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# Catalytic Asymmetric Synthesis of Chiral Phosphanes

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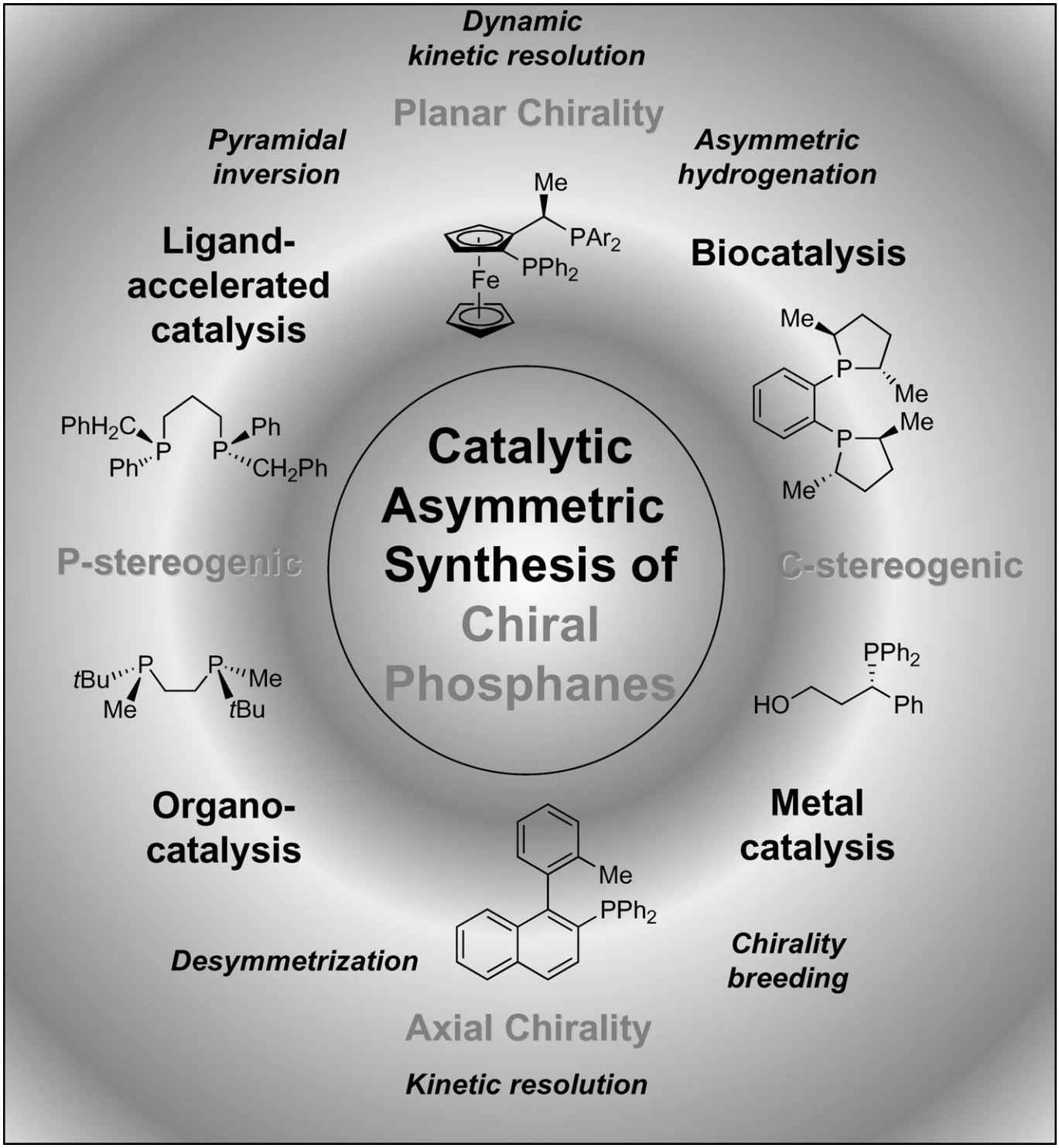


**Abstract:** Chiral phosphanes, important ligands for metal-catalyzed asymmetric syntheses, are often prepared with compounds from the chiral pool, by using stoichiometric chiral auxiliaries, or by resolution. In some cases, this class of valuable compounds can be prepared more efficiently by catalytic asymmetric synthesis. This Concepts article presents an overview of these synthetic methods, including recent advances in catalysis by metal complexes, biocatalysis, organocatalysis, and ligand-accelerated catalysis.

**Keywords:** asymmetric catalysis · biocatalysis · ligand-accelerated catalysis · metal complexes · organocatalysis · phosphanes

## Introduction

Chiral phosphanes are valuable ligands in asymmetric catalysis. Like other chiral compounds, they may be prepared from naturally occurring chiral starting materials, synthesized by using a stoichiometric amount of chiral auxiliary, or separated by resolution. These approaches are exemplified by the syntheses of some historically important $C_2$-symmetric diphosphanes (Figure 1). Kagan's DIOP was prepared from naturally occurring tartaric acid.[1] Another natural product, menthol, was used as a chiral auxiliary in Knowles' synthesis of DiPAMP; separation of diastereomers **1a** and **1b** controlled the phosphorus stereochemistry.[2] Finally, enantiomers of Noyori's BINAP were originally separated by resolution with chiral Pd complex **2**; more efficient syntheses started from resolved BINOL.[3]

Use of these ligands in asymmetric hydrogenation showed that valuable chiral compounds could be prepared efficiently through asymmetric catalysis.[4] The same is true for chiral phosphanes, for which this Concepts article presents an overview of catalytic asymmetric synthetic methods, including catalysis by metal complexes, biocatalysis, organocatalysis, and ligand-accelerated catalysis. Three general approaches have been reported: 1) chiral building blocks prepared through asymmetric catalysis are converted into chiral phosphanes, 2) catalytic modification of an organophosphorus substrate introduces asymmetry, and 3) the stereochemistry of P–C bond formation is controlled in a catalytic asymmetric process. After an introduction to the first two, well-established processes, this article describes the ideas behind the more recently developed third approach in more detail. In particular, new reactions which exploit the rapid pyramidal inversion in diastereomeric metal–phosphido complexes $[M(*L_n)(PR_2)]$ are highlighted.

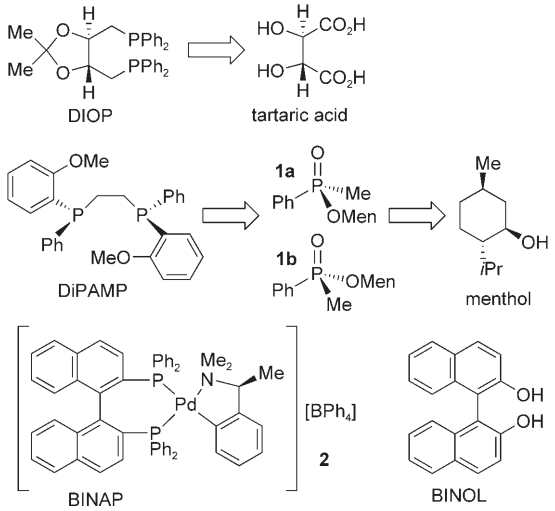
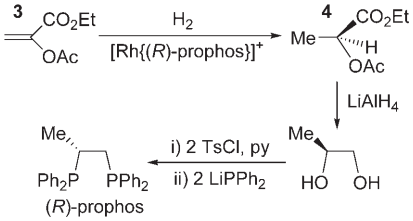



Figure 1. Sources of chirality in some famous $C_2$-symmetric diphosphanes.

## Chiral Building Blocks through Asymmetric Catalysis

**Chiral diols and alcohols through asymmetric hydrogenation or biocatalysis**: The most successful reaction in asymmetric catalysis, hydrogenation, was used as early as 1978 by Fryzuk and Bosnich to prepare the chiral diphosphane prophos via a chiral diol.[5] The [Rh{(*R*)-prophos}]-catalyzed asymmetric hydrogenation of **3** gave **4**, which was converted into more (*R*)-prophos (Scheme 1). As noted by Fryzuk and Bosnich, this "chirality breeding" means that "in principle, infinite amounts of chiral prophos can be produced by using very small amounts of …(*R*)-prophos."[5] This theme has been explored in detail since.[6]




Scheme 1. Chirality breeding in Rh-catalyzed synthesis of prophos.

Related chiral diols have been employed to prepare chiral phospholanes, as in the successful 1,2-bis(phospholanyl)-ethane (BPE) and 1,2-bis(phospholanyl)benzene (DuPhos) ligand families.[7] In the original DuPhos synthesis, [Ru-

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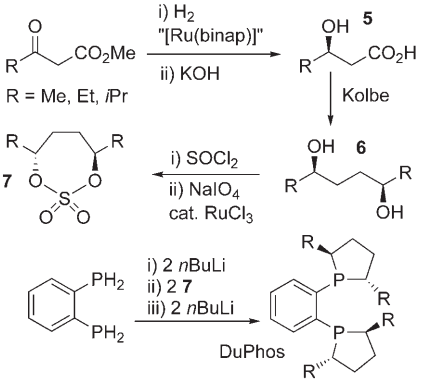
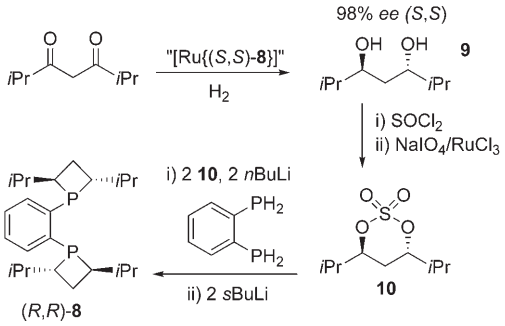
(binap)]-catalyzed hydrogenation of β-keto esters, followed by hydrolysis, gave acid **5**, which was converted into chiral diol **6** by electrochemical Kolbe coupling.[8] Ru-catalyzed formation of cyclic sulfate **7**, followed by nucleophilic P–C bond formation, gave the target heterocycles (Scheme 2).




Scheme 2. Asymmetric hydrogenation in synthesis of phospholanes.

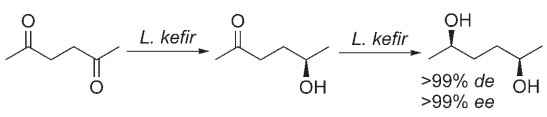
Ru-catalyzed asymmetric hydrogenation of diketones provides a more direct route to chiral diols. In an example of crossed self-breeding of chirality, a Ru complex of bis(phosphetane) (S,S)-**8** catalyzed the formation of diol **9**, which was then converted via cyclic sulfate **10** into the other enantiomer of **8** (Scheme 3).[9]



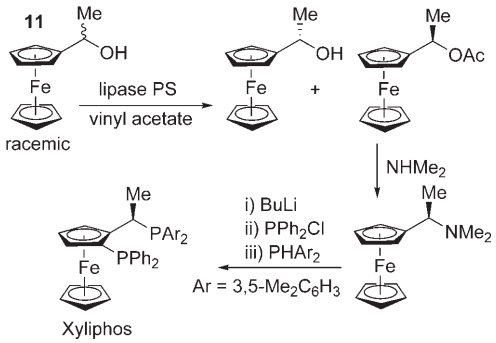

Scheme 3. Asymmetric hydrogenation of a diketone in synthesis of bis(phosphetane) **8**.

An alternative route to chiral diols, now preferred for synthesis of bis(phospholanes), uses enzymatic catalysis, as in the synthesis of a hexanediol precursor to Me-DuPhos (Scheme 4).[10] A catalytic reduction with baker's yeast yields the other enantiomer.[11]

Similarly, a chiral alcohol building block for the Josiphos derivative Xyliphos, which is used in the current largest scale application of asymmetric catalysis, was prepared by lipase-catalyzed kinetic resolution of racemic ferrocenylethanol **11** (Scheme 5).[12]

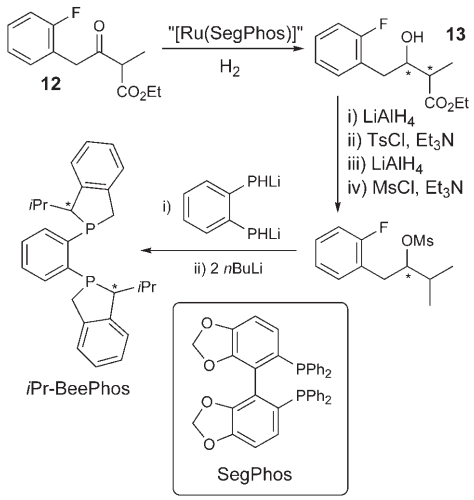



Scheme 4. Biocatalytic route to chiral diols.




Scheme 5. Xyliphos synthesis through kinetic resolution of alcohol **11**.

Here, the catalytically-derived stereocenter was used to control planar chirality in the ligand. Scheme 6 shows another relay approach, in which a carbon stereocenter controls stereochemistry at phosphorus. Asymmetric hydrogenation of **12** gave chiral alcohol **13**. Subsequent intramolecular nucleophilic formation of a bis(phospholane) gave *i*Pr-BeePhos.[13]

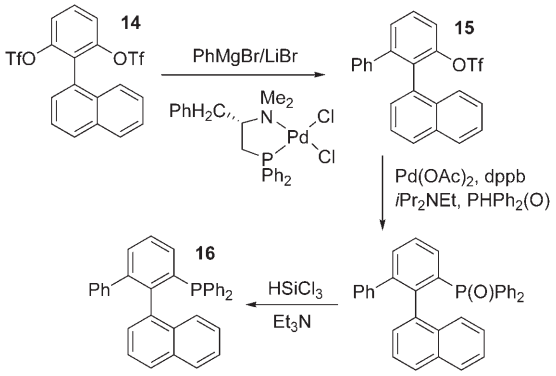



Scheme 6. Control of phosphorus stereochemistry by relay from a C stereocenter prepared by asymmetric hydrogenation of **12**.

**Axial or planar chirality from asymmetric catalysis**: In a related approach, building blocks with axial chirality can be prepared through asymmetric catalysis; P–C bond formation then yields a chiral phosphane. For example, enantioselective cross-coupling of bis(triflate) **14** with PhMgBr catalyzed by a Pd–Phephos complex gave **15**. Another Pd-catalyzed coupling, followed by reduction, gave phosphane **16** (Scheme 7).[14]

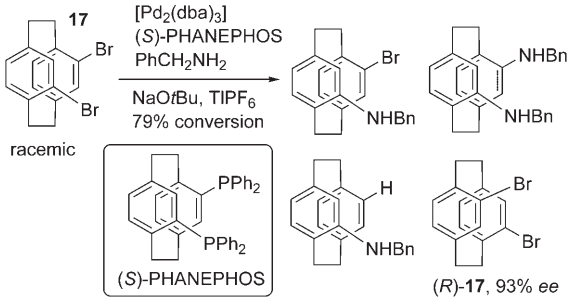
Planar-chiral building blocks have also been prepared by asymmetric catalysis. Pd–(*S*)-PHANEPHOS-catalyzed




Scheme 7. Synthesis of an axial-chiral phosphane by means of Pd-catalyzed coupling.

amination of racemic dibromocyclophane **17** gave a mixture of amines; kinetic resolution yielded unreacted (*R*)-**17** in high enantiomeric excess (*ee*; Scheme 8). Since **17** is a precursor to PHANEPHOS, which was originally obtained as a single enantiomer after resolution, this is another example of chirality breeding.[15]



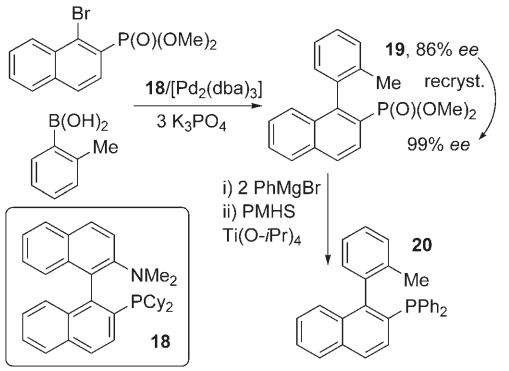

Scheme 8. Kinetic resolution of dibromocyclophane **17** by [Pd{(S)-PHANEPHOS)}-catalyzed amination.

## Modification of Organophosphorus Substrates by Asymmetric Catalysis

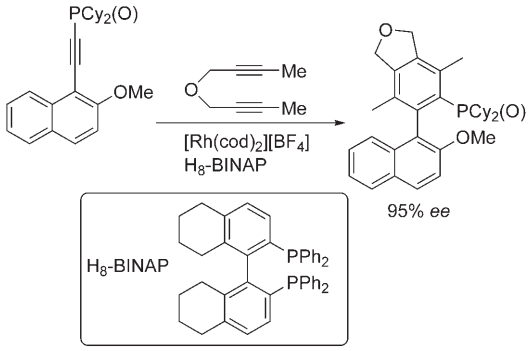
Chiral phosphanes have also been prepared by enantioselective reactions of substrates which already contain an organophosphorus group. Kinetic resolution and desymmetrization reactions have been the most popular, and asymmetric C–C bond formation to introduce axial chirality has also been reported.

**Axial chirality by asymmetric catalysis**: The axial chirality of ligand **18** led to axial-chiral biaryl **19**[16] through Pd-catalyzed asymmetric Suzuki coupling.[17] After the *ee* of **19** was increased by recrystallization, two more steps gave phosphane **20** in high *ee* (Scheme 9).[16]

In a more spectacular approach to axial chirality, two groups recently reported synthesis of biarylphosphanes by means of enantioselective [2+2+2] cycloadditions by using chiral Rh or Co catalysts (Scheme 10).[18,19] In some cases,



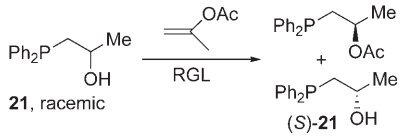

Scheme 9. Synthesis of a precursor to axial-chiral phosphane **20** by Pd-catalyzed asymmetric Suzuki coupling.




Scheme 10. Rh-catalyzed asymmetric synthesis of a biarylphosphane oxide by [2+2+2] alkyne cycloaddition.

$AlH_3$-mediated reduction of the resulting phosphane oxides (not shown) gave the desired chiral phosphanes.[19]

**Kinetic resolution—synthesis of C- or P-stereogenic phosphanes**: Rabbit gastric lipase (RGL) was used for kinetic resolution of β-hydroxyphosphane **21** by selective acylation of one enantiomer. At 56% conversion, 43% yield of (*S*)-**21** (98% *ee*) was recovered (Scheme 11).[20]

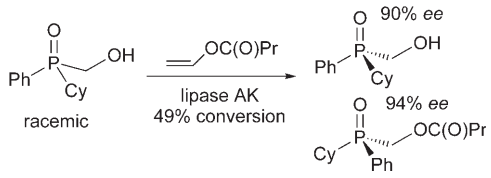



Scheme 11. Lipase-catalyzed kinetic resolution of a C-stereogenic β-hydroxyphosphane.

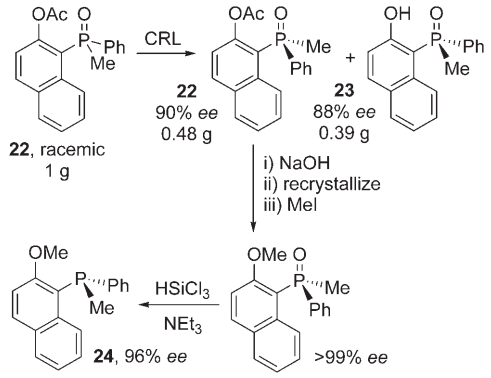
A similar kinetic resolution gave P-stereogenic phosphane oxides (Scheme 12).[21]

Hydrolysis of pendant acetate groups in chiral phosphanes and phosphane oxides was catalyzed by the lipase from *Candida rugosa* (CRL). Efficient kinetic resolution gave both unreacted **22** and alcohol **23** in high *ee*. These compounds could then be converted separately into the enantiomers of PAMP analogue **24** as shown for **22** (Scheme 13).[22]




Scheme 12. Lipase-catalyzed kinetic resolution of a P-stereogenic β-hydroxyphosphane oxide.

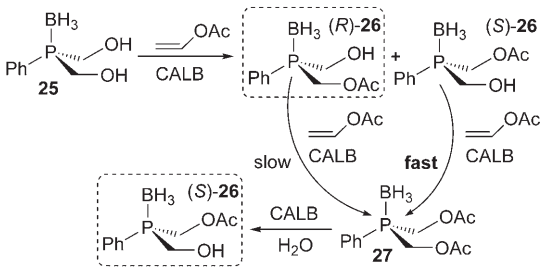



Scheme 13. Lipase-catalyzed kinetic resolution of a P-stereogenic phosphane oxide.

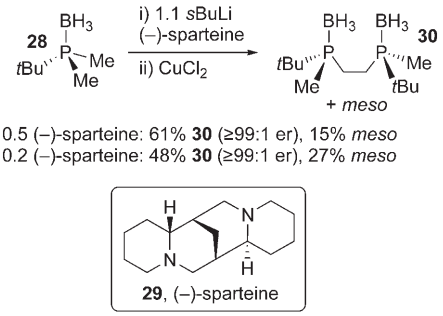
**Desymmetrization—biocatalysis and chemical catalysis**: Desymmetrization of bis(hydroxymethyl)phosphane–borane **25** using *Candida antarctica* lipase B (CALB) gave a mixture of enantiomers of **26**, enriched in (*R*)-**26**, plus over-acylated **27**. Conveniently, the minor enantiomer (*S*)-**26** was acylated to **27** more quickly than was (*R*)-**26**; this editing process yielded (*R*)-**26** of 92% *ee* in an approximately 1:1 mixture with **27**. The reverse reaction, lipase-catalyzed hydrolysis of **27**, selectively gave (*S*)-**26**, so that both enantiomers could be obtained in enantioenriched form (Scheme 14).[23]

Related desymmetrization of dimethylphosphane–borane **28** has been accomplished by ligand-accelerated catalysis, providing a new route to Imamoto's bis-P* diphosphane **30**. Enantioselective deprotonation of **28** with *s*BuLi and catalytic (−)-sparteine (**29**), followed by $CuCl_2$-mediated coupling, gave highly enantioenriched **30** (Scheme 15).[24]

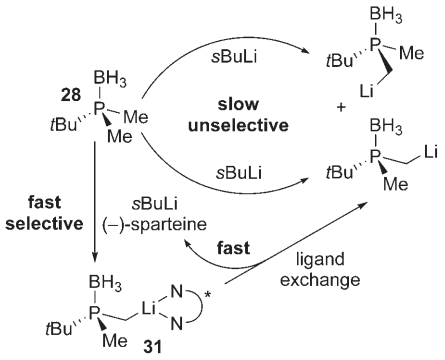
The idea behind these results is shown in simplified form in Scheme 16. The background reaction, deprotonation of **28** with *s*BuLi, is slow. However, this reaction is accelerated




Scheme 14. Synthesis of a P-stereogenic phosphane(borane) by lipase-catalyzed desymmetrization.




Scheme 15. Desymmetrization of a dimethylphosphane(borane) by (−)-sparteine-accelerated asymmetric deprotonation.




Scheme 16. Proposed ligand-exchange pathway for (−)-sparteine-catalyzed asymmetric deprotonation of a dimethylphosphane(borane). (−)-Sparteine is shown as *N–N.

(and made enantioselective!) by added (−)-sparteine. Catalytic turnover requires loss of (−)-sparteine from lithiated **31**; if this ligand substitution occurs more quickly than the unselective deprotonation of **28**, then (−)-sparteine can bind more *s*BuLi to deprotonate another equivalent of **28** enantioselectively.[24]

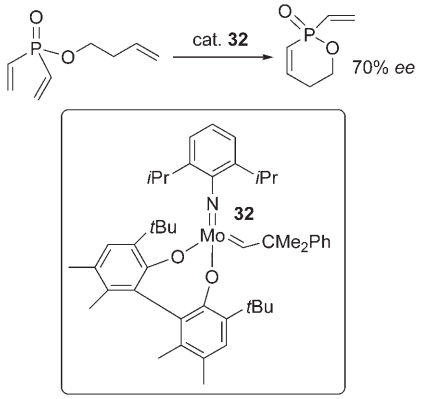
The relative rates of the background and ligand-accelerated deprotonations may be estimated from the yields of highly enantioenriched **30** and its *meso*-diastereomer in the presence of differing amounts of (−)-sparteine (Scheme 15). Even better results were obtained with a (+)-sparteine surrogate, for which only 10 mol% of the chiral ligand gave 45% yield of highly enantioenriched **30**.[24] Adding an achiral diamine to promote exchange of (−)-sparteine between **31** and *s*BuLi gave results similar to those in Scheme 15, so it is possible that the added diamine had no effect.[25]

Finally, desymmetrization of P-vinyl groups by means of an asymmetric ring-closing metathesis (ARCM) reaction with Schrock's chiral catalyst **32** was described in a recent patent (Scheme 17).[26]

## Controlling the Stereochemistry of Catalytic P–C Bond Formation

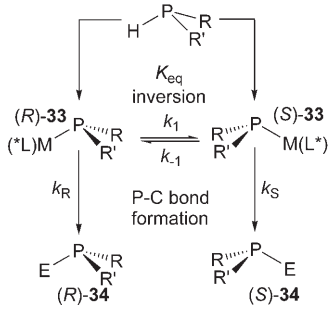
A more recently developed synthetic method uses chiral catalysts to control the stereochemistry at P and/or C during




Scheme 17. Desymmetrization of a divinylphosphane oxide by Mo-catalyzed asymmetric ring-closing metathesis.

the formation of P–C bonds. As shown in several examples below, C-stereogenic phosphanes can be prepared in catalytic processes in which the catalyst activates either a P nucleophile or a C electrophile and creates an asymmetric environment for P–C bond formation. A general approach to P-stereogenic phosphanes was developed to exploit rapid pyramidal inversion in catalytic intermediates. Scheme 18 summarizes the idea, which has recently been reviewed in more detail.[27]

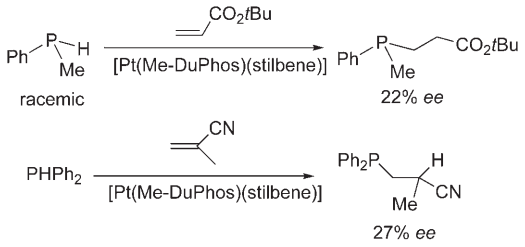



Scheme 18. Metal-catalyzed asymmetric synthesis of P-stereogenic phosphanes: P inversion and P–C bond formation. The group E comes from an electrophile (see the examples below).

On reaction with the catalyst precursor, a chiral metal complex, racemic secondary phosphanes are converted into diastereomeric metal–phosphido complexes **33**, which interconvert rapidly by P inversion. If this equilibrium is faster than their reaction with an electrophile, then P-stereogenic phosphanes **34**, in which pyramidal inversion is slow, can be formed enantioselectively. The product ratio in this dynamic kinetic asymmetric transformation[28] depends both on $K_{eq}$ and on the rate constants $k_S$ and $k_R$.[27]

This scheme describes reactions of secondary phosphanes with several electrophiles, including alkenes (hydrophosphination), aryl iodides (arylation), and alkyl halides (alkylation).

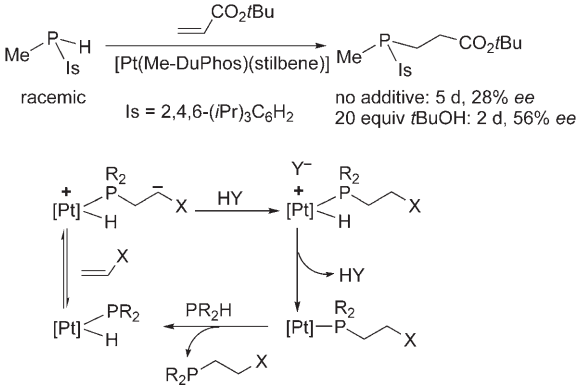
**Hydrophosphination**: In our original report of this approach (2000), Pt-catalyzed addition of secondary phosphanes to Michael acceptor alkenes gave chiral phosphanes with P or C stereocenters (Scheme 19). Although valuable as a proof




Scheme 19. Synthesis of chiral phosphanes through Pt-catalyzed asymmetric hydrophosphination.

of concept, these results were not synthetically useful because enantioselectivities were low and byproducts derived from more than one equivalent of the alkene were formed.[29]

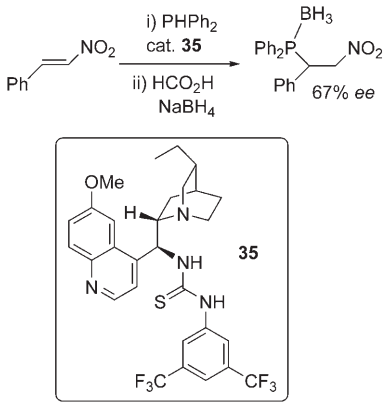
In these catalytic reactions, Pt–phosphido complexes are formed by P–H oxidative addition to $Pt^0$. P–C bond formation by nucleophilic addition of the $Pt–PR_2$ group to uncomplexed alkenes was proposed to yield zwitterions. Consistent with this idea, protic additives increased the reaction rate for some substrates; selectivity was also affected (Scheme 20).[30]




Scheme 20. Effects of the weak acid *tert*-butanol on Pt-catalyzed hydrophosphination of an acrylate. A proposed mechanism for formation of a zwitterionic intermediate and its protonation by a weak acid HY is shown ([Pt] = [Pt(Me-DuPhos)], X = CN or $CO_2tBu$, Y = O-*t*Bu).

Nucleophilic activation was also successful without a transition-metal catalyst in organocatalytic asymmetric hydrophosphination of nitroalkenes using bifunctional cinchona alkaloid/thiourea catalysts (Scheme 21). Although enantioselectivity was not high, recrystallization of the borane adducts of the product phosphanes enabled upgrade to 99% *ee* after recrystallization in some cases.[31] Presumably, the thiourea binds the nitro group,[32] while the tertiary amine base mediates proton transfer from phosphorus to carbon; the

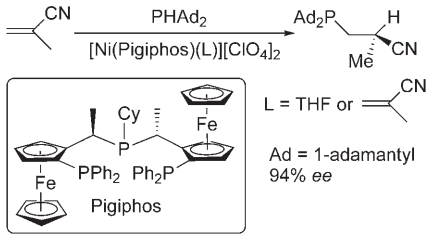
  




Scheme 21. Organocatalytic asymmetric hydrophosphination of a nitrostyrene.

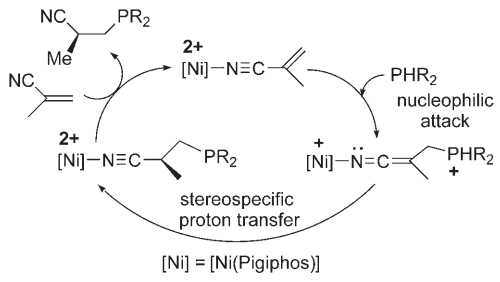
selectivity improvement observed with isopropanol as an additive has not been rationalized.[31]

In contrast to these examples of nucleophilic activation, [Ni(Pigiphos)]-catalyzed addition of secondary phosphanes to methacrylonitrile gave C-stereogenic phosphanes through an electrophile-activation pathway (Scheme 22).[33]



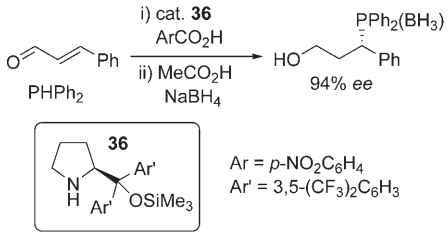

Scheme 22. Ni-catalyzed asymmetric hydrophosphination of methacrylonitrile.

After nitrile complexation by the chiral Ni Lewis acid, free phosphane was proposed to attack the terminal alkene carbon. Stereospecific proton transfer was then suggested to yield the product, which could be displaced from the [Ni(Pigiphos)] binding pocket by more methacrylonitrile (Scheme 23). Steric congestion at nickel thus speeds up turnover for bulky phosphane substrates and also limits possible catalyst inhibition by product binding.[33]




Scheme 23. Proposed mechanism of Ni-catalyzed asymmetric hydrophosphination of methacrylonitrile.

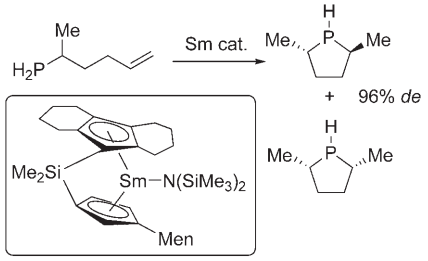
Electrophile activation in catalytic hydrophosphination was also reported simultaneously by two groups using an organocatalytic approach, conversion of an α,β-unsaturated aldehyde substrate to an iminium ion by using chiral pyrrolidine derivatives and acid (Scheme 24).[34] Workup with




Scheme 24. Organocatalytic hydrophosphination of an α,β-unsaturated aldehyde.

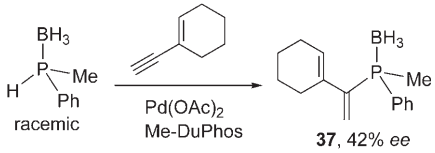
sodium borohydride both reduced the aldehyde and protected the phosphane as a borane adduct. Although mechanistic details have not been reported, presumably the catalyst activates the aldehyde for nucleophilic attack by the phosphane; a computational study suggested that the bulky organocatalyst side chain shields one face of the iminium ion substrate from attack.[34b]

Activation of both the nucleophile (a Sm–phosphido group) and the electrophile (a complexed alkene) is presumably involved in the diastereoselective synthesis of phospholanes through intramolecular hydrophosphination catalyzed by chiral organolanthanides (Scheme 25).[35]




Scheme 25. Diastereoselective lanthanide-catalyzed intramolecular hydrophosphination of a phosphinoalkene.

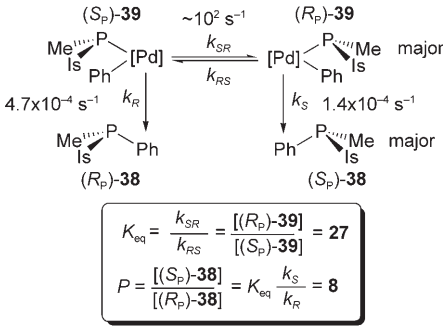
Finally, Pd-catalyzed asymmetric hydrophosphination of an alkyne under kinetic resolution conditions gave vinylphosphane **37**; little is known about the mechanism of this reaction (Scheme 26).[36]




Scheme 26. Pd-catalyzed asymmetric hydrophosphination of an alkyne.

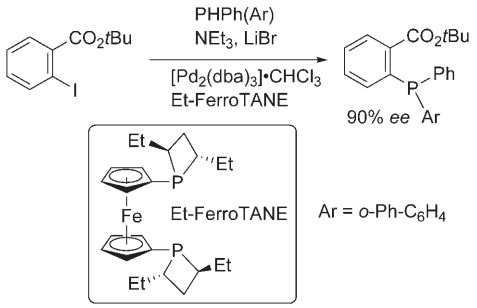
  

**Arylation of secondary phosphanes**: Asymmetric phosphination of aryl halides with the bulky secondary phosphane PHMe(Is) (Is = 2,4,6-($i$Pr)$_3$C$_6$H$_2$) gave tertiary phosphanes, such as **38** (from PhI). A mechanistic study, consistent with the general Scheme 18, concluded that the major enantiomer of the product ((*S*$_P$)-**38**) was formed from the major diastereomer of the Pd–phosphido intermediate ((*R*$_P$)-**39**), although the minor diastereomer ((*S*$_P$)-**39**) formed the product more quickly (Scheme 27).[37]




Scheme 27. Proposed origin of enantioselectivity in Pd-catalyzed asymmetric synthesis of phosphane **38** ([Pd] = [Pd((*R*,*R*)-Me-DuPhos)]).

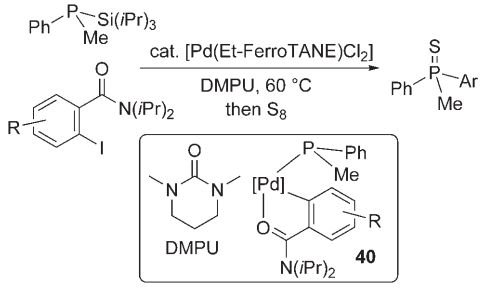
A related [Pd(Et-FerroTANE)] catalyst mediated the enantioselective synthesis of triarylphosphanes. An interesting additive effect was observed (LiBr gave higher enantioselectivity than the other lithium halides or Bu$_4$NBr), but its mechanistic origin is unclear (Scheme 28).[38]



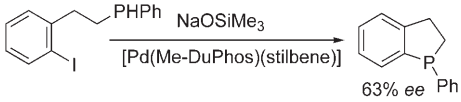

Scheme 28. [Pd(Et-FerroTANE)]-catalyzed asymmetric synthesis of a triarylphosphane.

[Pd(Et-FerroTANE)] also catalyzed phosphination of *o*-iodo-diisopropylbenzamides with silylphosphanes in the presence of *N*,*N*′-dimethyl-*N*,*N*′-propylene urea (DMPU) to give P-stereogenic tertiary phosphanes in >90% *ee* (Scheme 29). Chelation of the "privileged" benzamide O to Pd (perhaps in intermediate **40**?) was proposed to be responsible for the high selectivities, presumably by affecting the position of the equilibrium of the Pd–phosphido diastereomers, and/or their relative rates of reductive elimination (see Scheme 27).[39]

Intramolecular cross-coupling, yielding benzophospholanes, was also possible (Scheme 30).[40]

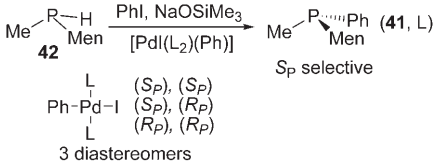



Scheme 29. [Pd(Et-FerroTANE)]-catalyzed asymmetric phosphination ([Pd] = [Pd(Et-FerroTANE)]).




Scheme 30. Asymmetric synthesis of a benzophospholane by Pd-catalyzed asymmetric phosphination.

Formal chirality breeding occurred in the diastereoselective synthesis of (*S*$_P$)-**41** by cross-coupling of secondary phosphane **42** with PhI, for which the diastereomerically pure Pd complex [PdL$_2$(Ph)(I)] (L = (*S*$_P$)-**41**, Scheme 31) was

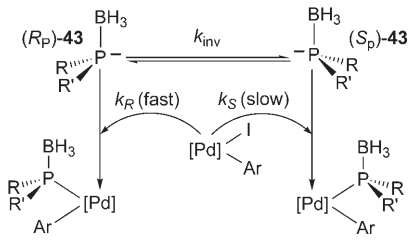



Scheme 31. Formal chirality breeding in diastereoselective synthesis of (*S*$_P$)-**41** catalyzed by a Pd complex of (*S*$_P$)-**41** (Men = (−)-menthyl).

a catalyst precursor. However, ligand substitution at Pd occurred during catalysis, and the structure of the active catalyst (or, more likely, catalysts) could not be determined.[41]

Related asymmetric arylations of secondary phosphane–boranes are mechanistically distinct, since pyramidal inversion in the Pd–phosphido(borane) intermediates is slow (Scheme 32).[42]

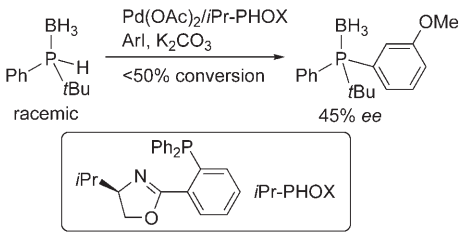
If one enantiomer of the phosphido–borane anion [PR(R′)(BH$_3$)]$^-$ (**43**) reacts more quickly than the other with a chiral [Pd(Ar)(diphos*)(I)] intermediate, and if inter-




Scheme 32. Key steps in Pd-catalyzed asymmetric arylation of racemic secondary phosphane–boranes: P inversion and Pd–P bond formation ([Pd] = [Pd(diphos*)]).

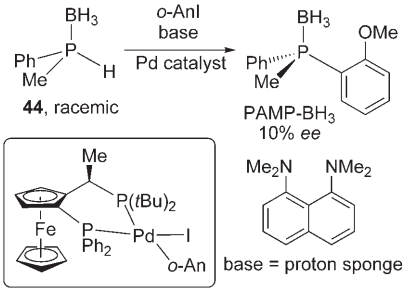
  

conversion of ($R_P$)-**43** and ($S_P$)-**43** by inversion is slow, kinetic resolution can result in enantioselective P–C bond formation, as recently demonstrated with a [Pd(PHOX)] catalyst (Scheme 33).[43]




Scheme 33. Kinetic resolution in Pd-catalyzed asymmetric arylation of a secondary phosphane–borane.

In a variation of the process in Scheme 32, if anion **43** undergoes P inversion more rapidly than Pd–P bond formation, a similar kinetic preference ($k_R > k_S$) may result in *dynamic* kinetic resolution. This was observed, albeit with low enantioselectivity, in Pd-catalyzed synthesis of PAMP–$BH_3$ from racemic **44** with a [Pd{(*t*Bu)-Josiphos}] catalyst (Scheme 34).[44]

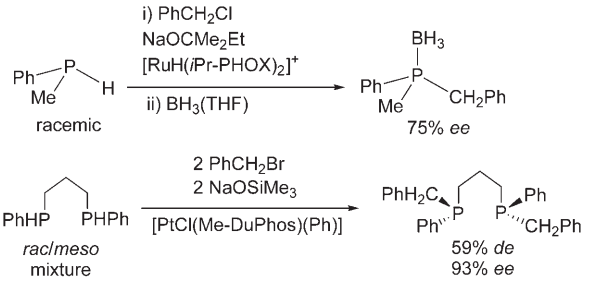



Scheme 34. Dynamic kinetic resolution in Pd-catalyzed asymmetric arylation of a secondary phosphane–borane.

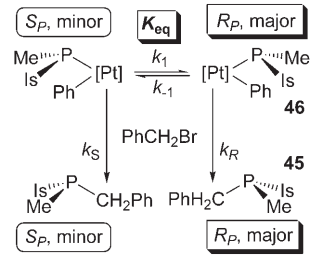
**Alkylation of secondary phosphanes**: Both [PtCl(DuPhos)(Ph)] and $[RuH(i\text{Pr-PHOX})_2]^+$ are catalyst precursors for the asymmetric alkylation of secondary phosphanes with benzyl halides to yield P-stereogenic phosphanes, including chelating bis(tertiary) phosphane ligands (Scheme 35). These reactions succeed because the metal-catalyzed reaction is faster than the achiral background reaction, base-mediated alkylation of the secondary phosphane.[45]

In analogy to the Pd-catalyzed phosphination of Scheme 27, a mechanistic study of Pt-catalyzed asymmetric alkylation of PHMe(Is) suggested that the major diastereomer of the product, ($R_P$)-**45**, was formed from the major diastereomer of the Pt–phosphido intermediate, ($R_P$)-**46** (Scheme 36).[46]

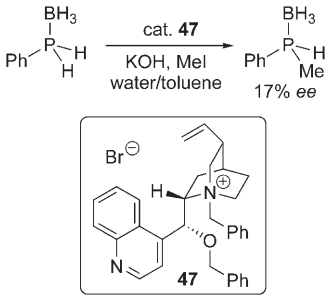
Similar asymmetric alkylation can be carried out without a metal catalyst. Deprotonation/methylation of phenylphosphane(borane) in the presence of Cinchona alkaloid-derived phase-transfer catalyst **47** occurred with low enantioselectivity (Scheme 37). Presumably ion-pairing of the chiral ammonium cation with the phosphido–borane anion is responsible for the selectivity. As in the Pt- and Ru-catalyzed alkylations, the catalytic pathway must outpace the background (achiral) reaction. Indeed, the ligand-accelerated asymmetric alkylation was at least four times faster than the analogous reaction using $n\text{Bu}_4\text{Br}$.[47]




Scheme 35. Metal-catalyzed asymmetric alkylation of secondary phosphanes.




Scheme 36. Proposed origin of enantioselectivity in Pt-catalyzed asymmetric alkylation of PHMe(Is) with benzyl bromide, yielding phosphane **45** ([Pt] = [Pt{(*R*,*R*)-Me-DuPhos}]).




Scheme 37. Organocatalytic asymmetric alkylation of phenylphosphane(borane).

## Conclusion

Catalytic asymmetric synthesis is a valuable method to prepare chiral phosphanes, themselves key ligands in metal-catalyzed asymmetric reactions. The possibility of breeding chirality by this approach was recognized early on and has been exploited frequently since then.

The industrial syntheses of DuPhos and Josiphos ligands illustrate the use of asymmetric hydrogenation and biocatal-

ysis to prepare chiral building blocks, which can be further elaborated to chiral phosphanes. Similarly, asymmetric catalytic transformations of organophosphorus substrates have also been used to prepare chiral phosphanes, particularly by means of kinetic resolution and desymmetrization routes.

The most recently developed synthetic method, which relies on control of the stereochemistry of P–C bond formation, offers a new way to prepare P-stereogenic phosphanes. These ideas are promising, but will require substantial further development before they become practical approaches to chiral phosphanes. However, mechanistic understanding of many of these reactions should assist rational development of new catalytic asymmetric transformations.

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