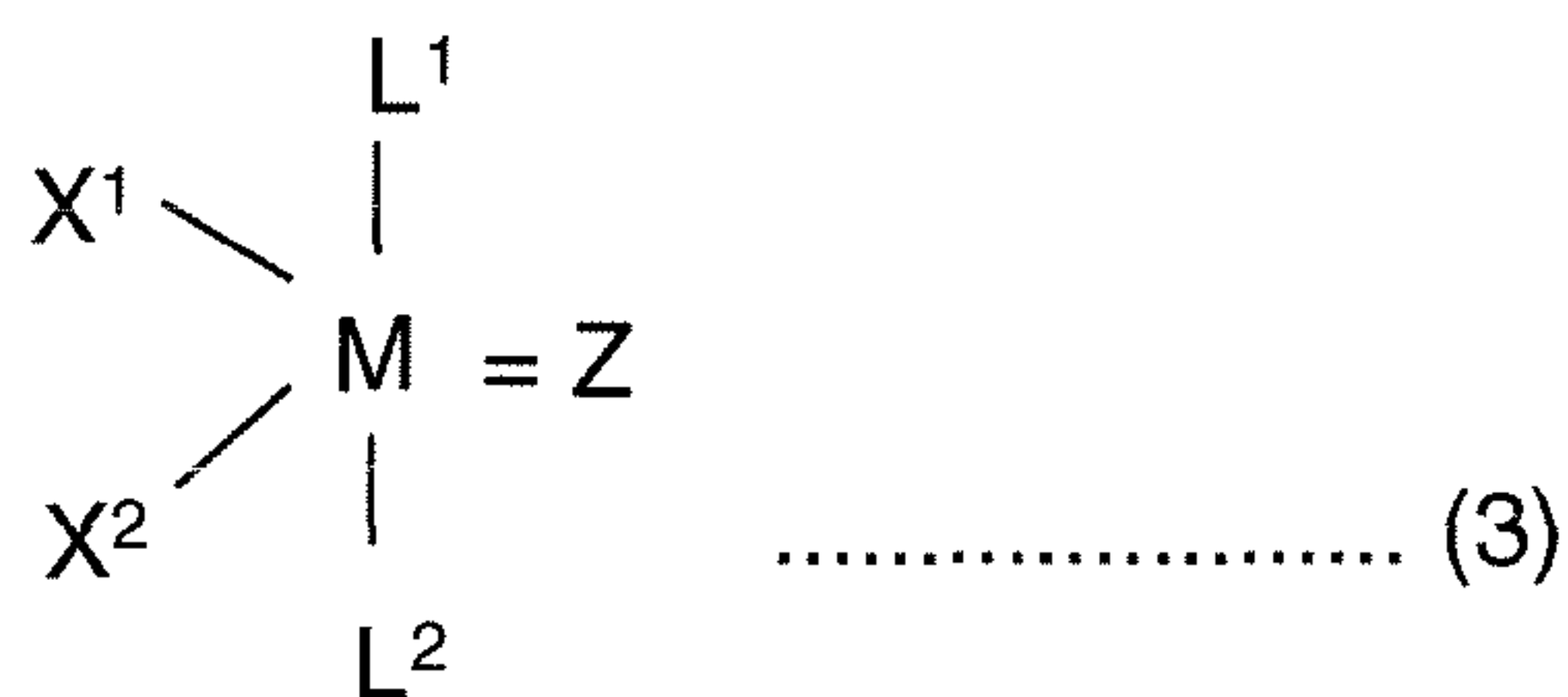
In one embodiment of the invention the cyclic organic ligand may comprise indenylidene or a substituted derivative thereof.

The transition metal may comprise a Group VIII metal, preferably Os or Ru,
5 preferably Ru.

The catalyst may include further ligands as defined below.

The metathesis reaction may comprise cross-metathesis (including self
10 metathesis and ethenolysis), ring-opening polymerisation metathesis, ring-closing metathesis, or acyclic diene metathesis.

According to another aspect of the present invention there is provided a compound of formula 3



15

wherein

M is a transition metal;

L¹ is a neutral electron donor ligand;

20 L² is a phosphorus containing ligand in the form of a heterocyclic organic compound with a ligating phosphorus atom which ligates with M, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound;

X^1 and X^2 are independently a ligand; and

Z is a cyclic organic ligand in the form of a cyclic organic compound with a ligating carbon atom in the cyclic ring structure of the cyclic organic compound which ligates with M by means of a double bond.

5

The transition metal M may be a transition metal as described earlier above, and preferably it is Ru.

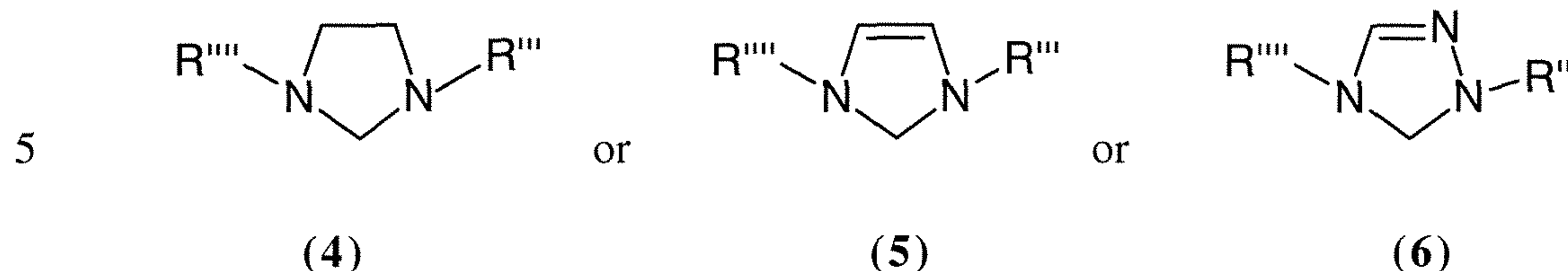
Preferably the compound is a catalyst, preferably a metathesis catalyst, and
10 preferably a homogeneous metathesis catalyst.

Ligand L^1

L^1 may be selected from the group consisting of a phosphine, sulfonated phosphine, phosphite, phosphinite, phosphonite, arsine, stibine, amine, amide, imine, nitrosyl, carbene and pyridine. In a preferred embodiment of the invention L^1 may be any neutral phosphine ligand or carbene ligand. Preferably L^1 is a phosphine preferably a phosphine of the formula $PR^3R^4R^5$, wherein R^3 , R^4 and R^5 are each independently an organic group, preferably an organyl group, preferably aryl, $C_1 - C_{10}$ alkyl or cycloalkyl. Preferably L^1 is
15 selected from the group consisting of $-P(\text{cyclohexyl})_3$; $-P(\text{cyclopentyl})_3$; $-P(\text{isopropyl})_3$; and $-P(\text{phenyl})_3$. Preferably L^1 comprises a phosphorus containing ligand as defined in respect of L^2 . Accordingly L^1 may be the same as L^2 .
20

In another embodiment of the invention L^1 may be selected from a group of
25 heterocyclic compounds containing substituted or unsubstituted five

membered rings which may be saturated or unsaturated and which may include at least two adjacent or non adjacent nitrogen ring atoms. Examples of such ligands are illustrated as formulas 4, 5 and 6:



10 wherein R'' and R''' may be any group such as H, an organic group (including an organyl group, preferably alkyl, aryl, cycloalkyl, adamantyl or the like, and may be further substituted with functional groups).

Ligand L²

15 L² is a phosphorus containing ligand as already defined with reference to formula(3). Preferably, the phosphorus containing ligand comprises a phosphine ligand, preferably a secondary or tertiary phosphine ligand, preferably a tertiary phosphine ligand. The ligating phosphorus atom may also be bound to a further moiety which is not part of the heterocyclic ring

20 structure. The further moiety bound to the ligating phosphorus atom may be an atom, and preferably it is H. In an alternative and preferred embodiment of the invention the said moiety may comprise an organic group, preferably an organyl group. The organyl group may comprise an alkyl, alkenyl, alkynyl, aryl, cycloalkyl, cycloalkenyl, cycloalkylenyl and optionally it may be

25 substituted. Preferably it comprises an alkyl, cycloalkyl or aryl.

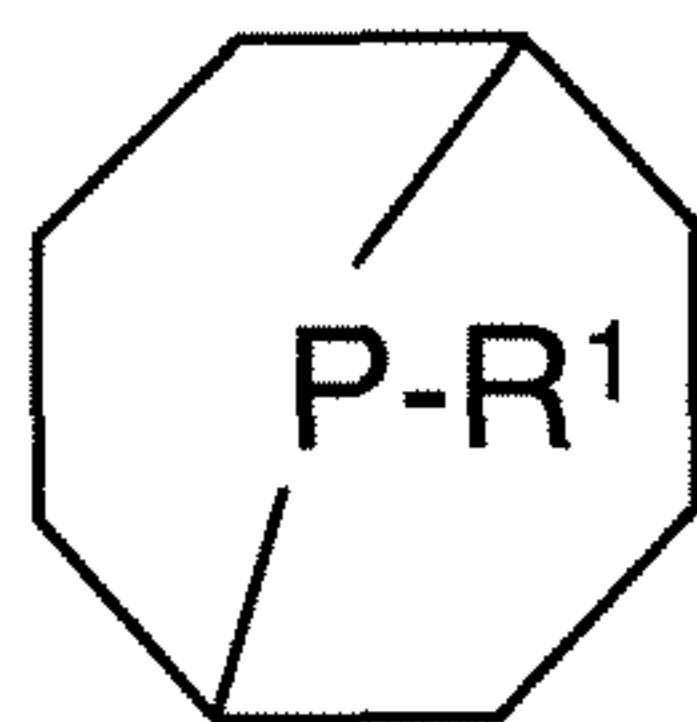
Preferably the heterocyclic organic compound has a single heteroatom in the form of the ligating phosphorus atom.

The heterocyclic organic compound may comprise a bicyclic organic
5 compound. Preferably the heterocyclic organic compound includes no unsaturated carbon to carbon bonds. Preferably the two ring structures have at least 3 shared atoms. Preferably the two ring structures do not have more than 12 ring atoms, preferably they have nine ring atoms.

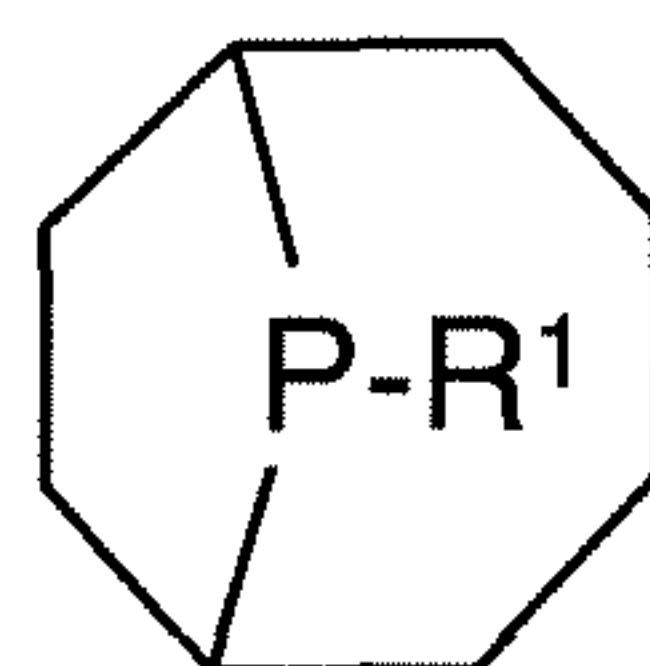
10 In a preferred embodiment of the invention the phosphine ligand comprises a bicyclic tertiary phosphine having a ligating phosphorus atom which is preferably bound to two first atoms (preferably carbon atoms) in the ring structure with each of said first atoms being bound to two other second atoms (preferably carbon atoms) in the ring structure. Preferably both the second
15 atoms are carbon atoms. It will be appreciated that in this embodiment each first atom is bound to three ring atoms.

In a preferred embodiment of the invention the heterocyclic organic compound comprises a phosphacycloalkane, preferably a phosphabicycloalkane,
20 preferably a phosphabicyclononane, each of which optionally may be substituted. Preferably it comprises a monophosphacycloalkane, preferably a monophosphabicycloalkane, preferably a monophosphabicyclononane. Preferably the compound comprises a tertiary phosphine.

In a preferred embodiment of the invention, the phosphabicyclononane is a 9-phosphabicyclo-[3.3.1]nonane of formula 2a or a 9-phosphabicyclo[4.2.1]nonane of formula 2b or mixtures thereof:



..... (2a)



..... (2b)

wherein R^1 is H, or an organic group (including an organyl group). Preferably

R^1 is an optionally substituted alkyl, or optionally substituted aryl, or an optionally substituted cycloalkyl.

The phosphabicyclononane may be a compound of formula 2a.

In one embodiment of the invention R^1 is alkyl, preferably $-C_{20}H_{41}$ also known as eicosyl. In this instance the ligand is known as eicosyl phoban (that is for both compounds of formula 2a and 2b where R^1 is $-C_{20}H_{41}$).

In one preferred embodiment of the invention R^1 is cyclohexyl. In this instance the ligand is known as cyclohexyl phoban (that is for both compounds of formula 2a and 2b where R^1 is cyclohexyl).

5 Ligands X^1 and X^2

X^1 and X^2 may be independently selected from the group consisting of hydrogen; halide; $C_1 - C_{20}$ alkyl; aryl; $C_1 - C_{20}$ alkoxide; aryloxy; $C_3 - C_{20}$ alkyldiketonate; aryldiketonate; $C_1 - C_{20}$ carboxylate; arylsulfonate; $C_1 - C_{20}$ alkylsulfonate; $C_1 - C_{20}$ alkylthiol; aryl thiol; $C_1 - C_{20}$ alkylsulfonyl; and $C_1 -$
 10 C_{20} alkylsulfinyl, the compound being optionally substituted with one or more other moieties selected from the group consisting of $C_1 - C_{10}$ alkyl; $C_1 - C_{10}$ alkoxy; aryl and halide. Preferably X^1 and X^2 are each independently selected from the group consisting of halide; CF_3CO_2 ; CH_3CO_2 ; CFH_2CO_2 ; $(CH_3)_3CO$; $(CF_3)_2(CH_3)CO$; $(CF_3)(CH_3)_2CO$; PhO ; MeO ; EtO ; tosylate; mesylate; and
 15 trifluoromethanesulfonate. Preferably X^1 and X^2 are each independently an anionic ligand, preferably a halide. Preferably X^1 and X^2 are each chloride.

Ligand Z

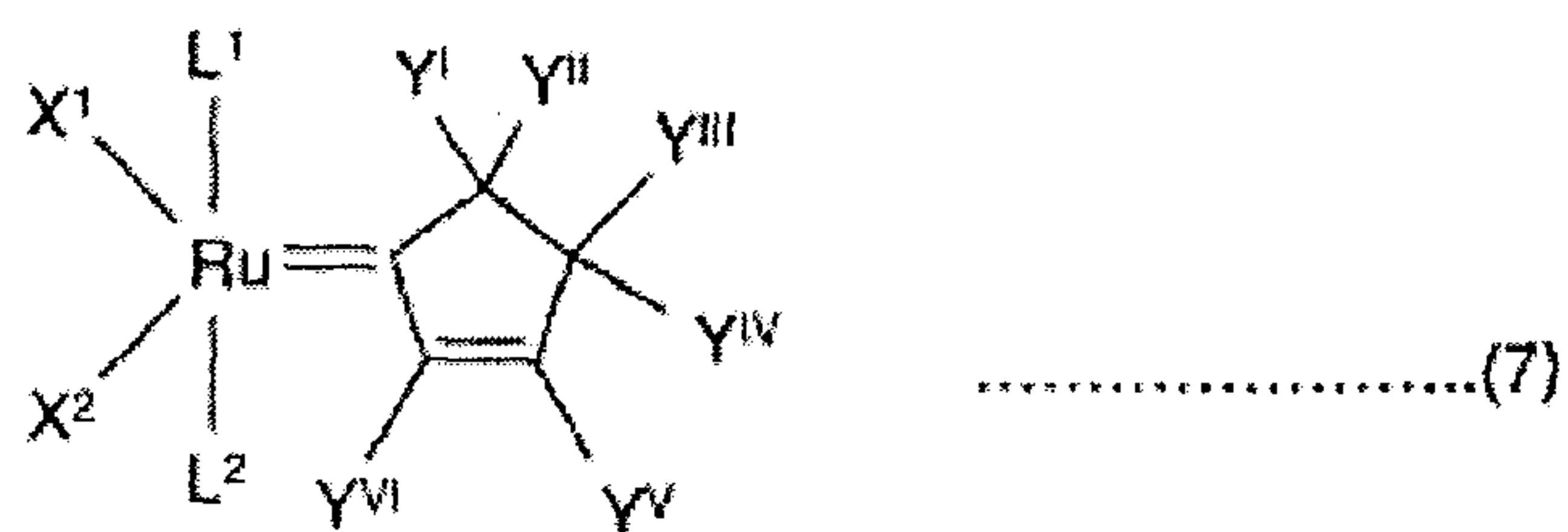
Z, the cyclic organic ligand, may be as described above.

20

In some cases some of the ligands X^1 , X^2 , L^1 , L^2 and Z may be linked to each other.

In one preferred embodiment of the invention, the compound of formula 3 may
 25 be a compound and of formula 7:

18

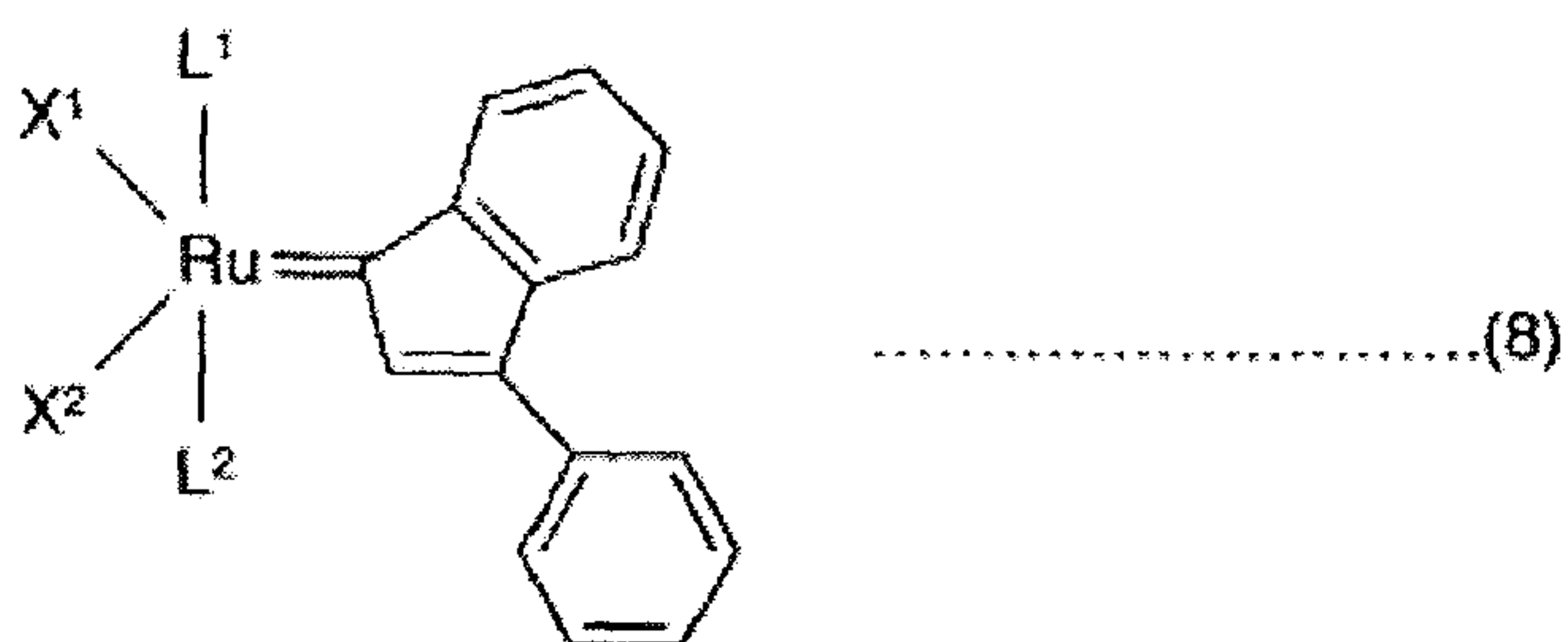


wherein

L^1 , L^2 , X^1 and X^2 are as defined above; and

- 5 each of Y^I , Y^{II} , Y^{III} , Y^{IV} , Y^V and Y^{VI} is independently H or a moiety other than H, including an organic group (preferably an organyl group), and at least some of Y^I to Y^{VI} may be linked to each other.

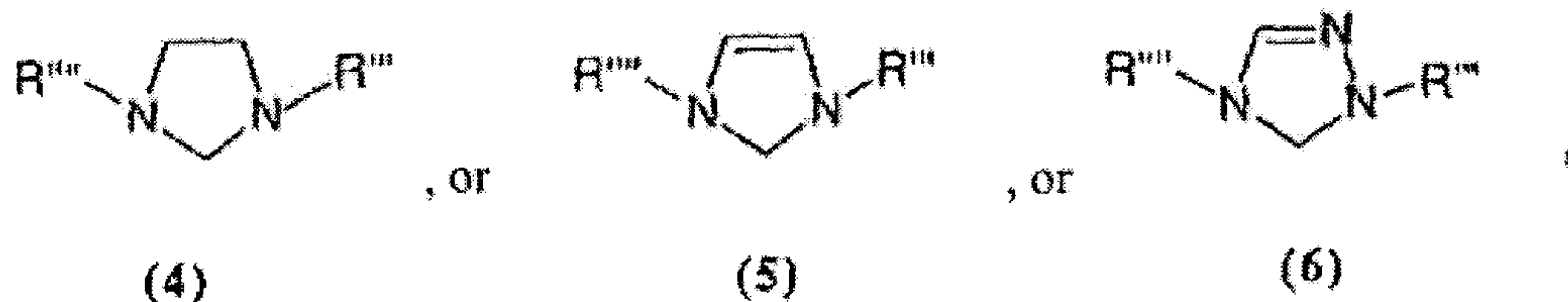
- 10 In one preferred embodiment of the invention the compound of formula 7 may be a compound of formula (8)



wherein X^1 , X^2 , L^1 and L^2 are as defined above.

15

In another embodiment, L^1 is a neutral electron donor ligand, $-P(\text{cyclohexyl})_3$, $-P(\text{cyclopentyl})_3$, $-P(\text{isopropyl})_3$, $-P(\text{phenyl})_3$,

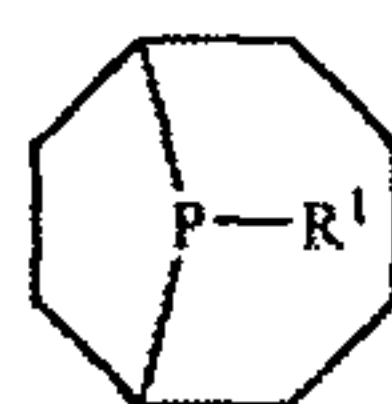


18a

wherein R''' and R'''' are H, an alkyl, an aryl, a cycloalkyl, or an adamantyl group; or a 9-phosphabicyclo-[3.3.1]nonane of formula 2a or a 9-phosphabicyclo[4.2.1]nonane of formula 2b or a mixture thereof:



(2a)



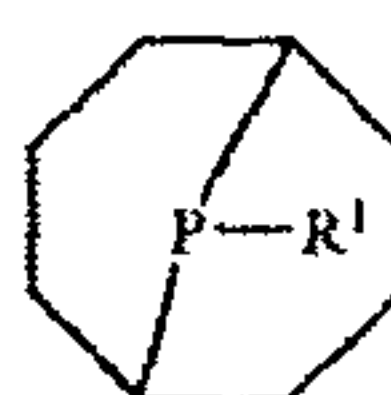
(2b)

5

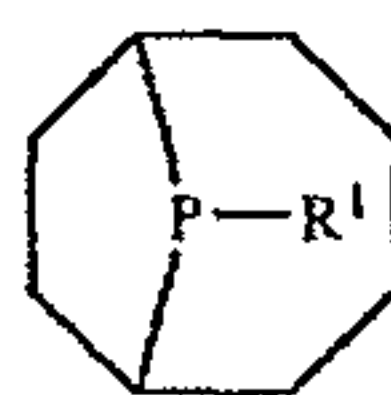
wherein R^1 is H, a substituted or unsubstituted alkyl, aryl or cycloalkyl group;

10 L^2 is a phosphorus containing ligand in the form of a heterocyclic organic compound with a ligating phosphorus atom which ligates with Ru, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound,

15 wherein the heterocyclic organic compound is a phosphabicyclononane which is a 9-phosphabicyclo-[3.3.1]nonane of formula 2a or a 9-phosphabicyclo[4.2.1]nonane of formula 2b or a mixture thereof:



(2a)



(2b)

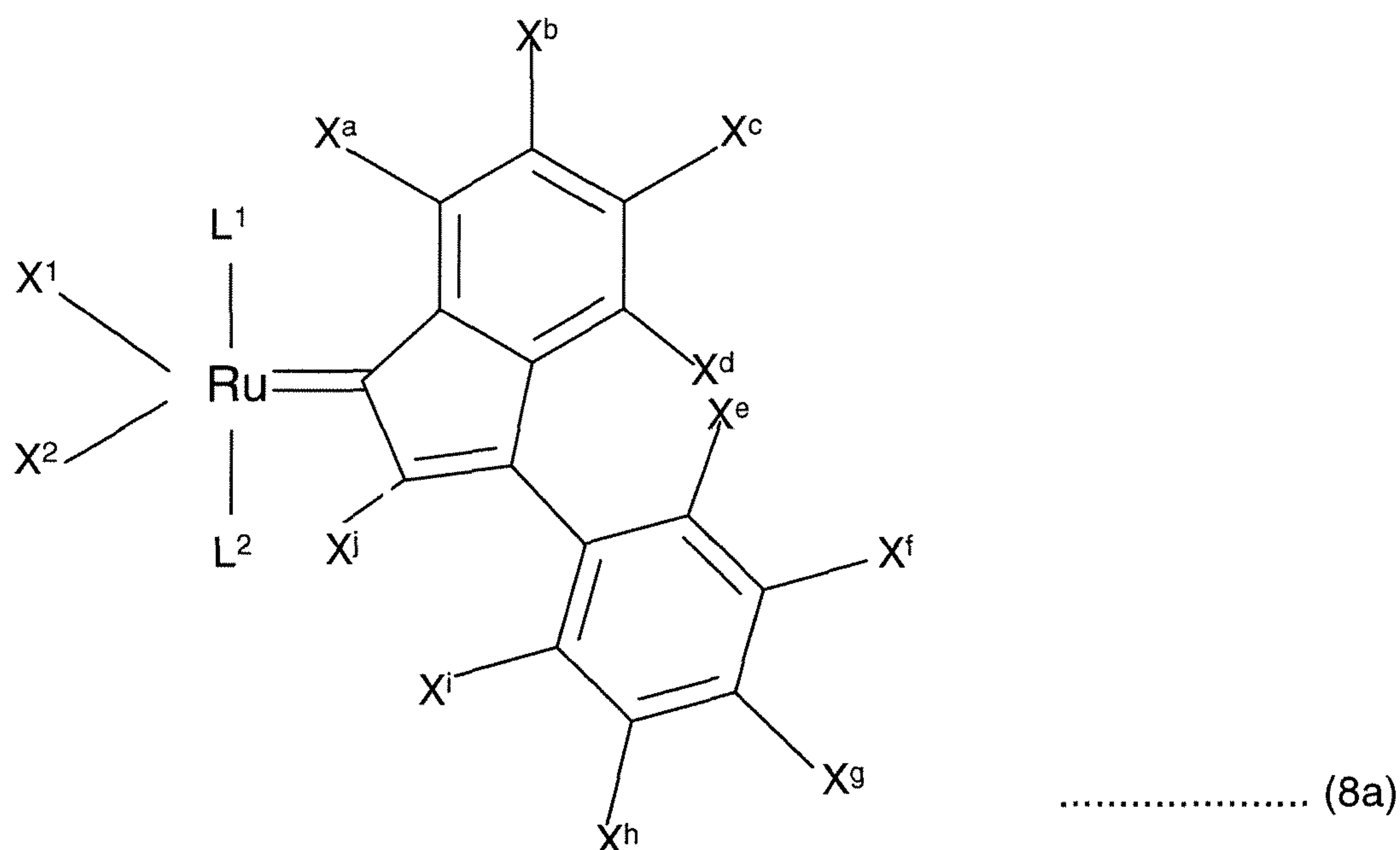
20

wherein R^1 is H, a substituted or unsubstituted alkyl, aryl or cycloalkyl group; and

18b

X^1 and X^2 are independently a ligand which is hydrogen, a halide ion, a C_1 - C_{20} alkyl, an aryl, a C_1 - C_{20} alkoxide, an aryloxy, a C_3 - C_{20} alkyldiketonate, an aryldiketonate, a C_1 - C_{20} carboxylate, an arylsulfonate, a C_1 - C_{20} alkylsulfonate, a C_1 - C_{20} alkylthiol, an aryl thiol, a C_1 - C_{20} alkylsulfonyl, or a C_1 - C_{20} alkylsulfinyl group, the compound being optionally substituted with at least one moiety which is a C_1 - C_{10} alkyl, a C_1 - C_{10} alkoxy, an aryl group, or a halide ion.

In another preferred embodiment of the invention the compound of formula 7 may be a compound of formula 8a:



wherein L^1 , L^2 , X^1 and X^2 are as defined above; and

X^a to X^j are independently hydrogen or a moiety other than H, (preferably
 5 halogen, NO_2 , OR, SR or NR_2) provided that at least one of X^a to X^j is not H.

According to another aspect of the invention there is provided the use of a catalyst as described hereinbefore including a catalyst of formula 3, in a metathesis reaction, preferably a homogeneous metathesis reaction.

10

The reaction is preferably a reaction of at least one olefinic compound in the form of an olefin with one or more double bonds or a compound which includes an olefinic moiety with one or more double bonds. The reaction conditions for the metathesis reaction wherein the catalyst is used may be in
 15 accordance to conditions which are well known to a person skilled in the art of metathesis reactions.

Preferably the olefinic compound has a single double bond in the case of a cross-metathesis reaction. Preferably the olefinic compound has two double bonds in the case of a ring-closing metathesis reaction. Preferably the olefinic compound is a cyclic olefin in the case of a ring-opening metathesis polymerisation reaction.

According to a further aspect of the invention there is provided a metathesis product produced by a metathesis reaction using a catalyst substantially as described hereinabove.

10

The metathesis catalyst may be a catalyst of formula 3 hereinbefore, preferably a homogeneous metathesis catalyst.

According to yet a further aspect of the invention there is provided a catalysed metathesis reaction wherein at least one olefinic compound in the form of an olefin with one or more double bonds or a compound which includes an olefinic moiety with one or more double bonds is subjected to metathesis in the presence of a catalyst of the type described hereinbefore. Preferably the metathesis reaction is a homogeneous metathesis reaction.

20

According to yet a further aspect of the invention there is provided a process for a ring closing metathesis reaction in the presence of a catalyst of the type described hereinbefore. According to yet a further aspect of the invention there is provided a process for a ring opening metathesis polymerization reaction in the presence of a catalyst of the type described hereinbefore.

25

According to yet a further aspect of the invention there is provided a process for a cross or self metathesis reaction in the presence of a catalyst of the type described hereinbefore. The cross metathesis reaction may specifically be an ethenolysis reaction (where one of the two olefinic compounds is ethylene).

- 5 The metathesis reactions preferably comprise homogeneous metathesis reactions.

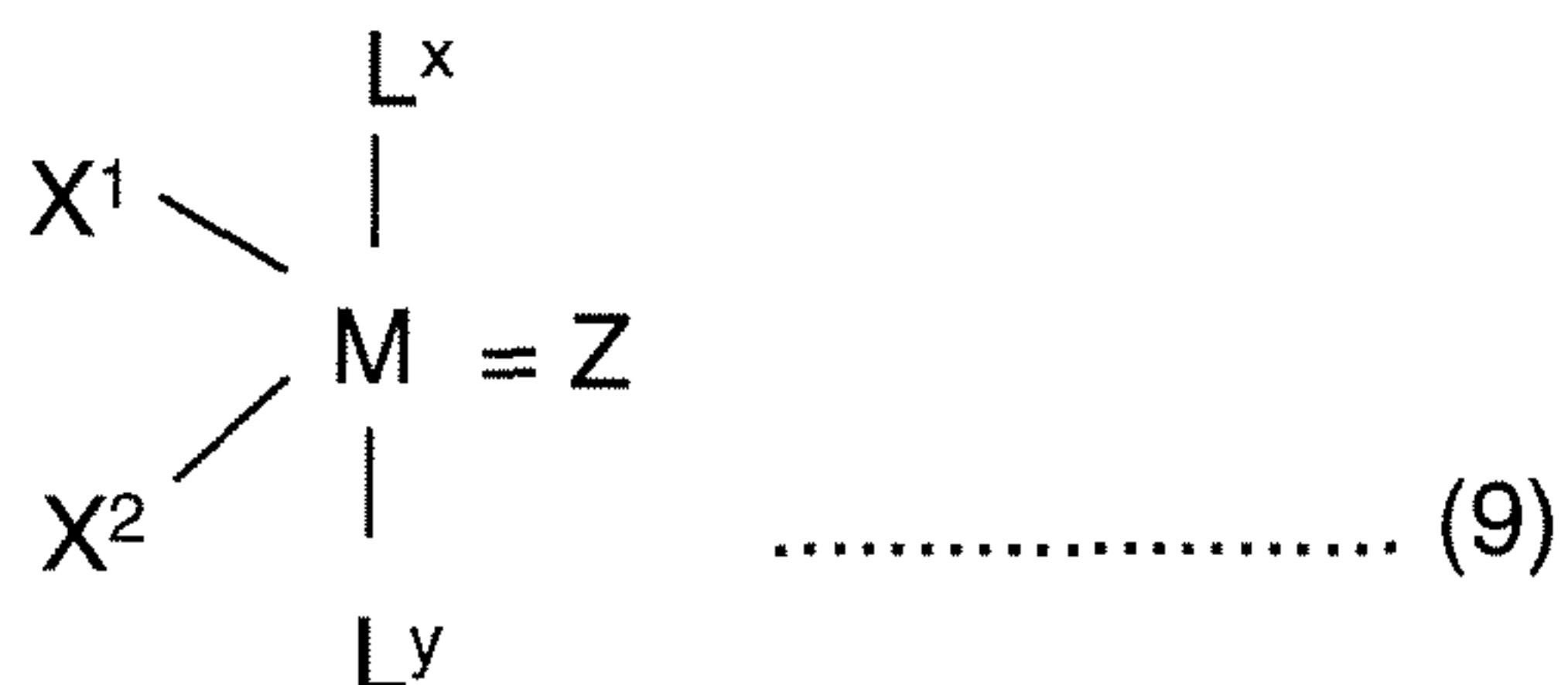
The process may include the step of forming the catalyst in situ. The process may then include the steps of adding together of a source of a transition
10 metal; a source of a phosphorus containing ligand in the form of a heterocyclic organic compound with a ligating phosphorous atom suitable for ligating with the transition metal in the source of the transition metal, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound; a source of a cyclic organic ligand in the form
15 of a cyclic organic compound with a ligating carbon atom in the cyclic ring structure of the cyclic organic compound which is suitable to ligate with the transition metal in the source of the transition metal by means of a double bond; and at least one olefinic compound to be metathesised which olefinic compound is an olefin or a compound which includes an olefinic moiety.

20

The source of transition metal may be a source of Ru, and preferably it is an inorganic salt of ruthenium such as $\text{RuCl}_3 \cdot x\text{H}_2\text{O}$.

- 25 According to another aspect of the present invention there is provided a method of preparing a compound of formula 3 by reacting a compound of

formula 9 with a source of L^1 and a source of L^2 , where L^1 and L^2 are as defined above:



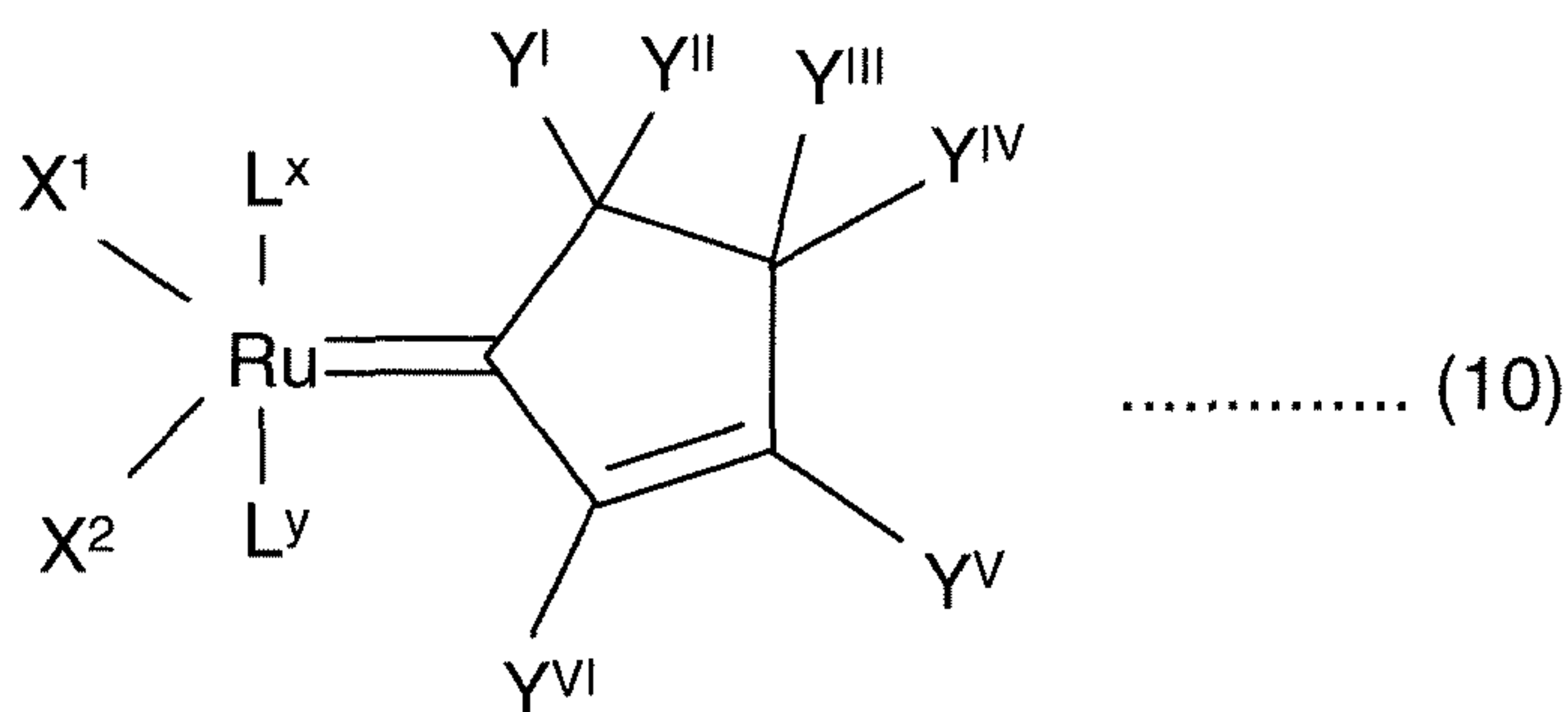
5

wherein

10 M , X^1 , X^2 and Z are as defined with reference to formula 3; and
 L^x and L^y are the same or different, each is a neutral ligand, and
each of L^x and L^y is not the same as L^1 or L^2 .

It will be appreciated that L^1 and L^2 may be the same and accordingly the
15 source thereof may be the same.

Preferably the compound of formula 9 is a compound of formula 10



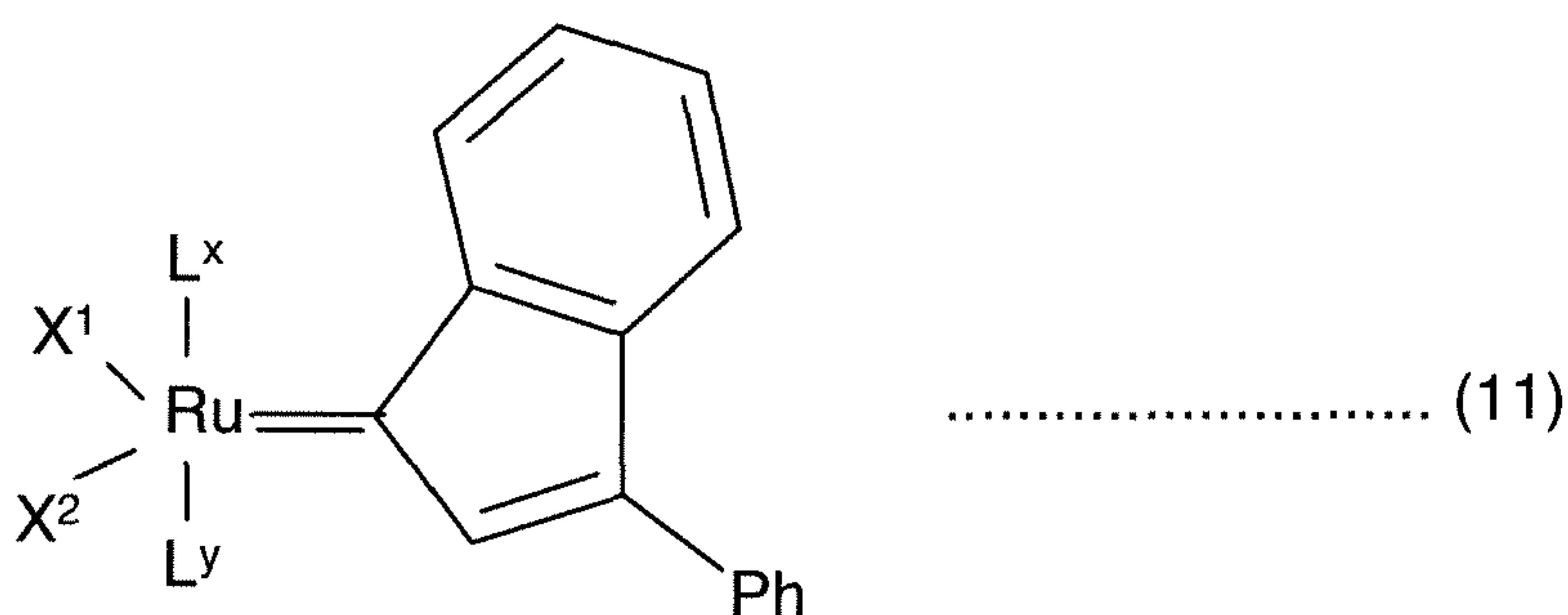
20

wherein

X^1 , X^2 , L^x and L^y are as defined above; and

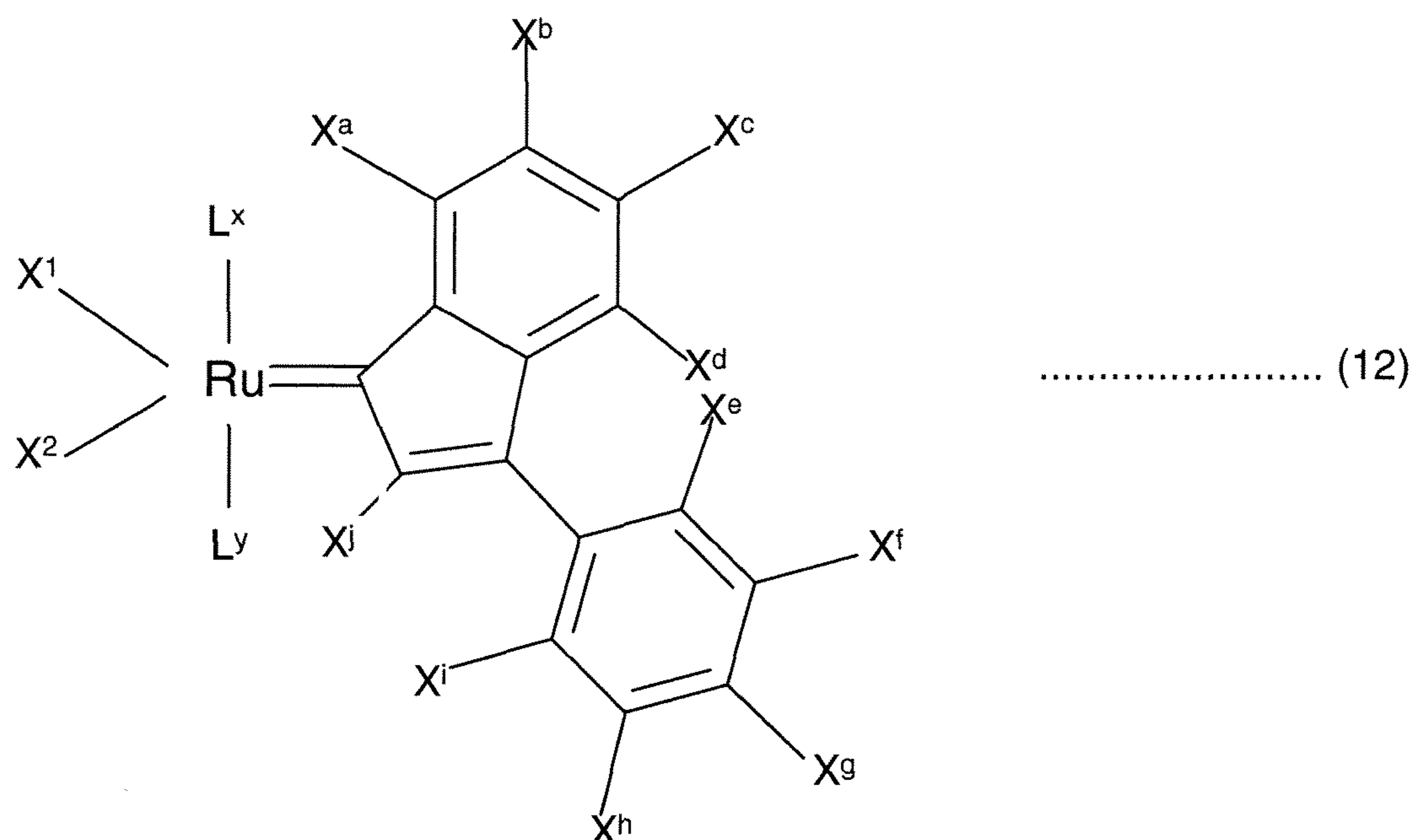
each of Y^I , Y^{II} , Y^{III} , Y^{IV} , Y^V and Y^{VI} is independently H or a moiety other than H, including an organic group (preferably an organyl group), and at least some of Y^I to Y^{VI} may be linked to each other.

Preferably the compound of formula 10 is a compound of formula 11.



wherein X^1 , X^2 , L^x and L^y are as defined above.

Preferably the compound of formula 10 is a compound of formula 12



wherein X^1 , X^2 , L^x , L^y are as defined above; and X^a to X^j are independently hydrogen or a moiety other than H, (preferably halogen, NO_2 , OR, SR or NR_2)
 5 provided that at least one of X^a to X^j is not H.

In a preferred embodiment L^x and L^y are identical and each is triphenylphosphine.

10 It will be appreciated that the above reaction of preparing a compound of formula 3 is a ligand exchange reaction.

The method of preparation may also include the step of preparing the compounds of formula 9, 10, 11 or 12 and the ligand exchange reaction may
 15 be performed in situ after preparation of the compound of formula 9, 10, 11 or 12.

The compound of formula 9 (preferably formulae 10 to 12) may be prepared from reacting a compound consisting of Ru, X¹, X², L^x and L^y only, only with a source of Z. Such a compound consisting of Ru, X¹, X², L^x and L^y only may be a phosphine–ruthenium–halide complex, preferably a phosphine-
5 ruthenium-chloride complex, preferably (PPh₃)₃ RuCl₂ or (PPh₃)₄ Ru Cl₂. This reaction may be carried out in a polar organic solvent. The resulting compound may be subjected to one or more ligand exchange reactions.

The source of Z may be an alcohol.

10

The compound consisting of Ru, X¹, X², L^x and L^y only may be prepared by reacting a ruthenium halide (preferably a ruthenium chloride) compound with a source of L^x, L^y and also a source of X¹ and X² where X¹ and X² are not halide. Preferably the reaction is between ruthenium chloride and PPh₃ only.

15 The reaction may be carried out in a solvent, preferably an organic solvent, preferably a alcohol, preferably ethanol.

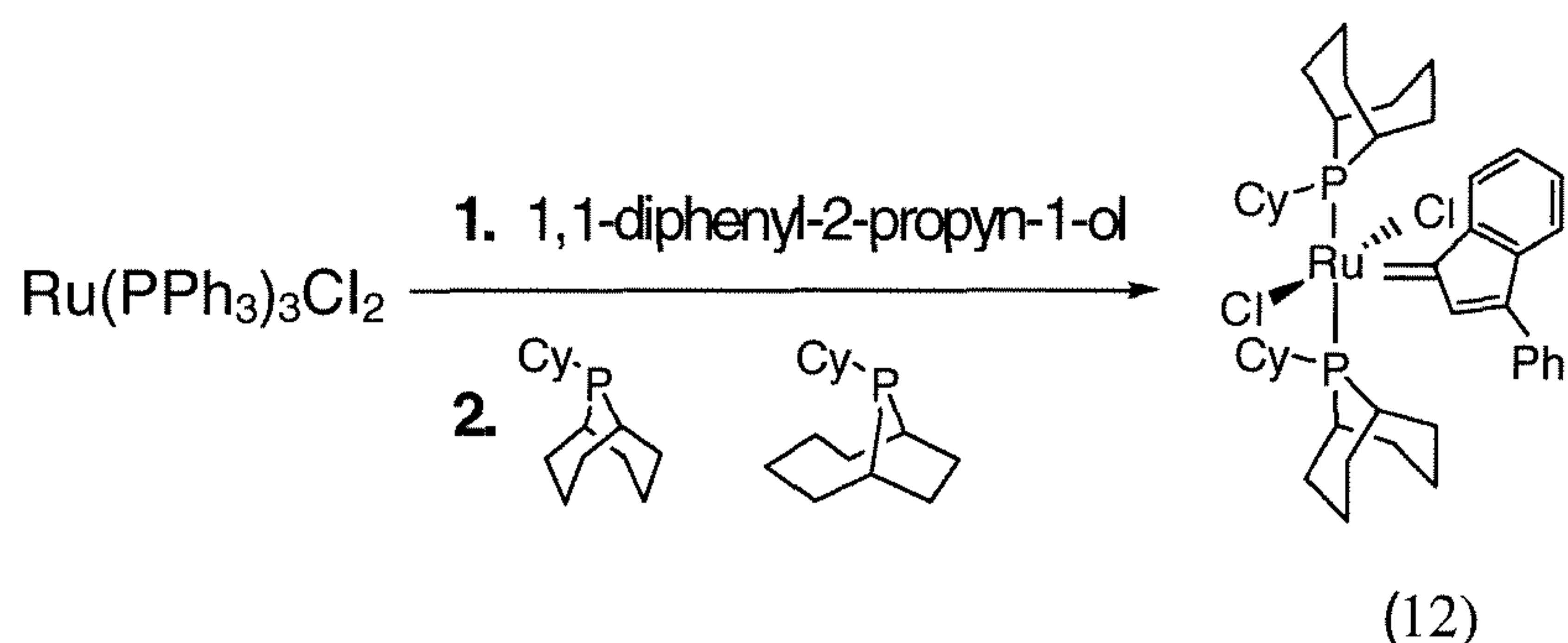
A compound of formula 7, preferably of formula 8, may also be prepared by reaction of a ruthenium-di-halide-bis-aryl-dimer complex, preferably [(p-cymene)RuCl₂]₂, with two ligands chosen from L^x, L^y, L¹ or L² as defined
20 above, and a di-aryl-propargylic alcohol, preferably 2,2-diphenyl-alkin-1-ol in an organic solvent, preferably followed by exchange of one or two ligands of type L^x, L^y, L¹ or L² with one or two other ligands of type L^x, L^y, L¹ or L², followed by isolation of the desired complex through standard procedures.

25

Without thereby limiting the scope of the invention it will now be further described with reference to the following non-limiting examples.

Example 1

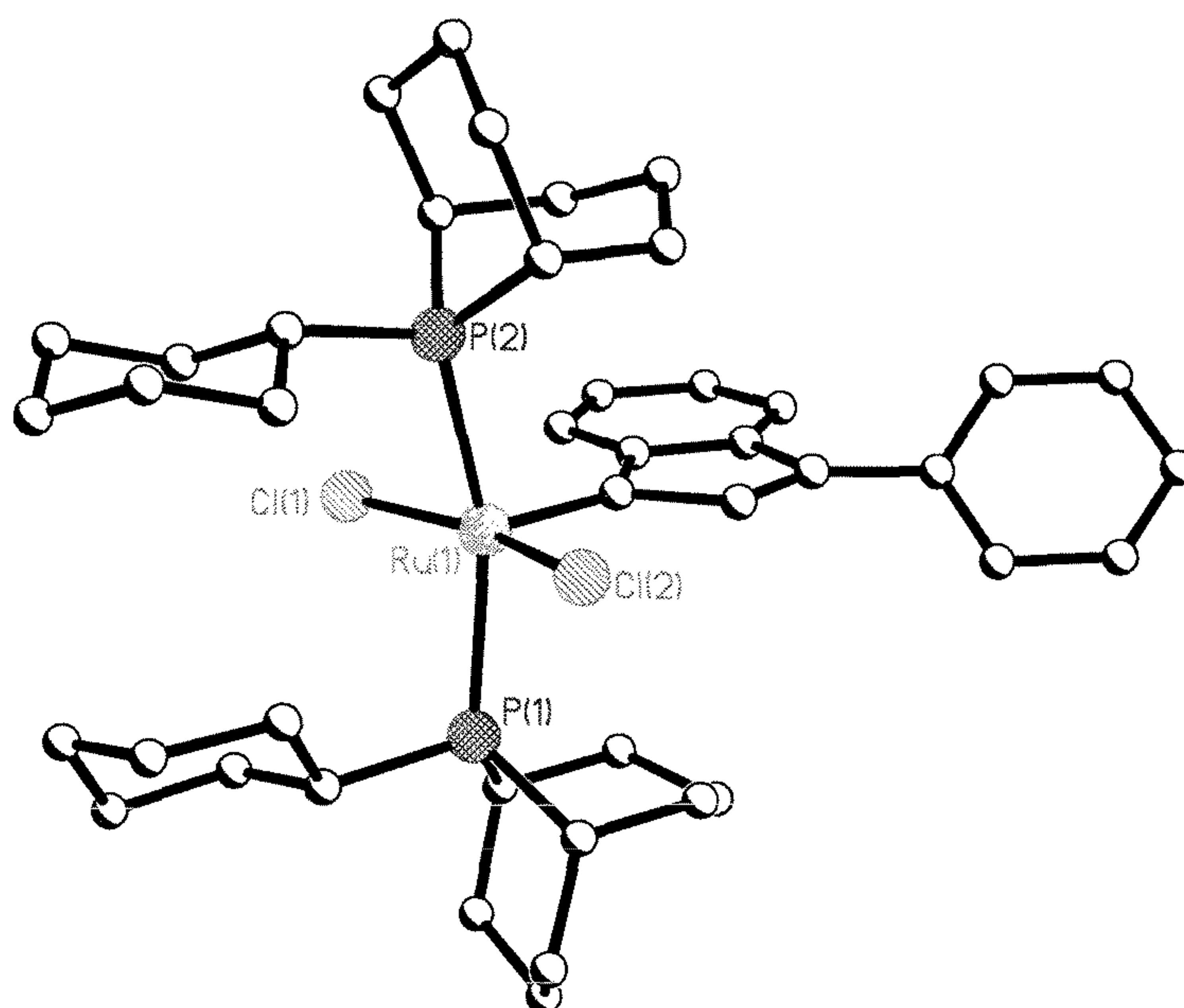
5 Preparation of complex (12)



In a 50 mL round-bottom flask was added $\text{Ru(PPh}_3)_3\text{Cl}_2$ (1.0 g, 1.04 mmol) and 1,1-diphenyl-2-propyn-1-ol (330 mg, 1.59 mmol) followed by degassed tetrahydrofuran (80 mL). The mixture was refluxed for 2 h and then the solvent was removed under reduced pressure. Cyclohexylphoban (ca. 3.1 mixture of [3.3.1] and [4.2.1] isomers, 672 mg, 3 mmol) in CH_2Cl_2 (20 mL) was added, and the mixture stirred for 24 h. After such time the solvent was removed and the residue taken up in hexane. The solid thus formed was sonicated for 10 minutes and stirred for for 1 hour then filtered to give the desired complex (12).

$^{31}\text{P}(^1\text{H})$ NMR (121 MHz, C_6D_6): δ = 22.0 (bs); ^1H NMR (300 MHz, C_6D_6): δ = 8.25 (s, 1H), 7.80-6.75 (m, 9H), 2.80 (s, 4H, PCH of Phoban), 2.26-0.40 (m, 46H, Phoban H).

Single crystals suitable for X-ray diffraction were obtained by recrystallization from evaporation of an ether solution. A crystal structure was obtained (below): $C_{43}H_{60}Cl_2P_2Ru$, $M_r = 810.82$, monoclinic, space group $P2(1)/c$, $a = 22.336(9)$, $b = 17.602(7)$, $c = 9.796(4)$ Å, $V = 3834(3)$ Å³, $T = 173(2)$ K, $Z = 4$, $\rho_{\text{calcd}} = 1.357$ gcm⁻³, SMART diffractometer, 51939 reflections collected, 6839 unique [$R_{\text{int}} = 0.1491$], $R_1 = 0.1137$, $wR2 = 0.2231$.



Example 2

10

Metathesis using complex (12) in the ethenolysis of methyl oleate to 1-decene and 9-methyldecenoate

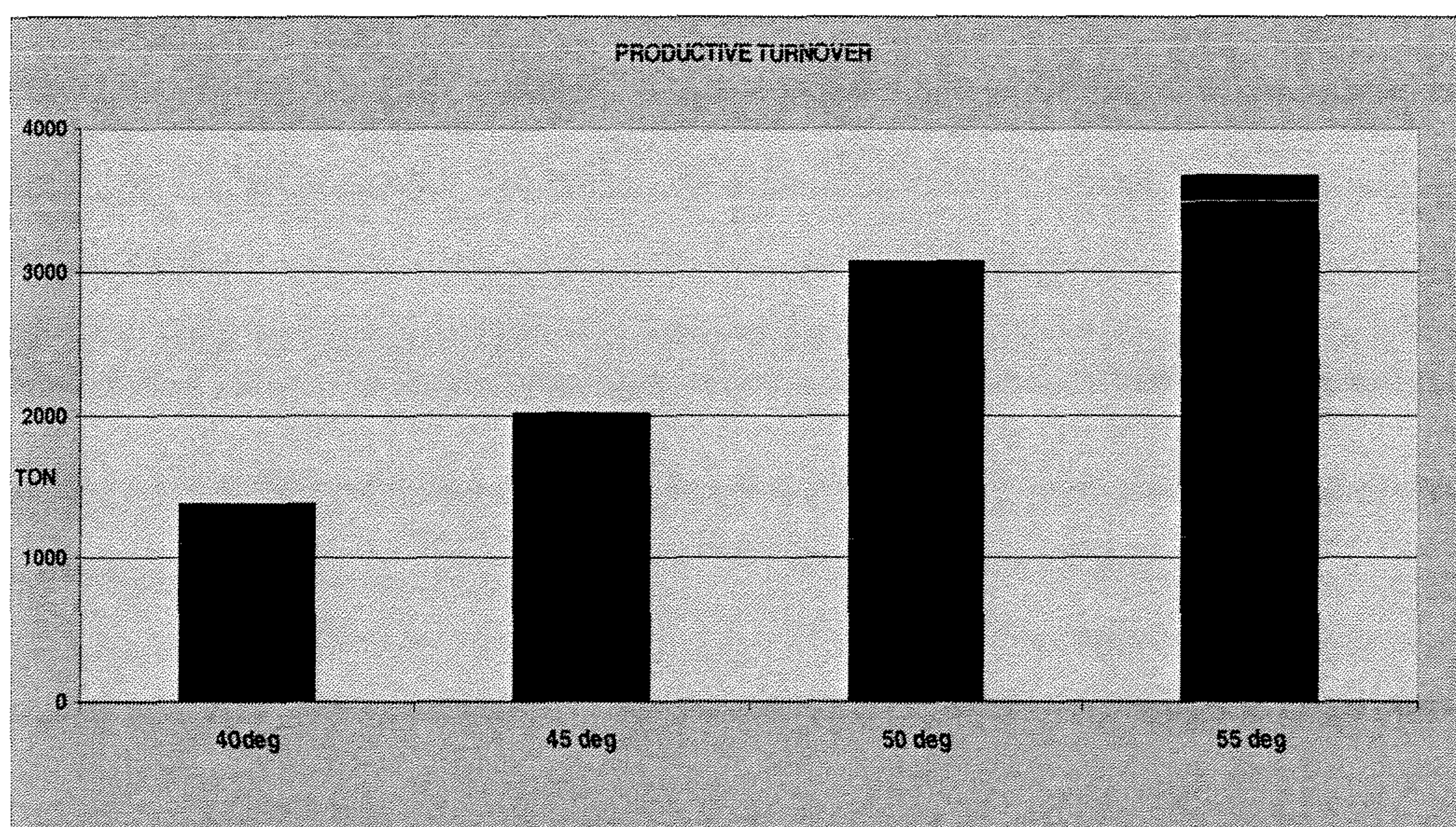
Methyl oleate (99%) was purchased from Aldrich and passed through a short (2 cm) pad of alumina before use. In a 50 mL stainless-steel autoclave fitted with dip-tube for sampling was charged methyl oleate (12 g, 40.0 mmol).

15

Tetradecane (2.5 g, internal standard) was added and the catalyst (12) of example 1 (0.010 mmol) was weighed and transferred into a Schlenk flask under argon. Toluene (5 mL, degassed) was added to the Schlenk flask and an aliquot (1 mL) of this stock solution was transferred to the autoclave. The autoclave was pressurized (4-20 bar (400 to 2000 kPa) of ethylene) and heated via computerized temperature controller to the desired temperature. Samples were taken at regular intervals using a dip-tube apparatus, and analyzed by GC with an MDN column.

The results below in figure 1 show the productive turonover obtained using catalyst (12) (S/C = 10 000:1) at 10 bar ethylene pressure at various temperatures.

Figure 1



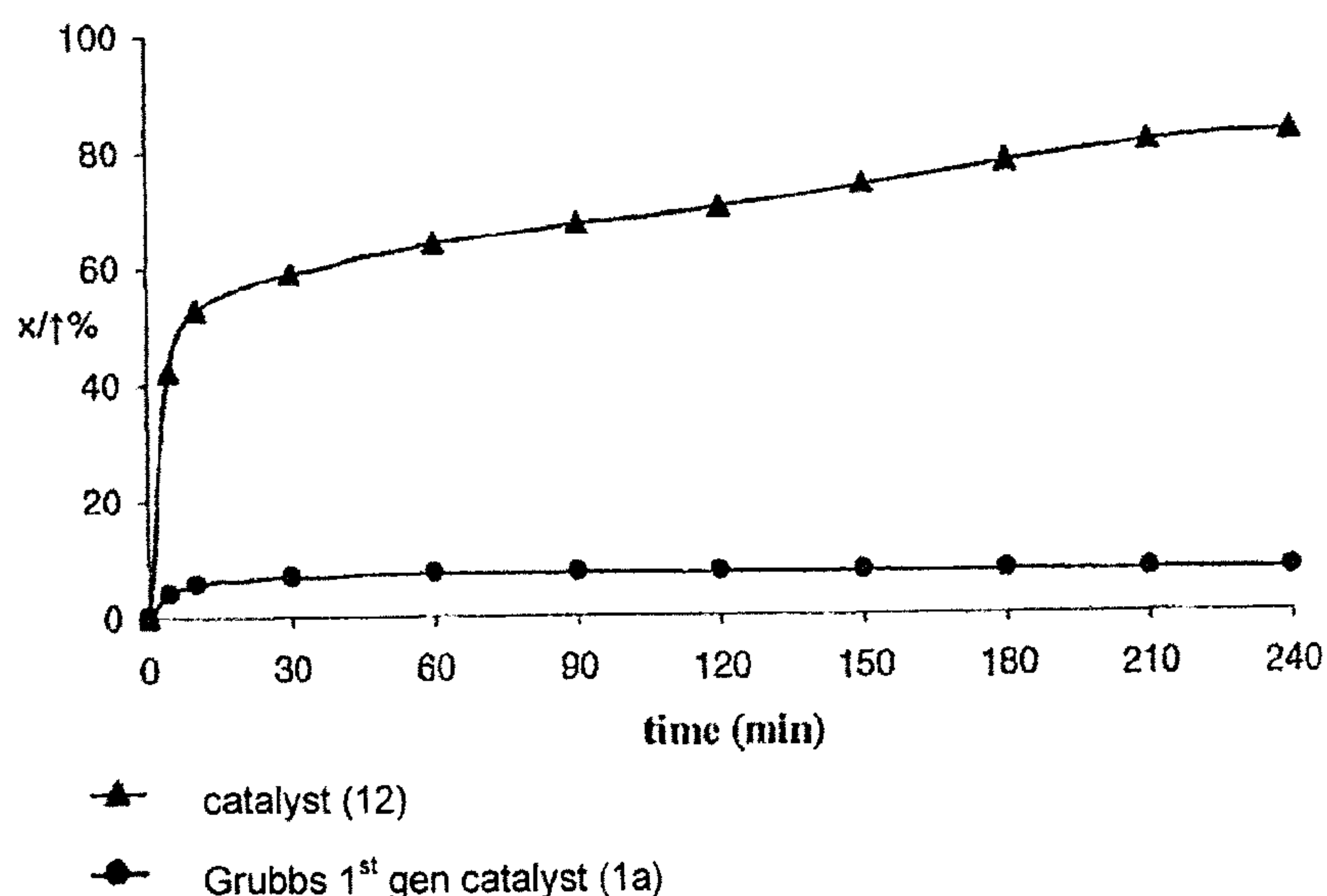
TON = Turnover number (number of moles of substrate consumed per mole of catalyst employed). Deg = degrees Celsius

Example 3Metathesis using complex (12) in the self-metathesis of 1-Decene

A 250 mL three-necked round bottom flask was fitted with a reflux condenser, thermometer and septum. A needle was inserted through the septum and connected to a gas supply *via* a needle valve to ensure a slow and steady stream of argon through the reaction solution. 1-Decene (24 mL, 0.127 mol) was added to the reaction vessel and the reaction was heated to 65 °C. The catalyst (12) of example 1 (11.0 mg, 0.014 mmol) was weighed into a custom-made aluminum weighing tray and added to the reaction mixture. Samples were taken at regular intervals *via* syringe through the septum. Samples were analysed by GC with a Pona column.

The results below in figure 2 show the % conversion obtained using catalyst (12) at 65 °C.

Figure 2

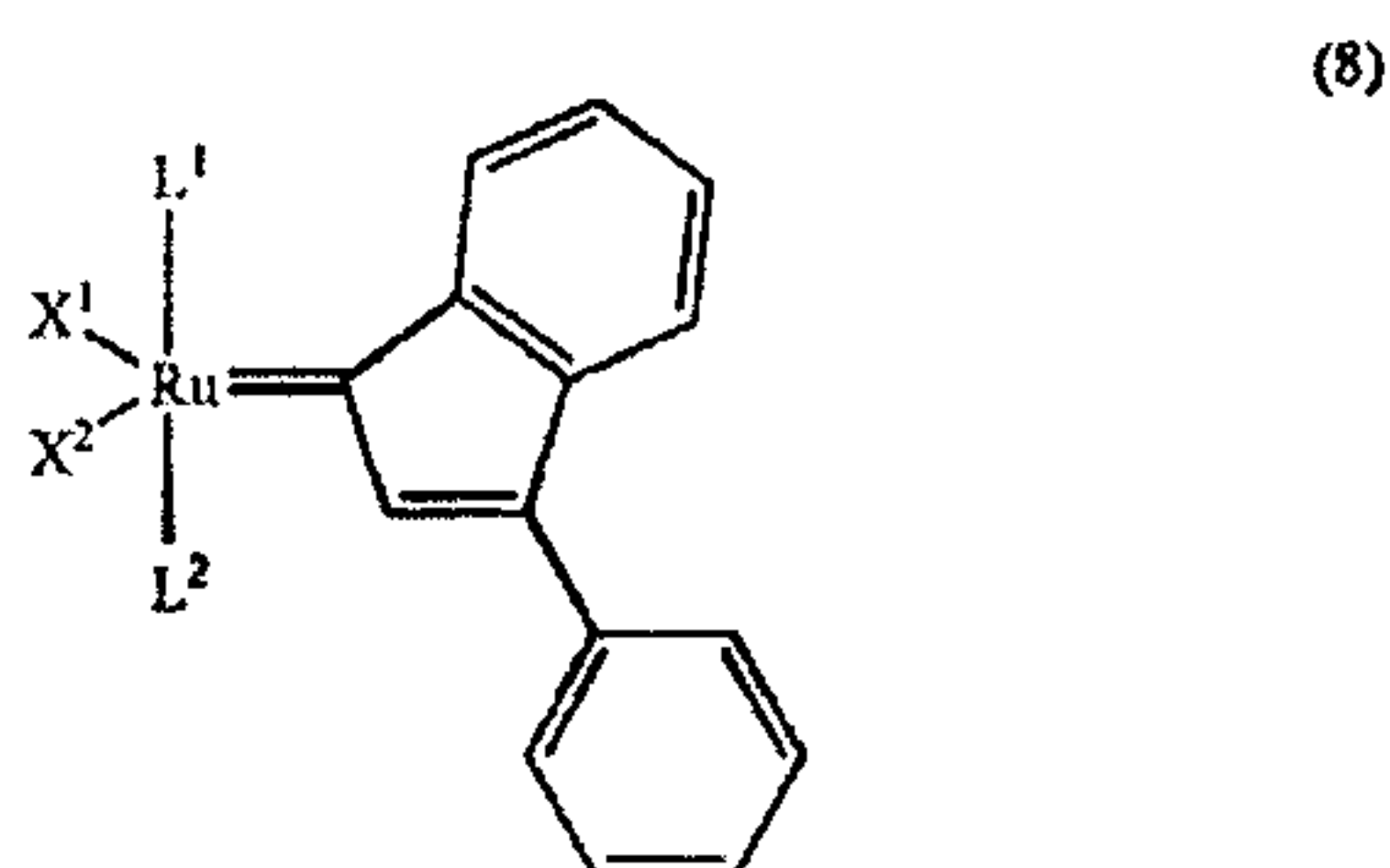


It will be appreciated that catalyst (12) was easy to prepare from well accessible, stable and essentially non-toxic starting materials and the catalyst can be isolated and stored. The catalyst exhibited a high catalytic activity, a good compatibility with functional groups and solvents and it need not be
5 activated by any additive.

It will be appreciated that complex a can be used for a variety of metathesis reactions and it will be appreciated that many variations in detail are possible. As such, the scope of the claims should not be limited by the preferred
10 embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

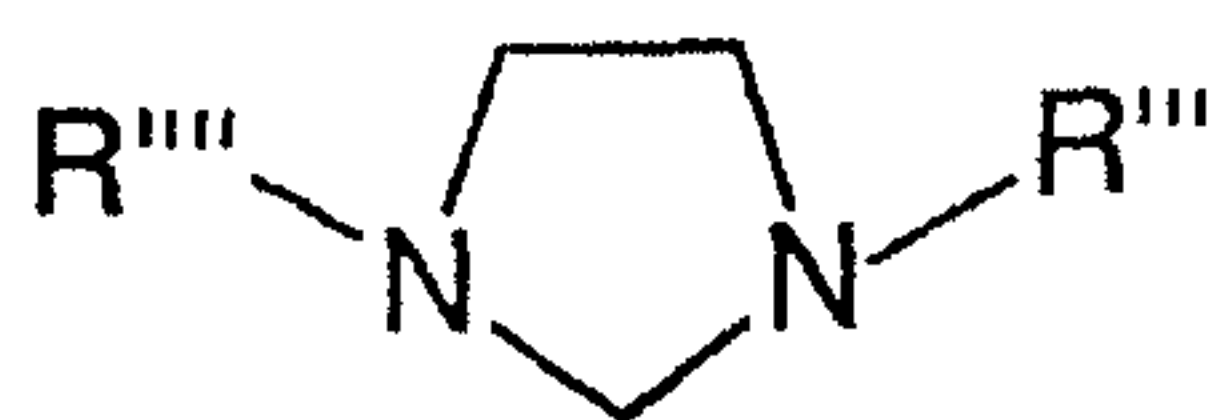
The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A compound of formula 8:

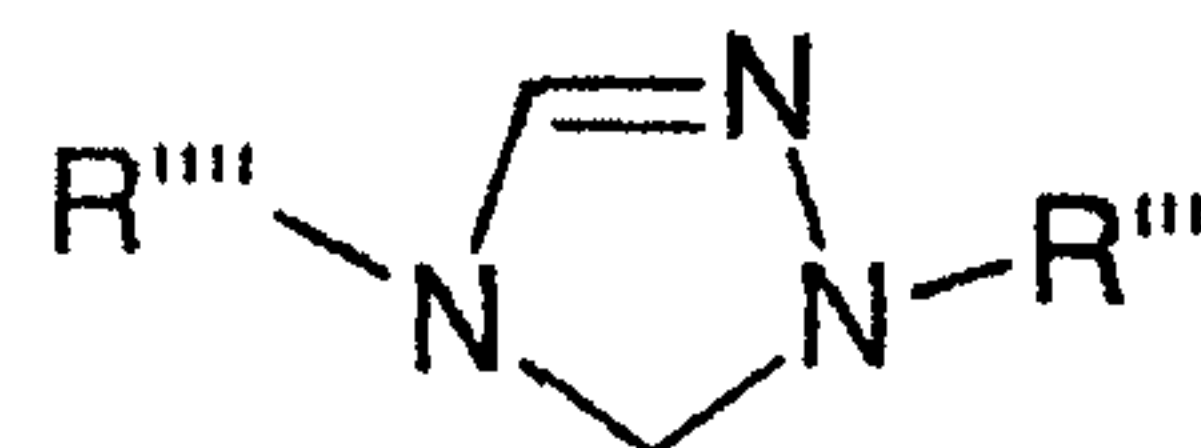


wherein:

L^1 is a neutral electron donor ligand which is $-P(\text{cyclohexyl})_3$, $-P(\text{cyclopentyl})_3$, $-P(\text{isopropyl})_3$, $-P(\text{phenyl})_3$,

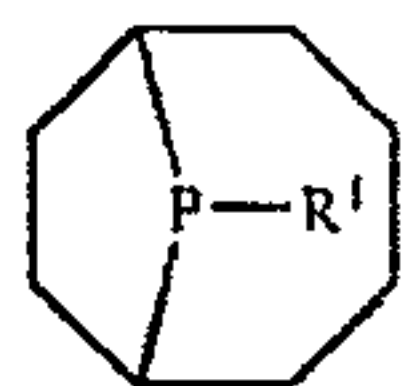
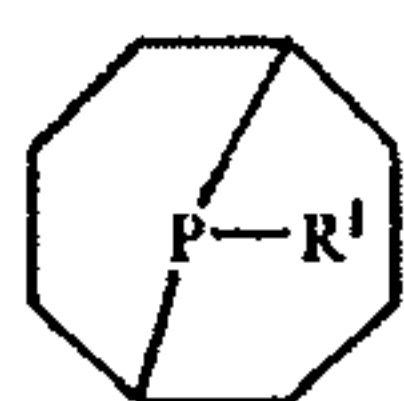


, or



;

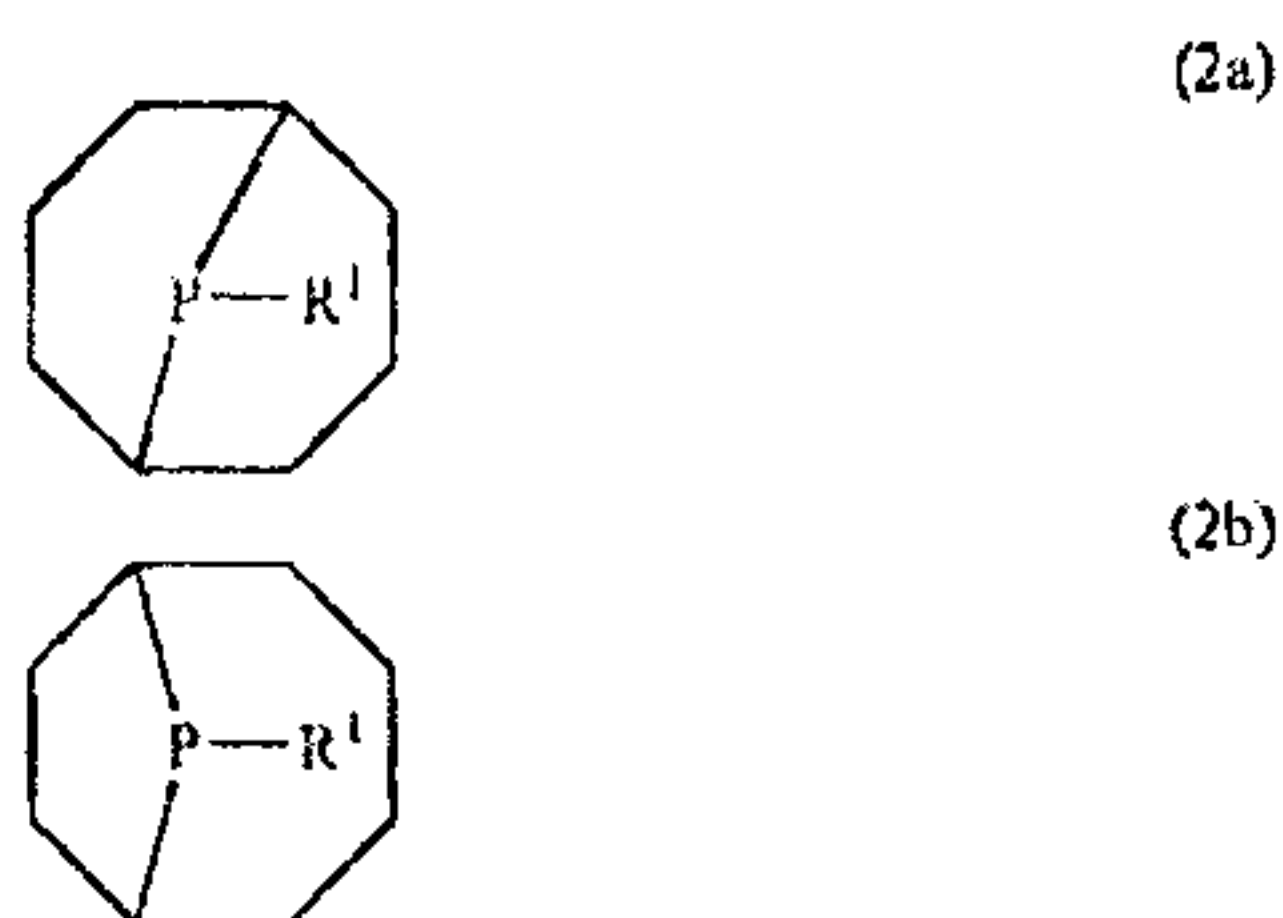
wherein R''' and R'''' are H, an alkyl, an aryl, a cycloalkyl, or an adamantyl group; or a 9-phospha-bicyclo-[3.3.1]nonane of formula 2a or a 9-phospha-bicyclo[4.2.1]nonane of formula 2b or a mixture thereof:



wherein R^1 is H, a substituted or unsubstituted alkyl, aryl or cycloalkyl group;

L^2 is a phosphorus containing ligand in the form of a heterocyclic organic compound with a ligating phosphorus atom which ligates with Ru, and which ligating phosphorus atom is an atom in the heterocyclic ring structure of the heterocyclic organic compound,

wherein the heterocyclic organic compound is a phosphabicyclononane which is a 9-phosphabicyclo-[3.3.1]nonane of formula 2a or a 9-phosphabicyclo[4.2.1]nonane of formula 2b or a mixture thereof:



wherein R^1 is H, a substituted or unsubstituted alkyl, aryl or cycloalkyl group; and

X^1 and X^2 are independently a ligand which is a halide, CF_3CO_2 , CH_3CO_2 , $CFHCO_2$, $(CH_3)_3CO$, $(CF_3)_2(CH_3)CO$, $(CF_3)(CH_3)_2CO$, PhO , MeO , EtO , tosylate, mesylate, or trifluormethanesulfonate.

2. The compound of claim 1, wherein L^1 and L^2 are the same.
3. The compound of claim 1, wherein R^1 is a substituted or unsubstituted alkyl, aryl or cycloalkyl group.
4. The compound of any one of claims 1 to 3, wherein X^1 and X^2 are each independently a halide.
5. A catalyst comprising a compound as defined in any one of claims 1 to 4 for use in a catalysed metathesis reaction, wherein at least one olefinic compound in the form of an olefin with one or more double bonds or a compound which includes an olefinic moiety with one or more double bonds is subjected to metathesis in the presence of the catalyst.
6. The catalyst of claim 5 for use in a homogeneous metathesis reaction.
7. The catalyst of claim 5 or 6, wherein the catalyst is formed in situ.

8. A method of preparing a compound as defined in claim 1 comprising reacting a compound which is $(PPh_3)_3RuCl_2$ or $(PPh_3)_4RuCl_2$ with an alcohol of 1,1-diphenyl-2-propyn-1-ol.