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(54) **Title:** FERROCENYL PHOSPHITE LIGANDS FOR ASYMMETRIC CATALYSIS AND A METHOD FOR THEIR PRODUCTION

(57) **Abstract:** The present invention relates to novel ferrocene compounds, their synthesis and their use as catalysts. The compounds of the invention are useful additives in transition metal-promoted transformations of organic molecules such as hydrogenations, additions of organometallic neucleophiles to carbonyl compounds and Michael acceptors.

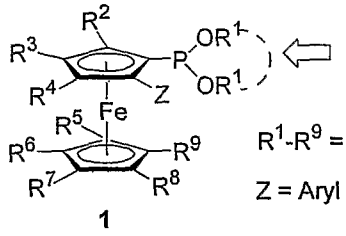
Ferrocenyl phosphite ligands for asymmetric catalysis and a method for their production

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

Phosphoramidites [$(RO)_2PNR_2$[are recent additions to the set of so-called "privileged" ligands leading to superlative asymmetric catalysis when coordinated to a range of metal centres for a variety of processes. The very high levels of enantioselectivity that are often realised with these ostensibly monodentate ligands are not expected if free rotation about the P-M_{cat} bond in the active catalyst [L_nM_{cat}-$P(OR)_2(NR_2)$] is present. We have found a novel class of catalysts which can attain a (P,C=C) chelate coordination mode in certain reactions including: nickel-catalysed alkene dimerisation, ruthenium-catalysed cyclopropanation and nickel-promoted additions of $AlMe_3$ to aldehydes, which we call "ferrophites". Throughout this patent (R) planar, axial and centrosymmetric stereochemical chemistry are distinguished by the descriptors (R_p), (R_a) and (R_c), respectively, for clarity.

An initial aspect of the present invention relates to new states of matter: the chiral 1,2-substituted ferrocenyl phosphite ligands **1** that are useful for coordination to transition metals or their derived compounds. A second aspect relates to a new method for the preparation of the species **1**. The resulting metal-ligand complexes or mixtures are of widespread utility in asymmetric catalysis for the production of fine chemicals, pharmaceutical intermediates and other chiral organic products.



1

Both cyclic or acyclic R^1 structures can be used.

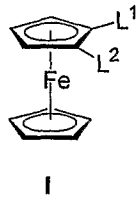
R^1-R^9 = H, alkyl, aryl or substituted versions thereof

Z = Aryl or alkenyl or substituted versions thereof

2. DESCRIPTION OF THE PRIOR ART

Kagan disclosed the preparation of the 1,2-disubstituted ferrocenyl species (**I**) which are chiral due to the presence of appropriate substituents on the upper cyclopentadienyl ring [O. Riant, G. Argouarch, D. Guillaneux, O. Samuel, H. Kagan, *J. Org. Chem.* **1998**, *63*, 3511-3514; L^1 = PPh_2, R^2 = CO_2Me, PCy_2 (Cy = *cyclo*-C_6H_{11})]. The phosphorus substituent is typically introduced by the reaction of (**I**) (L^1 = M, typically Li) followed by trapping with XPR_2 (X = a halogen, R = alkyl, aryl). Similar phosphine species have been prepared by Johannsen (**I** L^1 = PPh_2, PCy_2; L^2 = Aryl) [J. F. Jensen, I. Søtofe, H. Sørensen, M. Johannsen, *J. Org. Chem.* **2003**, *68*, 1258-1265; J. F. Jensen, M. Johannsen, *Org. Lett.* **2003**, *5*, 3025-3028]. Importantly however, no 1,2-disubstituted ferrocenyl phosphite species have been prepared by this approach as attempted preparations of (**I**) with L^1 = $P(OR)_2$, (R = alkyl aryl) using $XP(OR)_2$ (X = a halogen, R = alkyl, aryl) all fail to give synthetically useful yields. Ferrocenyl species containing asymmetric phosphite units are presently limited to species of types (**II**) introduced

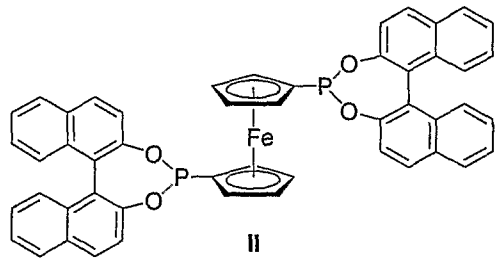
by Reetz [M. T. Reetz, A. Gosberg, R. Goddard, S.-H. Kyung, Suk-Hun, *Chem. Commun.* **1998**, 2077-2078.] and others (**III**) by separate workers [G. R. Knox, P. L. Pauson, D. Willison, *Organometallics* **1992**, *11*, 2930-2933; Compounds (**II**) and (**III**) are prepared indirectly through introduction of a $P(NR_2)_2$, substituent, its subsequent chlorination to a PCl_2 group and reaction with binol or other alcohols. Ferrocenyl ligands based on (**I**) where $L^1 = PR_2$ and L^2 = a chiral substituent such as CHMeX (X = PR_2, NR_2, etc.) form the basis of the *Josiphos* family of ligands [H.-U. Blaser, W. Brieden, B. Pugin, F. Spindler, M. Studer, A. Togni, *Solvias Josiphos ligands: from discovery to technical applications. Topics in Catalysis* **2002**, *19*, 3-16] but these are different from the structures claimed herein. No prior publication disclosed the constitution of (**I**) such that $L^1 = P(OR)_2$ and L^2 = Ar together with a strategy for their rapid synthesis in good yield. Two companies have independently claimed 1,2-substituted diphosphines of structural type (**IV**) but in these cases no phosphite structures were described by either Degussa AG [P. Knochel, P. J. J. Almena, K. Drauz, I. Klement, Eur. Pat. Appl. 1999, 10 pp. EP 965574 (*Chem. Abs. 132*, 35472], or the Kawaken Fine Chemical Co Ltd [T. Ito, T. Aoki, *PCT Int. Appl.* **2004**, 29 pp, WO2004078686-A1 (*Chem Abs. 141*, 260264)].



I

$L^1 = PAr_2$, $PAlkyl_2$

L^2 = Alkyl, Ar, or substituted version thereof



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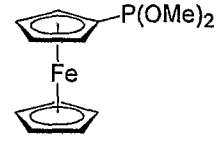

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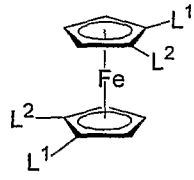


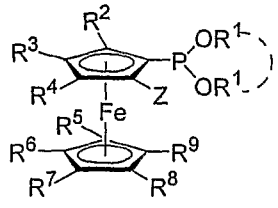
IV

$L^1 = PAr_2$, $PAlkyl_2$

L^2 = Alkyl, Ar, or substituted version thereof

SUMMARY OF THE INVENTION

This invention discloses new states of matter (**1**) that are prepared by the union of the widely available fragments (**2**) and (**3**) whereby: R^1 is derived from two suitable monoalcohols or one diol; R^2-R^9 are H, C_1-C_{20} alkyl, alkenyl, or aryl substituents or heteroatom substituents thereof; Z is a C_2-C_{20} unit or heteroatom substituted derivative thereof such that the initially attached carbon is sp^2 hybridised (representative examples of Z include vinyl or aryl groups or heteroatom substituted variants thereof); M is a Group 1-2 or 12-13 metal; R^{10}-R^{11} is a C_1-C_{20} alkyl, alkenyl, or aryl substituent or heteroatom substituted version thereof. The drawing (**1**) is not intended to represent or limit the invention to any specific stereoisomer. All potential stereoisomers arising from planar, axial or centrosymmetric stereoelements are claimed herein. The species (**1**) are useful additives in transition metal-promoted transformations of organic molecules such as hydrogenations, additions of organometallic neucleophiles to carbonyl compounds and Michael acceptors.



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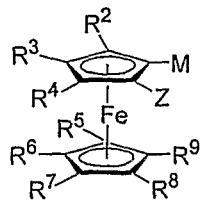

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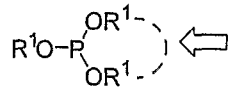


Both cyclic or acyclic R^1 structures can be used.

3

According to the present invention, there is provided a compound of Formula 1,
wherein each R^1 is independently selected from the group comprising: C_{1-20} alkyl, C_{1-20} haloalkyl, C_{2-20} alkenyl, and C_{2-20} alkynyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

or the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a monocyclic ring of up to 9 members, or a fused or conjugated polycyclic ring system containing up to to 24 atoms in the ring system, the or each ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

each of R^2 to R^9 is independently selected from the group comprising: H, C_{1-20} alkyl, C_{1-20} haloalkyl, C_{2-20} alkenyl, C_{2-20} alkynyl, CH_2OC_{1-20} alkyl, CH_2SC_{1-20} alkyl, aryl and het, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

and / or independently any adjacent two of the R^2 to R^9 groups joined to the same carbon, may together with the carbons to which they are attached form a ring of up to 6 members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

het is an aromatic or aliphatic heterocyclic group containing from 5 to 10 ring members and containing 1, 2 or 3 independently chosen N, O or S atoms; and

Z is a group including an sp2 hybridised atom through which Z is bound to the ferrocene ring.

Preferably, each R^1 is independently selected from the group comprising: C_{1-10} alkyl, C_{1-10} haloalkyl, C_{2-10} alkenyl, and C_{2-10} alkynyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

or the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a ring of up to 9 members, the ring being optionally substituted with from 1 to 3

substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

More preferably, each R^1 is independently selected from the group comprising: C_{1-6} alkyl, C_{1-60} haloalkyl, and C_{2-6} alkenyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

Another preferred embodiment is that in which the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a ring of up to 9 members, or a fused or conjugated polycyclic ring system containing up to 24 atoms in the ring system, the or each ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

In an embodiment, the fused or polycyclic ring may contain 1 to 4 atoms independently selected from N, O, or S.

A fused or polycyclic ring preferably has up to 20 members.

It is further preferred that the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a ring of 5, 6 or 7members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

Preferably het is selected from the group comprising: C-linked pyrrolyl, imidazolyl, triazolyl, thienyl, furyl, thiazolyl, oxazolyl, thiadiazolyl, oxadiazolyl, pyridinyl, pyrimidinyl, pyridazinyl, pyrazinyl, quinolinyl, isoquinolinyl, benzimidazolyl, quinazolinyl, phthalazinyl, benzoxazolyl and quinoxalinyl.

Preferably, Z is selected from the group comprising: het, C_{2-20} alkenyl, and aryl.

As used herein, the term "aryl", alone or in combination, means an unsaturated aromatic carbocyclic group having 6-14 carbon atoms having a single ring, for example, but not limited to, phenyl or multiple fused rings such as naphthyl. Aryl may optionally be further fused to an aliphatic or aryl group or can be substituted with one or more substituents such as, for example, but not limited to, halogen, hydroxy, C_1-C_7 alkyl, C_1-C_7 alkoxy or aryloxy, C_1-C_7 alkylthio or arylthio, alkylsulfonyl, cyano or primary or nonprimary amino.

Examples of aryl include: phenyl, naphthyl and indenyl.

In an embodiment, each of R^2 to R^9 is independently selected from the group comprising: H, C_{1-7} alkyl, C_{1-7} haloalkyl, C_{2-70} alkenyl, C_{2-7} alkynyl, CH_2OC_{1-7} alkyl, CH_2SC_{1-7} alkyl, aryl and het, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

and / or independently any adjacent two of the R^2 to R^9 groups joined to the same carbon, may together with the carbons to which they are attached form a ring of up to 6 members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

In a further embodiment, each of R^2 to R^9 is independently selected from the group comprising: H, C_{1-7} alkyl, C_{1-7} haloalkyl, and C_{2-70} alkenyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

In an alternative embodiment, each of R^2 to R^9 is independently selected from the group comprising: C_{2-7} alkynyl, CH_2OC_{1-7} alkyl, CH_2SC_{1-7} alkyl, aryl and het, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

In another embodiment, any adjacent two of the R^2 to R^9 groups joined to the same carbon, may together with the carbons to which they are attached form a ring of up to 6 members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

DETAILED DESCRIPTION OF THE INVENTION

Our synthetic route began with (S_c)-**1** prepared from ferrocene by Kagan's method by use of the known Andersen sulfoxide (Scheme 1). All of the ligands in this patent could be prepared in either enantiomeric series, but are shown throughout as originating from natural L-menthol for consistency. Stereoselective lithiation and trapping with $B(OMe)_3$ allows access to (R_pS_c)-**2** using literature procedures. Optimal coupling of (R_pS_c)-**2** with suitable ArX (X = I, Br) occurred with 8 mol-% $Pd(dppf)Cl_2$ and sodium hydroxide promotion at reflux within 4 hours to give good yields for both sterically encumbered and electron-deficient aryl halides (R_pS_c)-**3a-c** (Scheme 1).

The sulfoxide auxiliary of (R_pS_c)-**3a** was cleaved under Kagan's conditions to afford the derived oranolithium species (S_p)-**4a** (Scheme 2). The change in stereochemical descriptor is caused only by the peculiarities of the CIP nomenclature (C has greater priority than Li).

Addition of $P(OPh)_3$ to organolithium species (Sp)-**4a** resulted in an almost immediate (<2 min at -78°C) colour change in the reaction mixture from deep orange-red to pale orange-yellow. On workup

the desired product (R_p)-**7a** was isolated as an orange oil (69%). Compounds (R_p)-**7b,c** were similarly prepared in 33 and 56% yield, respectively (Scheme 2).

We performed the equivalent reaction of the anions **4a-c**, both with 1,1-bi-naphthol- and 1,1-biphenol-derived phosphates. The precursor phosphates were easily prepared by the reaction of PCl_3 with the appropriate diol in the presence of NEt_3, to yield the chlorophosphites **6b-c** (Scheme 3). Subsequent addition of phenol and further NEt_3 allowed the isolation of **5b-c** in moderate yield (53-74% based on the diol) after column chromatography on silica.

Reaction of **5b-c** with the organolithiums **4a-c** proceeded in a modular fashion to complete a small library of ferrophite ligands (Scheme 2).

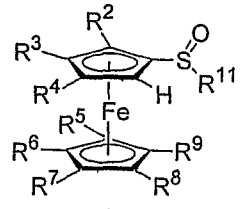
Scheme 1

Scheme 2

Scheme 3

The novel ligands (**1**) are prepared by phosphorus-carbon coupling of fragments (**2**) and (**3**) examples of some of which are known.

Fragment (**2**): The precursor fragment (**2**) is available through literature procedures. Thus, Lithiation of ferrocene [D. Guillaneux, H. B. Kagan, *J. Org. Chem.* **1995**, *60*, 2502-2505]] followed by trapping with menthyl-*p*-tolunenesulfinate to afford (**4**) is available in the open literature (R^2-R^9 = H, R^{11} = 4-tolyl). Either stereoisomer of the sulfinate can be prepared by use of the (*R*) or (*S*) menthol-derived auxiliary [J. M. Klunder, K. B. Sharpless, *J. Org. Chem.* **1987**, *52*, 2598-2602]. Highly stereospecific deprotonation of (**4**) with LiN*i*Pr_2 generates the organolithium species (**5**, M = Li) which can be transmetallated to a range of species including M = ZnCl, ZnCl, $B(OH)_2$, $B(OR)_2$ etc. Under palladium catalysis (**5**) can be coupled with sp^2 hybridised electrophiles such as **6**, **7** where R^{12}-R^{19} are H, alkyl alkenyl, aryl, halogen, OR, NR_2, CO_2R, COR, $CONH_2$, SO_3R derivatives and X is a halogen, triflate (OSO_2CF_3) or nonaflate ($OSO_2C_4F_9$)] to afford (**8**). Examples of (**8**) are documented in the open literature [J. F. Jensen, I. Søtofe, H. Sørensen, M. Johannsen, *J. Org. Chem.* **2003**, *68*, 1258-1265; J. F. Jensen, M. Johannsen, *Org. Lett.* **2003**, *5*, 3025-3028; H. K. Cotton, F. F. Huerta, Fernando J.-E. Bäckvall, *Eur. J. Org. Chem.* **2003**, 2756-2763] and these include the fragments (**8a-b**) which constitute preferred embodiments for the synthesis of the unreported compounds (**1**). Reaction of (**8**) with *tert*-BuLi is known [G. Argouarch, O. Samuel, O. Riant, J.-C. Daran, H. B. Kagan, *Eur. J. Org. Chem.* **2000**, 2893-2899.] to result in cleavage of the sulfoxide leading to direct formation of (**2**, M = Li)



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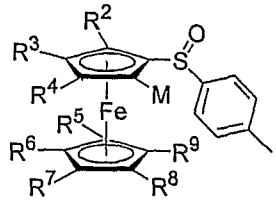

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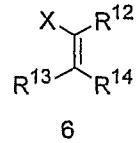

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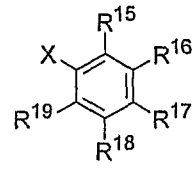

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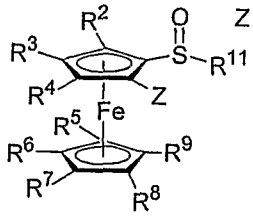

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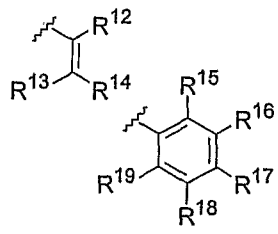
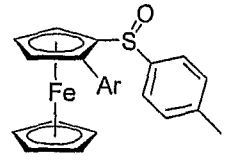
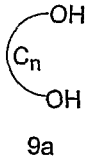


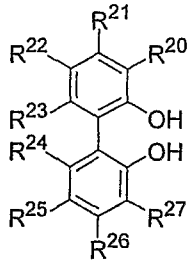


8a Ar = Ph
8b Ar = 1-$C_{10}H_7$
8c Ar = 2-$C_{10}H_7$
8d Ar = 4-(CF_3)Ph

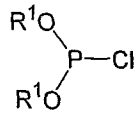
Fragment (**3**): Fragment (**3**) is available through routine application of known prior art. Direct reaction of PCl_3 with suitable mono (R^1OH) or diols (of general formula **9a-9b**, where R^{20}-R^{27} = H, halogen, C_1-C_{20} alkyl, alkenyl, halogen, OR, NR_2, CO_2R, COR, $CONR_2$, SO_3R or aryl substituent or heteroatom substituented version thereof) affords $ClP(OR^1)_2$ as exemplified by (**10a-b**). Subsequent reaction of these monochloro phosphorus species with R^2OH (halogen, C_1-C_{20} alkyl, alkenyl, halogen, OR, NR_2, CO_2R, COR, $CONR_2$, SO_3R or aryl substituent or heteroatom substituented version thereof) affords the mixed species (**3**). Preferred forms of the present invention, for reaction with fragment (**2**) include: $P(OPh)_3$ (**3a**) and the biphenyl (**3b**)and binaphthyl (**3c**) derived ligands. Either potential stereoisomer is implied by the representation of the binaphthyl. Compound (**3c**) is known [P. H. Dussault, K. R. Woller, *J. Org. Chem.* 1997, 62, 1556-1559]. A process route to compounds (**3b-c**) has been claimed [U. Scholz, E. Vogl, A. Gerlach, J. Hassfeld, B. Meseguer, Benjamin. *Eur. Pat. Appl.* **2004**, 24 pp. CODEN: EPXXDW EP 1394168 A1 20040303 *Chem Abs. 140*, 217810] but this involves use of R^1PCl_2 not **10a**.



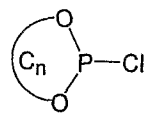
9a



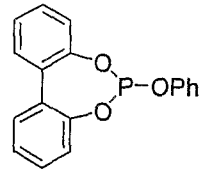
9b



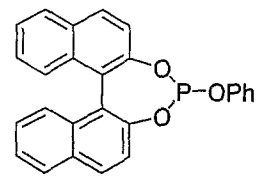
10a



10b



3b



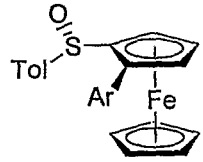
3c

A new class of chiral ferrocenyl-based phosphate (ferrophite) ligands has been prepared that mimic the π contacts thought to be realised in Feringa's phosphoramidite ligand **14**.

EXAMPLES

General. The precursor fragments (**2**, M = Li and **3**) were prepared by the literature approaches given above. New states of mater **1** were prepared by the union of these as outlined below. For compounds **1**, the first letter represents the sp^2 (aryl or alkenyl) group attached to the cyclopentadienyl ring: **a** = Ph, **b** = 1-naphthyl, **c** = 2-naphthyl, **d** = 4-(CF_3)Ph. The second letter the substituents at phosphorus: **a** = $(OPh)_2$, **b** = 1,1'-biphenol derived, **c** = 1,1'-binaphthyl derived. Thus, compound **1da** has one attached 4-trifluoromethylphenyl group and one $P(OPh)_2$ group in a 1,2 relationship on one cyclopentadienyl ring. These representative preparations the planar chirality stereodiscriptor is indicated first followed by either the centrosymmetric or axial chirality. However it will be understood here within that all potential stereiosomers can be accessed by routes described herein.

*Representative preparation of aryl sulfoxides – compound **8b***



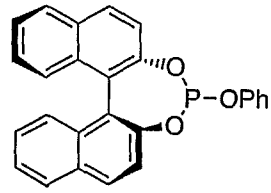
Ar = 1-$C_{10}H_7$

To a mixture of sulfoxide (*R,S*)-**5** (R^2-R^9 = H; R^{11} = 4-Tolyl, M = $B(OH)_2$) (1.95 g, 5.23 mmol), $PdCl_2(dppf)\cdot CH_2Cl_2$ (340 mg, 0.41 mmol), 1-iodonaphthalene (1.14 ml, 7.80 mmol) and toluene (60 ml) under argon was added sodium hydroxide (2 N, 5.10 ml). The solution was heated at reflux for 4 hours then allowed to cool and concentrated under reduced pressure. The crude oil was purified by column chromatography on silica gel (8:1:1 petrol:ethyl acetate:dichloromethane) to give (*R,S*)-**8b** (1.90 g, 81 %) as an orange crystalline solid. Similarly prepared were: (*R,S*)-**8a** (1.57 g, 75 %), (*R,S*)-**8c** (443 mg, 64 %), (*R,S*)-**8d** (608 mg, 84 %). Compounds **8a-b** had properties concordant with literature values [[J. F. Jensen, I. Søtofe, H. Sørensen, M. Johannsen, *J. Org. Chem.* **2003**, *68*, 1258-1265; J. F. Jensen, M. Johannsen, *Org. Lett.* **2003**, *5*, 3025-3028; H. K. Cotton, F. F. Huerta, Fernando J.-E. Bäckvall, *Eur. J. Org. Chem.* **2003**, 2756-2763].

Compound (*R,S*)-**8c** is previously unreported: ^{1}H NMR (500.1 MHz, $CDCl_3$) δ_H 8.29 (br s, 1 H, Ar), 8.03 (d, *J* = 8.5 Hz, 1 H, PhMe), 7.95-7.86 (m, 3 H, Ar and PhMe), 7.79 (br s, 2 H, Ar), 7.54-7.52 (m, 2 H, Ar), 7.37 (br s, 2 H, Ar), 4.90 (d, *J* = 1.7 Hz, 1 H, C_5H_3), 4.54 (br s, 1 H, C_5H_5) 4.24 (m, 1 H, C_5H_3) overlapped by 4.24 (s, 5 H, C_5H_5), 2.47 (s, 3 H, Ph*Me*); Anal. calcd. for $C_{27}H_{22}FeOS$: C, 71.99%; H 4.93%; found: C, 71.96%; H, 4.92%. MS (ES) *m/z* 451 ($M+H^+$, 10%), 312 (M+H-S(O)tol$^+$, 20%); HRMS *m/z* (ES) found $[M+H]^+$ 451.0850; $C_{27}H_{23}FeOS$ requires 451.0819.

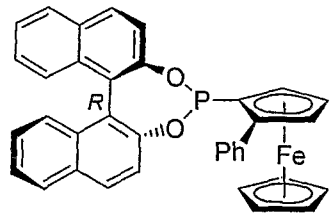
Compound (*R,S*)-**8d** is previously unreported: ^{1}H NMR (400.1 MHz, $CDCl_3$) δ_H 7.89 (d, *J* = 8.0 Hz, 2 H, C_6H_4), 7.61 (d, *J* = 8.0 Hz, 2 H, C_6H_4), 7.56 (d, *J* = 8.0 Hz, 2 H, C_6H_4), 7.27 (d, *J* = 8.0 Hz, 2 H, C_6H_4), 4.74 (app. dd, *J* = 2.6, 1.5 Hz, 1 H, C_5H_3), 4.49 (app. t, *J* = 2.6 Hz, 1 H, C_5H_3), 4.27 (app. dd, *J* = 2.6, 1.5 Hz, 1 H, C_5H_3), 4.22 (s, 5 H, C_5H_5), 2.42 (s, 3 H, Ph*Me*); ^{19}F NMR (282 MHz, $CDCl_3$) δ_F –63.0; MS (ES) *m/z* 469 ($M+H^+$, 10%), 330 (M+H-S(O)tol$^+$, 70%);HRMS (ES) *m/z* found $[M+H]^+$ 469.0516; $C_{24}H_{20}FeF_3OS$ requires 469.0536.

Representative preparation of phosphites - compound ***3c***



Under an atmosphere of argon a mixture of (*S*)-BINOL (2.00 g, 6.98 mmol) and THF (40 ml) was cooled to –40 °C. To this solution was added a solution of phosphorus trichloride (0.98 ml, 11.2 mmol) in THF (10 ml). After 10 mins triethylamine (1.95 ml, 14.0 mmol) was added and the reaction mixture allowed to warm to room temperature. After a further 4 hours the mixture was filtered through a frit and concentrated under reduced pressure. The mixture was then diluted with THF (50 ml) followed by addition of triethylamine (1 ml, 7.16 mmol) and phenol (470 mg, 5.00 mmol). After 1 hour the mixture was evaporated to dryness. The product was purified by column chromatography on silica gel (9:1 petrol:ether, dry loaded) to give (*S*)-**3c** (1.44 g, 50% based on BINOL) as a white solid. Compound **3b** was similarly prepared (1.20 g, 56% based on 1,1'-biphenol). ^{31}P NMR (162 MHz, $CDCl_3$) δ_P +146.1. For **3b**: ^{31}P NMR (162 MHz, $CDCl_3$) δ_P +144.9.

Representative preparation of the novel ligands ***1*** *– (S,R)- 1-(phenyl)-2-(3,5-Dioxa-4-phospha-cyclohepta[2,1-a;3,4-a']dinaphthalen-4-yl)ferrocene [CpFe(η^5-1,2-C_5H_3(Ph)(P($O_2C_{20}H_{12}$)))]****1ac***

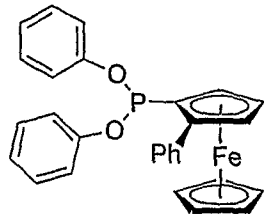


Under at atmosphere of argon a solution of sulfoxide **8a** (280 mg, 0.70 mmol) in THF (20 ml) was cooled to –78 °C. To the solution was added ^{t}BuLi (1.7 M, 0.5 ml, 0.85 mmol). After 5 minutes a solution of phosphite **3c** (300 mg, 0.74 mmol) in THF (3.5 ml) was added. The solution turned from dark orange in colour to yellow over 2 minutes and the reaction was stirred for 5 minutes before the addition of water (1 ml) The mixture was stirred for a further 45 minutes before the phases were separated. The aqueous layer was extracted with Et_2O (5 ml) then the combined organic phases were washed with water (10 ml), dried ($MgSO_4$) and evaporated to dryness. The crude reaction mixture was purified by column chromatography on silica gel (9:1 petrol:ether dry loaded) to give the product as an orange crystalline solid.

Yield 285 mg, 71%. ^{1}H NMR (500.1 MHz, [D_6]benzene): δ_H 8.03 (d, *J* = 8.0 Hz, 2 H, Ar), 7.82 (t, *J* = 8.7 Hz, 2 H, Ar), 7.75 (t, *J* = 8.7 Hz, 2 H, Ar), 7.65 (t, *J* = 7.5 Hz, 2 H, Ar), 7.62 (d, *J* = 8.7 Hz, 1 H, Ar), 7.34 (t, *J* = 5.8 Hz, 2 H, Ar), 7.31-7.22 (m, 3 H, Ar), 7.20 (d, *J* = 8.7 Hz, 1 H, Ar), 7.13-7.07 (m, 2 H, Ar), 4.60 (dd, *J* = 3.9, 2.0 Hz, 1 H, C_5H_3), 4.18 (s, 5 H, C_5H_5), 4.00-3.98 (m, 2 H, C_5H_3); ^{31}P NMR (162 MHz, $CDCl_3$) δ_P +189.3; HRMS (EI) *m/z* found $[M+H]^+$ 577.0975; $C_{36}H_{26}FeO_2P$ requires 577.1020. Anal. calcd. for $C_{36}H_{25}FeO_2P$: C, 75.01%; H 4.37%; found: C, 75.19%; H, 4.32%. $[\alpha]_D$ –386.0 (c = 1.00, chloroform). X-ray crystal structure obtained (**see Figure 1**).

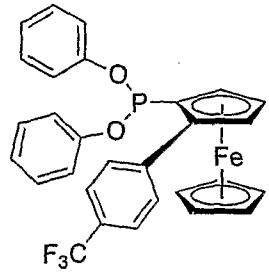
Additional representative examples:

Ligand (S)-1-(phenyl)-2-(diphenylphosphonityl)ferrocene [CpFe(η^5-1,2-C_5H_3(Ph)(P(OPh)$_2$)] ***1aa***



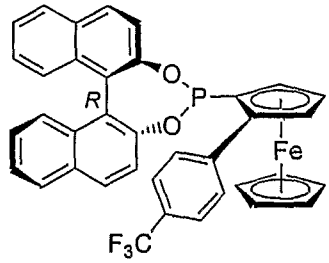
Yield 66 g, 69%. ^{1}H NMR (400.1 MHz, $CDCl_3$) δ_H 7.96 (dd, *J* = 7.2, 1.2 Hz, 2 H, Ph-*o*), 7.45 (dd, *J* = 7.6, 1.2 Hz, Ph-*o*), 7.32-6.85 (m, 11 H, Ph-*m*+*p*), 4.88 (m, 1 H, C_5H_3), 4.60 (m, 1 H, C_5H_3), (app. t, *J* = 2.4 Hz), 4.12 (s, 5 H, C_5H_5); ^{31}P NMR (162 MHz, $CDCl_3$) δ_P +174.3; MS (EI) *m/z* 479 ($M+H^+$, 70%), 385 (*M* -OPh^+, 30%), 262 ($M+H-P(OPh)_2^+$, 100%); HRMS (EI) *m/z* found $[M+H]^+$ 479.0872; $C_{28}H_{24}FeO_2P$ requires 479.0863.

Ligand (S)-1-(4-trifluoromethylphenyl)-2-(diphenylphosphonityl)ferrocene [CpFe(η^5-1,2-C_5H_3(4-CF_3Ph)(P(OPh)$_2$)] ***1da***



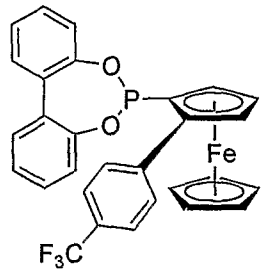
Yield 71 g, 56%. ^{1}H NMR (400.1 MHz, [D_6]benzene) δ_H 7.67 (d, *J* = 8.0 Hz, 2 H, Ph-*o*), 7.35-7.29 (m, 4 H, Ar), 7.12-7.08 (m, 2 H, Ar), 6.98-6.91 (m, 4 H, Ar), 6.90-6.86 (m, 1 H, Ph-*p*), 6.80-6.77 (m, 1 H, Ph-*p*), 4.75 (m, 1 H, C_5H_3), 4.38 (m, 1 H, C_5H_3), 4.15 (app. t, *J* = 2.5 Hz, 1 H, C_5H_3), 3.95 (s, 5 H, C_5H_5); ^{31}P NMR (162 MHz, [D_6]benzene) δ_P +173.4; ^{19}F NMR (282 MHz, $CDCl_3$) δ_F –62.3; MS (ES) *m/z* 547 ($M+H^+$, 35%), 453 (M -OPh^+, 50%), 330 ($M+H-P(OPh)_2^+$, 10%); HRMS (ES) *m/z* found $[M+H]^+$ 547.0716; $C_{29}H_{23}FeF_3O_2P$ requires 547.0737.

Ligand (S,R)-1-(4-trifluoromethylphenyl)-2-(3,5-Dioxa-4-phospha-cyclohepta[2,1-a;3,4-a']dinaphthalen-4-yl)ferrocene [CpFe(η^5-1,2-C_5H_3(4-CF_3Ph)(P($O_2C_{20}H_{12}$))] ***1dc***



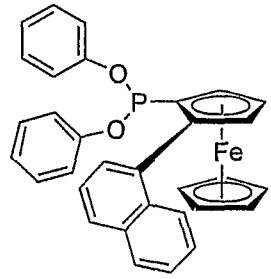
Yield 285 mg, 44%. ^{1}H NMR (500.1 MHz, [D$_6$]benzene): δ_H 7.86-7.83 (m, 3 H, Ar), 7.80 (d, J = 8.2 Hz, 1 H, Ar), 7.77-7.75 (m, 2 H, Ar), 7.66-7.62 (m, 3 H, Ar), 7.47 (d, J = 8.2 Hz, 2 H, Ar), 7.31-7.27 (m, 2 H, Ar), 7.16 (d, J = 8.7 Hz, 1 H, Ar), 7.07-7.11 (m, 2 H, Ar), 4.74 (dd, J = 3.7, 2.0 Hz, 1 H, C_5H_3), 4.13 (s, 5 H, C_5H_5), 4.00-3.98 (m, 2 H, C_5H_3); ^{31}P NMR (162 MHz, $CDCl_3$) δ_P +187.6; ^{19}F NMR (282 MHz, $CDCl_3$); $[\alpha]_D$ –285.8 (c = 1.00, chloroform). X-ray crystal structure obtained (**see Figure 2**).

Ligand (S,R)-1-(4-trifluoromethylphenyl)-2-(3,5-Dioxa-4-phospha-cyclohepta[2,1-a;3,4-a']biphenalen-4-yl)ferrocene [CpFe(η^5-1,2-C_5H_3(4-CF_3Ph)(P($O_2C_{12}H_8$))] ***1db***



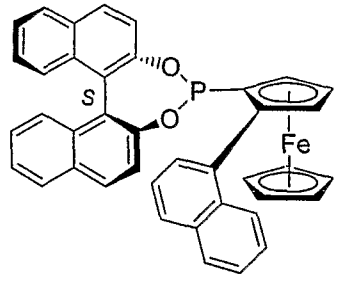
Yield 73 mg, 14%. ^{1}H NMR (400.1 MHz, [D$_6$]benzene) δ_H 7.69 (d, J = 8.0 Hz, 2 H, $C_6H_4CF_3$), 7.32 (d, J = 8.0 Hz, 2 H, $C_6H_4CF_3$), 7.27 (dd, J = 7.4, 1.9 Hz, 1 H, biphenyl-H3 or 3'), 7.26 (dd, J = 7.5, 1.7 Hz, 1 H, biphenyl-H3 or 3'), 7.19 (dt, J = 8.0, ~0.8 Hz, 1 H, biphenyl-H6 or 6'), 7.11 (td, J = 7.5, 1.6 Hz, 1 H, biphenyl-H4,4' or 5,5'), 7.01 (tdd, J = 7.5, 1.6, ~0.8 Hz, 1 H, biphenyl-H4,4' or 5,5'), 6.95 (td, J = 7.5, ~0.8 Hz, 1 H, biphenyl-H4,4' or 5,5'), 6.92 (td, J = 7.5, 1.6 Hz, 1 H, biphenyl-H4,4' or 5,5'), 6.77 (dd, J = 7.5, ~0.8 Hz, 1 H, biphenyl-H6 or 6'), 4.39 (m, 1 H, C_5H_3), 4.23 (m, 1 H, C_5H_3), 4.03 (app. t J = 2.4 Hz, 1 H, C_5H_3) overlapped by 4.02 (s, 5 H, C_5H_5); ^{31}P NMR (162 MHz, [D$_6$]benzene) δ_P +203.7; ^{19}F NMR (282 MHz, $CDCl_3$) δ_F –62.3; MS (ES) m/z 545 ($M+H^+$, 100%), 330 (M+H-P(Obiphen)$^+$, 90%); HRMS (ES) m/z found $[M+H]^+$ 545.0557; $C_{29}H_{21}FeF_3O_2P$ requires 545.0581. $[\alpha]_D$ –85.4 (c = 1.08, chloroform).

Ligand (S)-1-(1-naphthyl)-2-(diphenylphosphinityl)ferrocene [CpFe(η^5-1,2-C_5H_3(1-$C_{10}H_8$)(P(OPh)$_2$)] ***1ba***



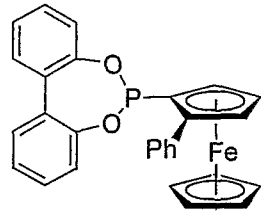
Yield 40 mg, 33%. ^{1}H NMR (500.1 MHz, [D_6]benzene) δ_H 8.46 (dt, *J* = 7.0, 1.0 Hz, 1 H, $C_{10}H_7$), 8.20 (d, *J* = 8.0 Hz, 1 H, $C_{10}H_7$), 7.77-7.73 (m 2 H, Ar), 7.47 (dd, *J* = 8.5, 7.5 Hz, 1 H, $C_{10}H_7$), 7.35-7.24 (m, 4 H, Ar), 7.17-7.11 (m, 2 H, Ph-*m*), 6.94 (t, *J* = 7.5 Hz + unresolved long range couplings, 1 H, Ph-*p*), 6.90-6.84 (m, 2 H, Ph-*m*), 6.75 (t, *J* = 7.5 Hz + unresolved long range couplings, 1 H, Ph-*p*), 6.66 (d, *J* = 8.5 Hz, 2 H, Ar), 4.96 (app dd, *J* = 1.0, ~0.6 Hz, 1 H, C_5H_3), 4.52 (app q, *J* = 2.06 Hz, 1 H, C_5H_3), 4.35 (app. t, *J* = 2.5 Hz, 1 H C_5H_3), 4.29 (s, 5 H, C_5H_5); ^{31}P NMR (162 MHz, $CDCl_3$) δ_P 177.9; MS (ES) *m/z* 529 ($M+H^+$, 35%), 435 ($M-OPh^+$, 50%), 312 ($M+H-P(OPh)_2^+$, 10%); HRMS (ES) *m/z* found $[M+H]^+$ 529.1023; $C_{32}H_{26}FeO_2P$ requires 529.1020.

Ligand (S,S)-1-(1-naphthyl)-2-(3,5-Dioxa-4-phospha-cyclohepta[2,1-a;3,4-a']dinaphthalen-4-yl)ferrocene [CpFe(η^5-1,2-C_5H_3(4-CF_3Ph)(P($O_2C_{20}H_{12}$))] ***1bc***



Yield 40 mg, 8%. ^{1}H NMR (500.1 MHz, [D_6]benzene) δ_H 8.26 (dd, *J* = 7.1, 1.1 Hz, 1 H, Ar), 7.66 (br d, *J* = 7.0 Hz, 1 H, Ar), 7.69-7.63 (m, 3 H, Ar), 7.54 (d, *J* = 7.8 Hz, 1 H, Ar), 7.46 (dd, *J* = 8.6, 2.8 Hz, 1 H, Ar), 7.44-7.34 (m, 5H, Ar), 7.32-7.22 (m, 3H, Ar), 7.21-7.17 (m, 1 H, Ar), 7.14-7.10 (m, 1 H, Ar), 7.04-7.01 (m, 1 H, Ar), 6.99-6.95 (m, 1 H, Ar), 4.67-4.65 (m, 1 H, C_5H_3) 4.46 (s, 5 H, C_5H_5), overlapped by 4.48-4.45 (m, 1 H, C_5H_3), 4.28 (app. t *J* = 2.5 Hz, 1 H, C_5H_3); ^{31}P NMR (162 MHz, $CDCl_3$) δ_P +196.8; X-ray crystal structure obtained (**see Figure 3**).

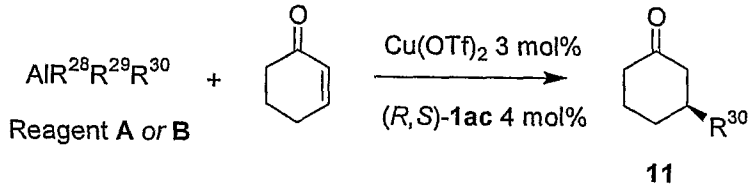
Ligand (S,R)-1-(phenyl)-2-(3,5-Dioxa-4-phospha-cyclohepta[2,1-a;3,4-a']biphenalen-4-yl)ferrocene [CpFe(η^5-1,2-C_5H_3(Ph)(P($O_2C_{12}H_8$))] ***1ab***



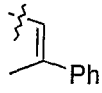
Yield 48 mg, 43%. ^{1}H NMR (400.1 MHz, [D$_6$]benzene) δ_H 7.87 (d, J = 8.0 Hz, 2 H, $C_6H_4CF_3$), 7.27 (dt, J = 7.6, 2.0 Hz, 2 H, Ar), 7.21-7.16 (m, 3 H, Ar), 7.12-7.06 (m, 2 H, Ar), 7.00 (tdd, J = 7.5, 1.6, ~0.8 Hz, 1 H, biphenyl-H4,4' or 5,5'), 6.95 (td, J = 7.5, 1.1 Hz, 1 H, biphenyl-H4,4' or 5,5'), 6.89 (td, J = 7.4, 1.8 Hz, 1 H, biphenyl-H4,4' or 5,5'), 6.77 (dd, J = 7.6, ~0.8 Hz, 1 H, biphenyl-H6 or 6'), 4.50 (m, 1 H, C_5H_3), 4.22 (m, 1 H, C_5H_3), 4.08 (s, 5 H, C_5H_5) 4.03 (app. T J = 2.4 Hz, 1 H, C_5H_3); ^{31}P NMR (121.5 MHz, [D$_6$]benzene) δ_P 206.25 (s); *m/z* (ES) 527 (M+H$^+$, 100%), 312 (M+H-P(Obiphen)$_2^+$, 100%); *m/z* (ES) found [M+H]$^+$ 527.0863; $C_{32}H_{24}FeO_2P$ requires 527.0863. $[\alpha]_D$ –386.0 (c = 1.00, chloroform).

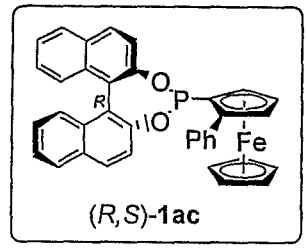
*Representative use of **1** in a catalytic asymmetric process*

A representative use of the ligands described herein is in asymmetric conjugate addition reactions two examples of which are described with reference to Figure **5** below.



11

Reagent	R^{28}	R^{29}	R^{30}	ee of product **11**
A	Et	Et	Et	92%
B	Me	Me		85%



(*R,S*)-**1ac**

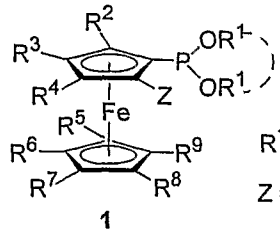
Ligand (*R,S*)-**1ac** (11.5 mg, 4 mol%) was added to a suspension of Cu(OTf)$_2$ (3.6 mg, 2 mol%) in diethyl ether (1 ml) at -30 °C. Subsequently either organoaluminium reagent **A** or **B** (0.70 mmol) was added together with cyclohex-2-en-1-one (0.50 mmol). The reactions were carried out using appropriate procedures from the literature [A. Alexakis, V. Albrow, K. Biswas, M. d'Augustin, O. Prieto, S. Woodward, *Chem. Commun.* **2005**, 2843-2845]. After an appropriate time the reaction mixtures were analysed and the products **11** found to be attained in improved stereoselectivities compared to previous optimal ligands for this process. Chemical yields were comparable to the literature procedures using phosphoramidites.

SUMMARY

This invention relates to the following technical areas:

1. The preparation of new states of matter of composition 1 where R^1 is derived from two suitable monoalcohols or one diol; R^2-R^9 are H, C_1-C_{20} alkyl, alkenyl, or aryl substituents or heteroatom substituents thereof; Z is a C_2-C_{20} unit or heteroatom substituted derivative thereof such that the

initially attached carbon is sp^2 hybridised (representative examples of Z include vinyl or aryl groups or heteroatom substituted variants thereof);



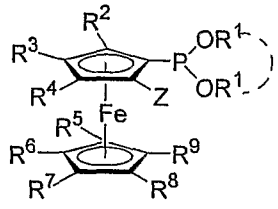
Both cyclic or acyclic R^1 structures can be used.

R^1-R^9 = H, alkyl, aryl or substituted versions thereof

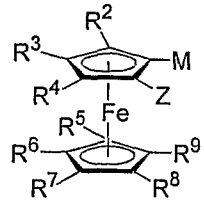
Z = Aryl or alkenyl or substituted versions thereof

1

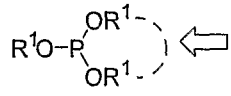
2. A novel route for the preparation of **1** through the reaction of organometallic anion sources **2** and phosphite structures (**3**) where: R^1 is derived from two suitable monoalcohols or one diol; R^2-R^9 are H, C_1-C_{20} alkyl, alkenyl, or aryl substituents or heteroatom substituents thereof; Z is a C_2-C_{20} unit or heteroatom substituted derivative thereof such that the initially attached carbon is sp^2 hybridised (representative examples of X include vinyl or aryl groups or heteroatom substituted variants thereof); M is a Group 1-2 or 12-13 metal; R^{10}-R^{11} is a C_1-C_{20} alkyl, alkenyl, or aryl substituent or heteroatom substituted version thereof.



1



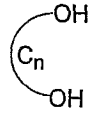
2



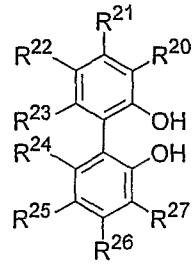
Both cyclic or acyclic R^1 structures can be used.

3

3. A preparative route to phosphites **3** attained by successive reaction of PCl_3 with diols of type **9a** (general) or **9b** (specific), where: R^{20}-R^{27} = H, halogen, C_1-C_{20} alkyl, alkenyl, halogen, OR, NR_2, CO_2R, COR, $CONR_2$, SO_3R or aryl substituent or heteroatom substituented version thereof, where each R is independently selected from the group comprising: $C_{1\text{-}20}$ alkyl, $C_{1\text{-}20}$ haloalkyl, $C_{2\text{-}20}$ alkenyl, and $C_{2\text{-}20}$ alkynyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: $C_{1\text{-}7}$alkyl, $C_{1\text{-}7}$haloalkyl, $C_{1\text{-}7}$alkoxy, halogen, -CN, and $-CF_3$. Preferably R^{20}-R^{27} are independently selected from: H, halogen, C_1-C_{10} alkyl, C_1-C_{10} alkenyl, and aryl.



9a

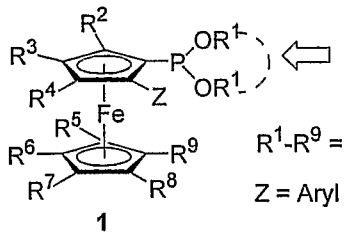


9b

4. Application of ligands **1** in fields of use encompassing the preparation of fine chemicals and pharmaceutical intermediates via the medium of asymmetric catalysis.

CLAIMS

1. A compound of Formula 1



Both cyclic or acyclic R^1 structures can be used.

R^1-R^9 = H, alkyl, aryl or substituted versions thereof

Z = Aryl or alkenyl or substituted versions thereof

1

wherein

each R^1 is independently selected from the group comprising: C_{1-20} alkyl, C_{1-20} haloalkyl, C_{2-20} alkenyl, and C_{2-20} alkynyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and -CF_3;

or the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a monocyclic ring of up to 9 members, or a fused or conjugated polycyclic ring system containing up to to 24 atoms in the ring system, the or each ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and -CF_3;

each of R^2 to R^9 is independently selected from the group comprising: H, C_{1-20} alkyl, C_{1-20} haloalkyl, C_{2-20} alkenyl, C_{2-20} alkynyl, CH_2OC_{1-20} alkyl, CH_2SC_{1-20} alkyl, aryl and het, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and -CF_3;

and / or independently any adjacent two of the R^2 to R^9 groups joined to the same carbon, may together with the carbons to which they are attached form a ring of up to 6 members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and -CF_3;

het is an aromatic or aliphatic heterocyclic group containing from 5 to 10 ring members and containing 1, 2 or 3 independently chosen N, O or S atoms; and

Z is a group including an sp2 hybridised atom through which Z is bound to the ferrocene ring.

2. A compound according to claim 1, wherein each R^1 is independently selected from the group comprising: C_{1-10} alkyl, C_{1-10} haloalkyl, C_{2-10} alkenyl, and C_{2-10} alkynyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$;

or the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a ring of up to 9 members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

3. A compound according to claim 2, wherein each R^1 is independently selected from the group comprising: C_{1-6} alkyl, C_{1-60} haloalkyl, and C_{2-6} alkenyl, wherein each of these groups may be optionally substituted by 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

4. A compound according to claim 1, wherein the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a ring of up to 9 members, or a fused or conjugated polycyclic ring system containing up to 24 atoms in the ring system, the or each ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

5. A compound according to claim 4, wherein the fused or polycyclic ring may contain 1 to 4 atoms independently selected from N, O, or S.

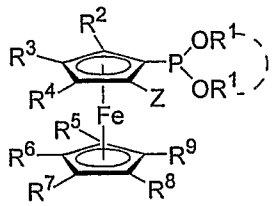
6. A compound according to claim 5 wherein the fused or polycyclic ring has up to 20 members.

7. A compound according to claims 1, 2 or 4, wherein the two R^1 groups may together with the oxygen atoms to which they are attached and the phosphorus atom form a ring of 5, 6 or 7members, the ring being optionally substituted with from 1 to 3 substituents independently selected from the group comprising: C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}alkoxy, halogen, -CN, and $-CF_3$.

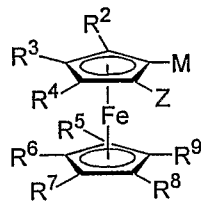
8. A compound according to any of claims 1 to 7, wherein het is selected from the group comprising: C-linked pyrrolyl, imidazolyl, triazolyl, thienyl, furyl, thiazolyl, oxazolyl, thiadiazolyl, oxadiazolyl,

pyridinyl, pyrimidinyl, pyridazinyl, pyrazinyl, quinolinyl, isoquinolinyl, benzimidazolyl, quinazolinyl, phthalazinyl, benzoxazolyl and quinoxalinyl.

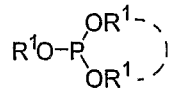
9. A process for the preparation of a compound of formula **1** through the reaction of organometallic anion sources **2** and phosphite structures (**3**)



1



2

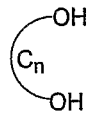


Both cyclic or acyclic R^1 structures can be used.

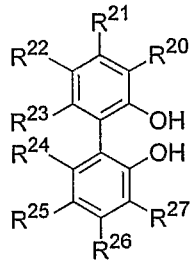
3

where: R^1 to R^9 are as defined in any of claims 1 to 8, Z is a C_2-C_{20} unit or heteroatom substituted derivative thereof such that the initially attached carbon is sp^2 hybridised ; M is a Group 1-2 or 12-13 metal; R^{10}-R^{11} is a C_1-C_{20} alkyl, alkenyl, or aryl substituent or heteroatom substituted version thereof.

10. A process for the preparation of a phosphate compound of formula **3** attained by successive reaction of PCl_3 with diols of type **9a** (general) or **9b** (specific),



9a



9b

where: R^{20}-R^{27} are independently slected from: H, halogen, C_1-C_{20} alkyl, alkenyl, halogen, OR, NR_2, CO_2R, COR, $CONR_2$, SO_3R or aryl or het, wherein aryl and het are as defined in claims 1 to 8.

11. Use of a compound as claimed in any of claims 1 to 8, as a catalyst.

Figures

Figure 1. X-ray crystal structure of a representative stereoisomer of ligand **1ac** (and structural line formula for clarity).

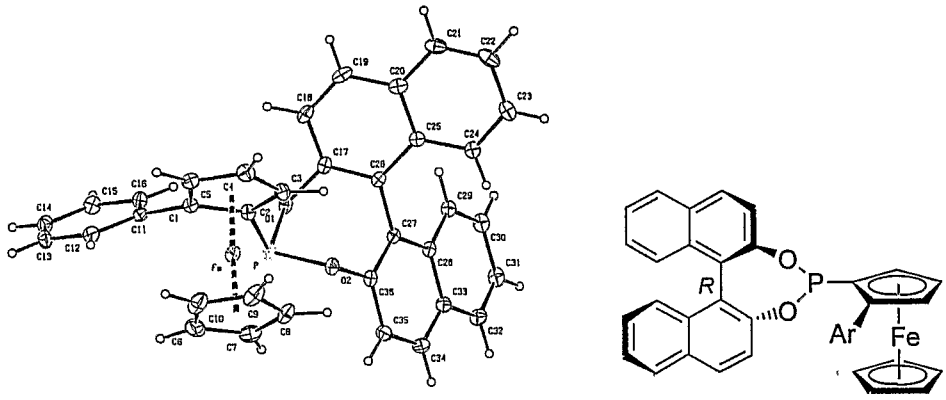


Figure 2. X-ray crystal structure of a representative stereoisomer of ligand **1dc** (and structural line formula for clarity).

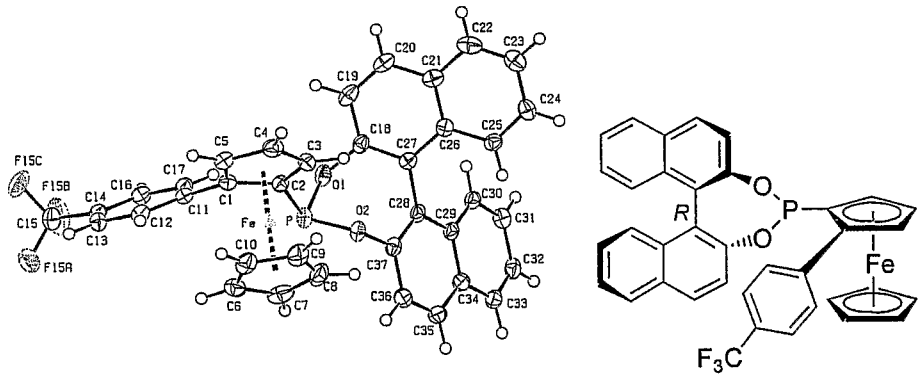


Figure 3. X-ray crystal structure of a representative stereoisomer of ligand **1dc** (and structural line formula for clarity).

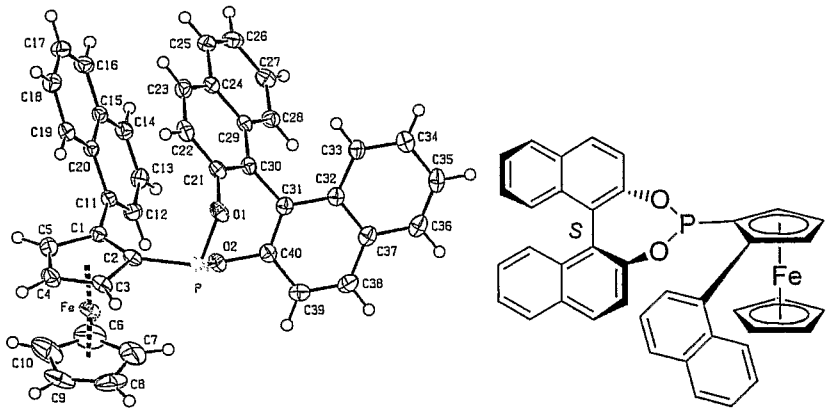


Figure 4. X-ray crystal structure of a representative stereoisomer of ligand **1dc** (and structural line formula for clarity).

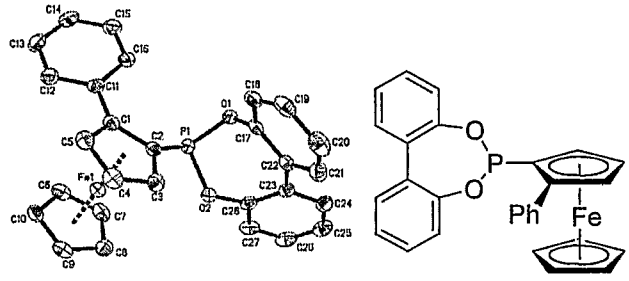
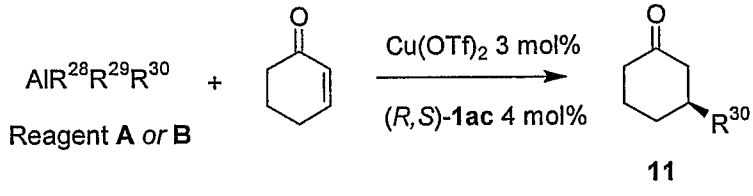
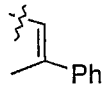
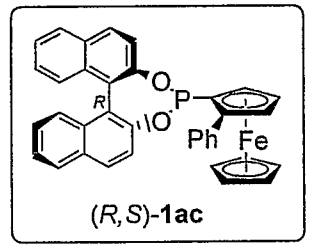


Figure 5.



Reagent	R^{28}	R^{29}	R^{30}	ee of product **11**
A	Et	Et	Et	92%
B	Me	Me		85%



(*R,S*)-**1ac**

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2006/003550

A. CLASSIFICATION OF SUBJECT MATTER
INV. C07F17/02

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C07F

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 198 40 279 A1 (STUDIENGESELLSCHAFT KOHLE MBH [DE]) 9 March 2000 (2000-03-09) page 2, lines 42,43 page 15, lines 1-15	1-11
A	EP 0 965 574 A2 (DEGUSSA [DE]) 22 December 1999 (1999-12-22) page 8, lines 32-45; claim 1	1-11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 February 2007	15/02/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Jeanjean, Fabien

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2006/003550

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 19840279 A1	09-03-2000	AT 237624 T	15-05-2003
		CA 2342238 A1	16-03-2000
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		JP 2002524464 T	06-08-2002
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		US 6348620 B1	19-02-2002