

Supported catalysts and their applications in synthetic organic chemistry

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1 Introduction

This review covers the most significant publications during the period from April 1999 to March 2000 on supported catalysts with an emphasis on their applications in organic synthesis. Extensive reviews of the literature in this field prior to 1999 can be found.^{1–5} The most comprehensive recent review (covering the literature dating from 1983 to 1997) was published in 1997 by Shuttleworth *et al.*⁶ In 1999, a review on polymer-supported reagents and their use in organic synthesis was put forward by Drewry and co-workers.⁷

Recent reviews^{8,9} have covered in detail the use of supported catalysts in combinatorial chemistry as well as the latest advances in polymer-supported reagents and scavengers and their uses in combinatorial, parallel, or multi-step synthesis. This will therefore remain outside the scope of this review.

Finally, it must be noted this article intends to provide selected coverage on the key advances in the field, rather than a fully comprehensive review.

Polymer supported chemistry had not attracted much interest until the introduction of solid-phase peptide synthesis (SPPS) by Merrifield in 1963.^{10–12} This was followed by a great deal of research during the 1970s and 1980s into the development of new polymer-bound reagents, catalysts and protecting groups for use in organic synthesis. In the early 1990s, pharmaceutical companies and other researchers turned to solid-phase synthesis for the rapid preparation of large numbers of molecules in the hope of accelerating the lead discovery and optimisation process in drug discovery and so Combinatorial Chemistry^{13–17} was born and in the last 10 years we have seen many great advances in the area of solid-phase organic synthesis (SPOS).^{18–20}

More recently, there has been a move away from the preparation of libraries on solid-phase, mainly due to the problems associated with reaction monitoring on solid-phase.^{21,22} This has led to a shift towards multiple parallel synthesis using solution phase chemistry facilitated by polymer-supported reagents, catalysts or scavengers. Many solid-supported reagents and scavengers are now commercially available and their use for rapid purification in solution-phase synthesis^{9,23} has become widespread.

Each supported catalyst will be discussed briefly and an example of its use in organic synthesis will be provided. The reader is encouraged to consult the literature source for more detailed information. Cross-linked polystyrene was the support of choice unless otherwise stated, as it was by far the most commonly used.

2 Chiral catalysts for asymmetric organic synthesis

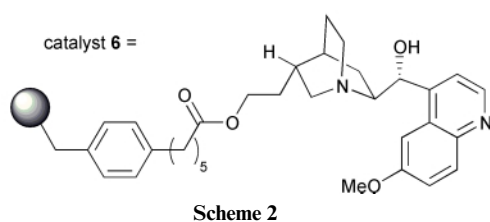
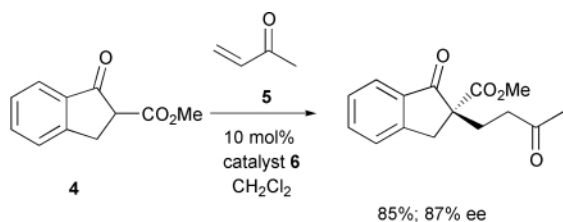
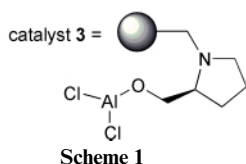
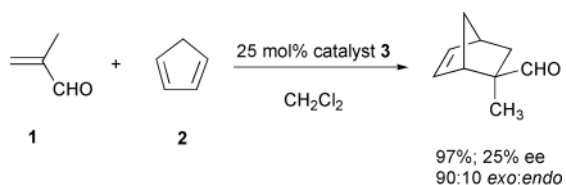
The high cost of chiral catalysts means that they are not often used industrially (or on a large scale). It is therefore very worthwhile to prepare supported chiral catalysts for asymmetric synthesis as these can then be recycled. Furthermore, immobilisation of these expensive catalysts onto insoluble supports leads to simplified purification of the resulting chiral product.

This section of the review will focus on some of the most recent advances in the rapidly growing field of supported asymmetric catalysts, grouped together according to their application in organic synthesis.

2.1 Enantioselective C–C bond formation

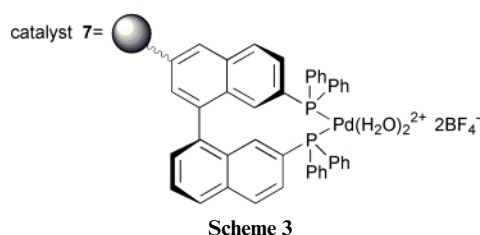
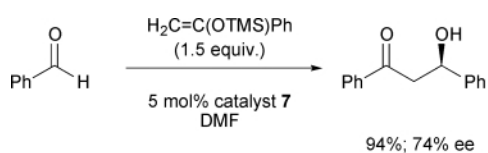
The formation of new C–C bonds enantioselectively using chiral catalysts has received a great deal of attention in the past year, and this is reflected in the large number of reports in this area.

Altava *et al.*²⁴ have reported further studies on their supported chiral Lewis acid catalyst **3** and its use in the Diels–Alder reaction of methacrolein **1** and cyclopentadiene **2** (Scheme 1). A chiral prolinol moiety was introduced (by either grafting or polymerisation) onto a polystyrene support prior to treatment of the bound alcohol with AlCl_2Et to give the desired catalyst. It was shown that the polymer microenvironment plays a major role in the selectivity observed. In the case of this reaction, resins prepared by polymerisation and with high degrees of cross-linking (90%) gave the best results (25% ee). The enantioselectivity achieved by this catalyst was low compared to others previously reported⁶ which had shown up to 65% ee for this reaction. The *exolendo* selectivity was found to be constant (90:10 ratio) regardless of which resin was used to anchor the catalyst. It was also noted that the presence of coordinating species on the polymer backbone (such as PEG) led to a decrease in enantioselectivity (2% ee) possibly due to coordination of the active site.

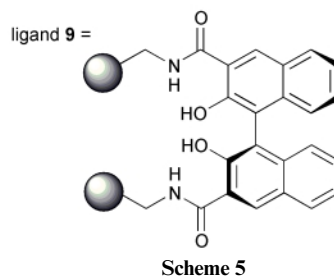
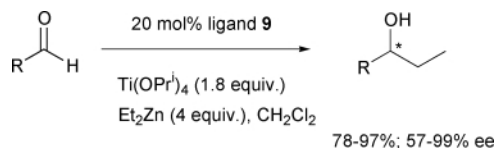
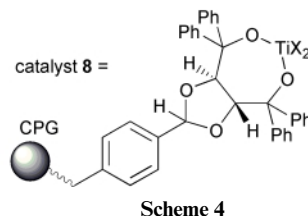
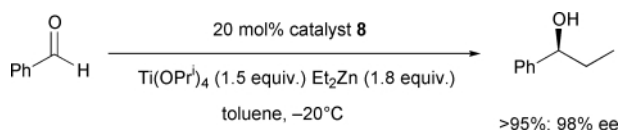


The use of polystyrene-supported *Cinchona* alkaloid derivatives **6** as catalysts in the asymmetric Michael reaction between a β -keto ester **4** and methyl vinyl ketone **5** (Scheme 2) has been investigated.²⁵ It was found that there was an optimum spacer length required to obtain good enantioselectivity ($n = 5$, shown below). In the case of catalysts with shorter or longer spacer chains ($n = 3$ or 9), there was a dramatic decrease in the ee values observed.

Many reports on polymer-supported BINAP catalysts have appeared recently in the literature (see section 2.3). The supported BINAP-palladium diaqua **7** (and hydroxo) complexes have been shown²⁶ to be efficient catalysts in the asymmetric aldol reaction (Scheme 3) as well as in Mannich-type reactions. The addition of small amounts of water (0.2 equiv.) led to an improvement in the chemical yield of this aldol reaction.



Recently, most of the research activity in this area has concentrated on the enantioselective addition of diethylzinc to aldehydes. Five independent research groups have developed different types of supported catalysts for use in this reaction. Seebach and Heckel²⁷ have developed a new supported system involving a TADDOL ligand immobilised on controlled-pore glass (CPG) and the resulting Ti-containing species **8** (where X = OTs, OⁱPr) has shown activity in the Lewis-acid catalysed



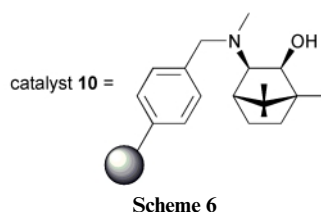
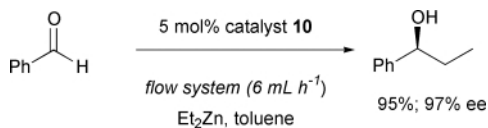
enantioselective diethylzinc addition to aldehydes (Scheme 4) as well as in (3 + 2) cycloaddition reactions (not shown here). The re-usability of the supported TADDOL ligand has also been demonstrated.

A new polystyrene-supported BINOL ligand **9** (Scheme 5) has also been reported.²⁸ Its catalytic activity in the titanium-catalysed alkylation of aldehydes with diethylzinc has been demonstrated and the supported catalyst has been found to be more enantioselective than the corresponding free analogue (Ti(BINOL)(OⁱPr)₂) possibly due to the increased steric effect by the support on the catalytic species.

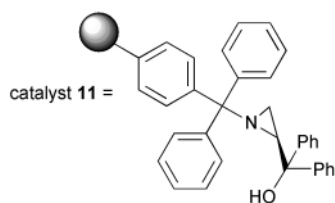
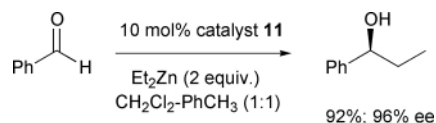
The previous review of this field⁶ covered a system (designed by Pu and co-workers) in which the use of a highly rigid chiral polymeric catalyst led to very high enantioselectivities for this reaction. In addition, there were many reports on immobilised chiral amino alcohols by several groups (such as Itsuno and Soai) included in that review.

Interest in this type of catalyst has continued to grow, and very detailed studies have been carried out by Sung *et al.*²⁹ culminating in the development of a new "flow system" (Scheme 6).³⁰ However it was found that using the polymer-supported camphor derivative **10** for an extended period of time (*ca.* 275 h), led to a marked decrease in performance possibly due to degradation of the catalyst.

A novel polymer-supported *N*-tritylaziridinyl alcohol ligand **11** (Scheme 7) has also been reported.³¹ In this case, very high

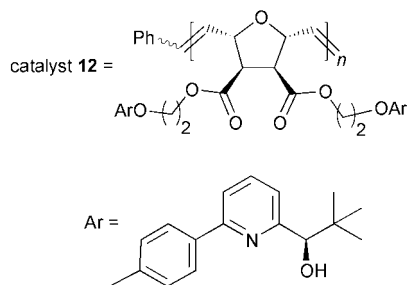
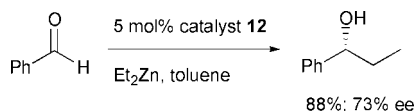


enantioselectivities were observed for both aliphatic and aromatic aldehydes. In addition, the activity and selectivity of the catalyst were retained upon recycling (up to three times).



Scheme 7

Finally, a novel polymeric catalyst (Scheme 8) was developed by Bolm *et al.*³² based on a chiral hydroxypyridinyl moiety (Ar) attached to a norbornene monomer unit which was polymerised by ROMP to yield the soluble polymeric catalyst **12**. The enantioselectivity observed for this polymeric catalyst ($n = 20$) was comparable to that obtained from the corresponding low molecular weight (monomeric) catalysts, despite the longer reaction times required on the polymeric system.

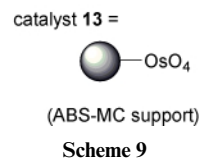
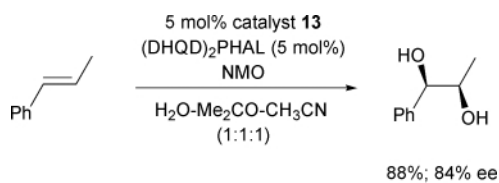


Scheme 8

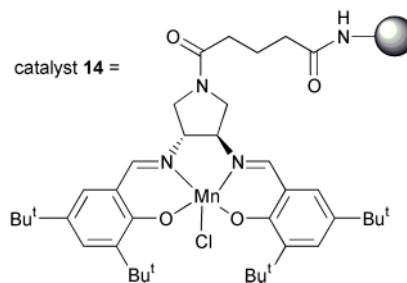
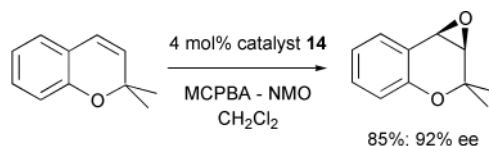
2.2 Asymmetric oxidation

The asymmetric dihydroxylation of alkenes is a valuable synthetic procedure for the preparation of chiral diols and therefore became the focus of many studies aiming at the immobilisation of the chiral ligand.³³ The microencapsulation of osmium tetroxide developed by Kobayashi³⁴ has now led to a reusable catalyst for the asymmetric dihydroxylation of olefins (Scheme 9). This is achieved by encapsulating the highly toxic osmium catalyst within an acrylonitrile-butadiene-polystyrene (ABS) co-polymer **13**. Catalytic amounts of a chiral ligand, dihydroquinidinyolphthalazine ((DHQD)₂PHAL), were also employed in conjunction with stoichiometric co-oxidant *N*-methylmorpholine *N*-oxide (NMO). Good yields and enantioselectivities were obtained under the standard Sharpless conditions. Furthermore, the catalyst and chiral ligand were recoverable and could be re-used without a decrease in activity or selectivity.

Song *et al.*³⁵ reported a supported manganese catalyst **14** for the asymmetric epoxidation of alkenes which gave excellent enantioselectivities (Scheme 10). The catalyst consisted of a (pyrrolidine salen) ligand immobilised onto a PS-PEG resin using a highly flexible linkage, and its catalytic activity and selectivity were comparable to those of the analogous homogeneous catalyst. Despite the positive results, this catalyst was found to decompose under the reaction conditions and thus could not be recycled effectively.



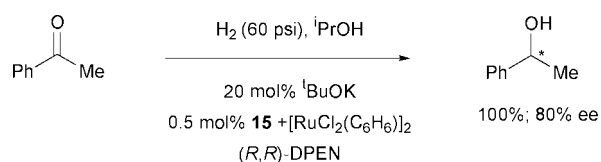
Scheme 9



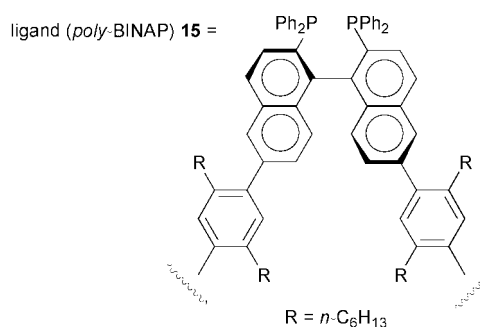
Scheme 10

2.3 Asymmetric reduction

The heterogenisation of hydrogenation catalysts based on the chiral BINAP ligand has received much attention during recent years. Pu and co-workers³⁶ have prepared a new soluble polymeric BINAP **15** which is highly rigid and optically active (Scheme 11), and they have investigated its use in the asymmetric hydrogenation of ketones. Their studies demonstrate that this poly(BINAP) leads to very good enantioselectivities, similar to those obtained using the homogeneous catalysts. Furthermore, the catalyst recovered after one use (by precipitation with methanol) displayed similar activity and selectivity to the freshly prepared catalyst.

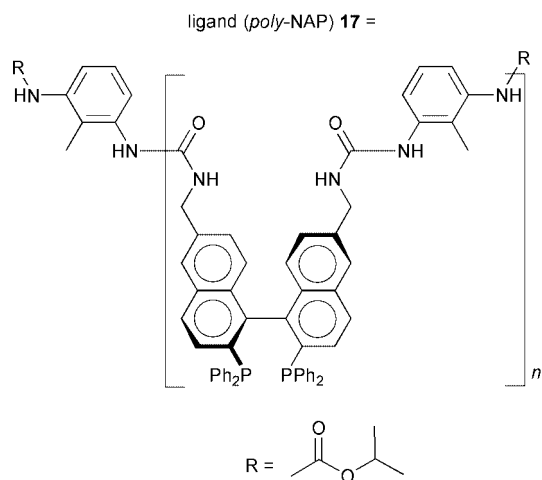
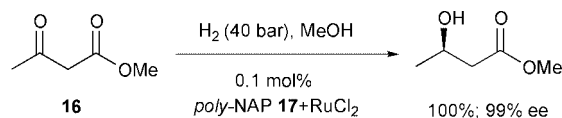


DPEN = 1,2-diphenylethylenediamine



Scheme 11

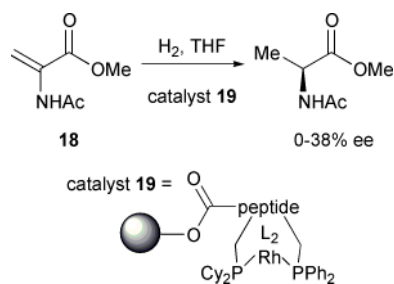
Another polymeric BINAP has also been reported³⁷ and shown to lead to a highly efficient catalyst for the hydrogenation of β -ketoesters **16** (Scheme 12). The ligand (poly-NAP) **17** was



Scheme 12

prepared by polymerisation of a modified monomer to yield a polymer with backbone chirality and solubility in some solvents (DMF and DMSO). The excellent enantioselectivities and high catalytic activities observed were retained after the catalyst was reused four times.

Combinatorial approaches for the acceleration of the catalyst discovery process have been the subject of a review.³⁸ Gilbertson and Wang³⁹ have recently reported an attempt to implement this strategy. In this case, the parallel synthesis of peptide-containing phosphine ligands was achieved and the resulting rhodium complexes **19** were tested for catalytic activity in the asymmetric hydrogenation of enamides **18** (Scheme 13). However, the enantiomeric excesses observed were only moderate.



Scheme 13

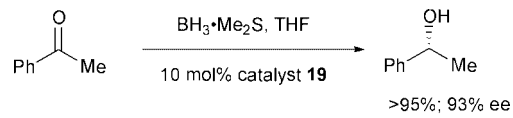
Finally, a microgel-bound chiral oxazaborolidine (CBS) catalyst⁴⁰ **19** has been successfully prepared and used in the asymmetric reduction of prochiral ketones (Scheme 14). The use of these soluble microgels as the polymeric supports for the CBS catalyst leads to selectivity values comparable to those obtained with the homogeneous counterpart and previously reported heterogenised CBS catalysts.⁶ These cross-linked polymers display good solubility but can be easily removed by ultrafiltration. Thus it has been possible to recycle these catalysts up to three times with little or no loss of enantioselectivity.

3 Non-chiral catalysts for organic synthesis

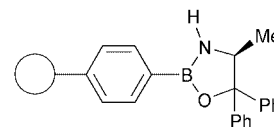
3.1 C–C bond formation

3.1.1 Palladium catalysts

The area of most intense research activity has been the development of polymer-supported palladium catalysts for cross-



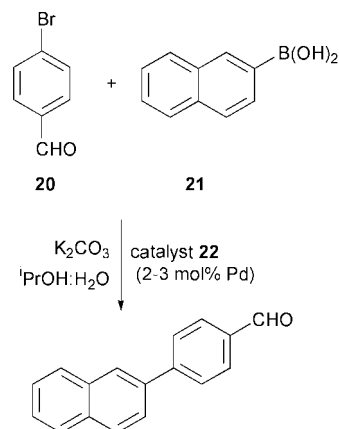
catalyst **19** (microgel-supported) =



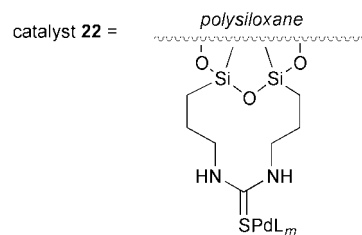
Scheme 14

coupling reactions, mainly Heck and Suzuki, which are key C–C bond forming reactions.

Zhang and Allen⁴¹ have developed a polysiloxane-supported palladium complex **22** as a catalyst for Suzuki reactions between aryl halides **20** and arylboronic acids **21** (Scheme 15). The supported catalyst was prepared directly from a commercial resin (Deloxan[®] THP) which is macroporous and has a high degree of cross-linking. These resins do not swell appreciably upon addition of solvent and are thus compatible with all solvents including water. The reaction could therefore be carried out in a mixture of isopropanol and water and led to rates and yields comparable to those obtained using the soluble Pd(PPh₃)₄ catalyst. Surprisingly, the supported species displayed much higher stability to air, moisture and storage than its soluble analogues. Although the reaction worked well with aryl iodides, the presence of electron-withdrawing activating groups was needed for the less reactive aryl bromides. Metal leaching from the polymer was found to be extremely low (below 3 ppm per batch); however, recycling 2–3 times led to a gradual deterioration of the catalyst.

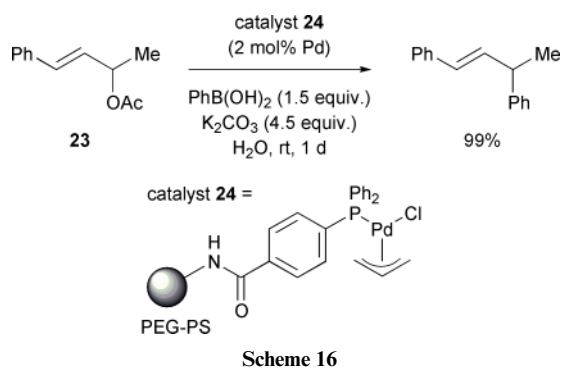


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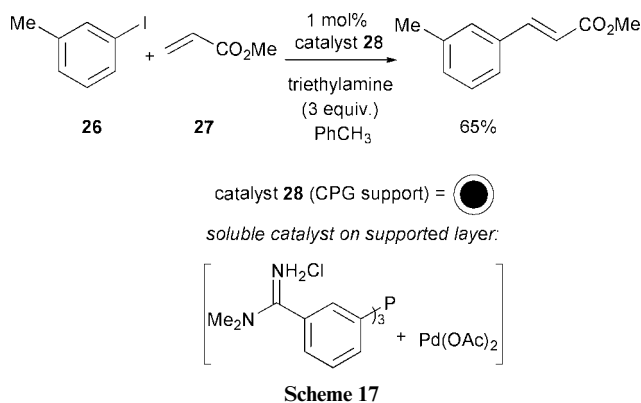
Scheme 15

There is a drive towards generating more environmentally benign catalysts, known as *green catalysts*, that do not require the use of harmful and costly organic solvents. Uozumi's group⁴² have continued their work on palladium complexes (e.g. **24**, Scheme 16) bound to amphiphilic polystyrene-based resins containing PEG grafts (such as Argogel and Tentagel). Their



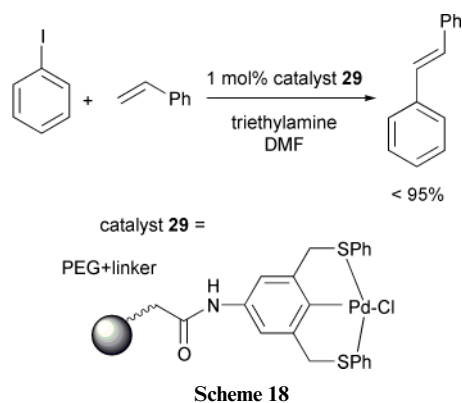
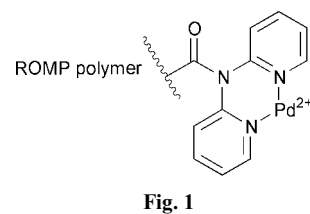
catalysts could be used in water for the Suzuki coupling of aryl halides to arylboronic acids with a great deal of success, and showing better activities than the conventional soluble catalysts. The use of these superior catalysts in the arylation of allyl acetates **23** in water has also been demonstrated (Scheme 16). Further reports by this group⁴³ have demonstrated the usefulness of this catalyst in the hydroxycarbonylation of aryl halides in water to yield carboxylic acids under mild conditions. In addition, substitution of allyl esters by a variety of nucleophiles in an aqueous system has also been reported.⁴⁴

Supported catalysts for the Heck reaction have also been developed by several groups. In each case, a different type of support was employed. Glass beads were used in a supported liquid-phase catalysis approach.⁴⁵ This was achieved by treating the hydrophilic surface of the controlled-pore glass (CPG) beads with a mixture of the ligand and metal complex in a polar solvent, resulting in the formation of a supported layer **28** (Scheme 17). Despite the non-covalent nature of the attachment, the catalyst only leached small amounts (0.1–0.2% Pd on each run) and worked well in the Heck coupling between aryl iodides **26** and substituted alkenes **27**. Some Sonogashira coupling reactions between aryl iodides and alkynes were also successful.



A different type of palladium catalyst (with a tridentate SCS ligand) was also successfully immobilised onto a soluble PEG polymer.⁴⁶ The most important feature of this palladacycle catalyst **29** was its robust nature (being both thermally and oxidatively stable) which made it suitable for recycling. It was shown to be an effective catalyst for the Heck coupling between aryl iodides and alkenes (Scheme 18). The catalyst was recovered (by solvent precipitation) and reused three times with no loss of activity.

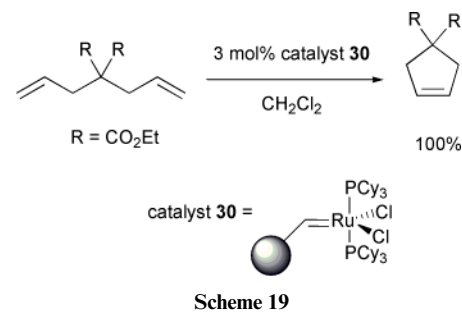
Finally, a well-defined heterogeneous catalyst (Fig. 1) for mediating Heck reactions and amination of aryl bromides was also investigated.⁴⁷ The preparation of this new catalyst involved polymerisation of a ligand-containing norbornene unit by ring-opening metathesis polymerisation (ROMP) as in a previous example (Scheme 8), followed by treatment with palladium(II). Contrary to the usual trend observed when comparing heterogeneous and soluble catalysts, this supported



complex displayed higher catalytic activity than its homogeneous counterpart.

3.1.2 Metathesis catalysts

Ring-closing metathesis is an extremely useful tool in synthetic chemistry. However the widely used Grubbs catalyst is a soluble complex, and thus has all the disadvantages associated with homogeneous catalysts. There is therefore a great need for new supported catalysts for olefin metathesis. Barrett's⁴⁸ team have addressed this problem by supporting Grubbs catalyst onto vinyl polystyrene **30** (Scheme 19). Although the catalyst could be recycled (up to three times), there was found to be considerable leaching of ruthenium from the support. The preparation of the catalyst and its use in the synthesis of new high loading resins has also been reported.⁴⁹

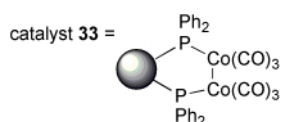
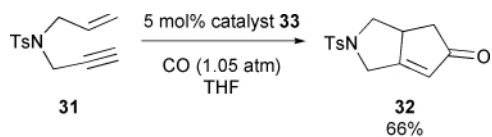


The use of supported catalysts in ROMP was investigated by Li.⁵⁰ A tungsten-containing system [WCl₆-PhCOMe-Et₂AlCl] immobilised on a polystyrene resin was assayed for its effectiveness in ring-opening polymerisation of dicyclopentadiene, and showed an improvement in activity as well as a 2-fold increase in catalyst lifetime when compared to the homogeneous system.

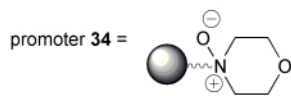
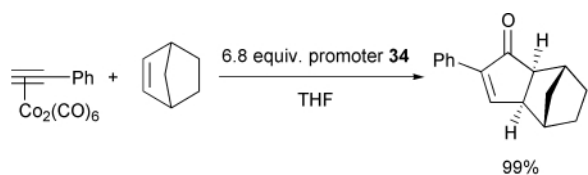
3.1.3 Catalysts for the Pauson–Khand reaction

Two teams have pioneered the use of polymer supports in the well-established Pauson–Khand reaction for the synthesis of cyclopentenones: Gibson and co-workers⁵¹ have shown that the cobalt carbonyl catalyst can be supported onto polystyrene resins with phosphine functionality **33** (Scheme 20) and then used successfully to convert the enyne substrate **31** to the cyclopentenone **32** in the presence of carbon monoxide.

Kerr *et al.*⁵² have developed a new supported amine oxide promoter **34** for the Pauson–Khand reaction (Scheme 21). Even



Scheme 20

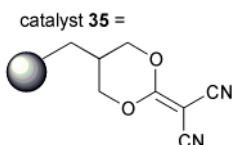
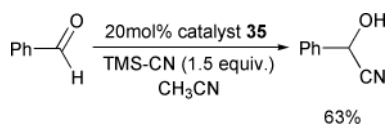


Scheme 21

though it is not in itself a catalyst, the supported oxide facilitates product purification as the cobalt residues are retained on this resin at the end of the reaction. As well as being a good promoter for the reaction, it was possible to reuse it five times without any change in activity.

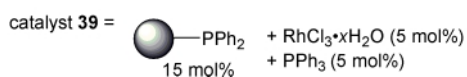
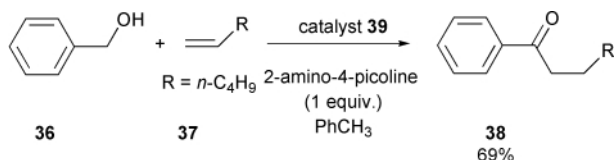
3.1.4 Miscellaneous catalysts

Other studies on supported catalysts for C–C bond forming reactions have also been carried out. These include the use of a supported dicyanoketene acetal catalyst **35** for the reaction of ketones, aldehydes and acetals with silylated nucleophiles to give the corresponding substituted cyanohydrins (Scheme 22). The yield of product was very dependent on the nature of the substrate, with aldehydes and dimethyl acetals favouring better conversions than ketones.



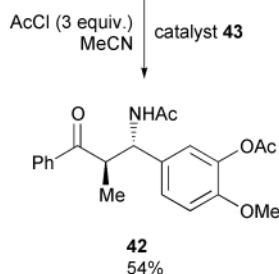
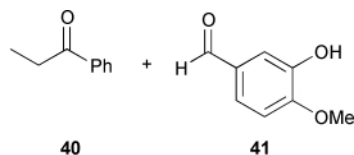
Scheme 22

Conversion of benzyl alcohol **36** to a ketone derivative **38** (Scheme 23)⁵⁴ by treatment with the corresponding alkene **37** was achieved by *in situ* generation of a supported rhodium catalyst **39**. Its utility was demonstrated for a number of *para*-substituted benzyl alcohols, and in each case the catalyst was shown to work without deterioration after being recycled (up to four times).



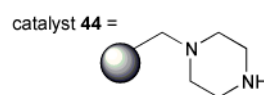
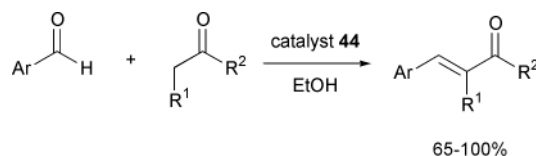
Scheme 23

β -Amino acid derivatives **42** have been prepared using a polymer-supported cobalt catalyst **43** via a three-component condensation reaction (Scheme 24) between a ketone **40**, an aldehyde **41** and acetonitrile. The greatest advantage of this procedure is that the products are obtained in very high purity. However the yields and diastereoselectivities are not high.



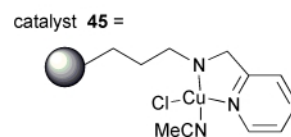
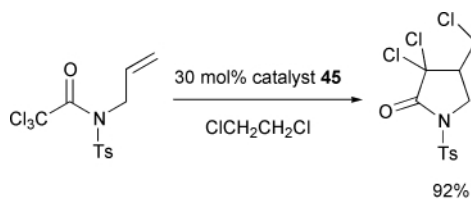
Scheme 24

The Knoevenagel condensation reaction has been successfully achieved in the presence of a polystyrene-supported piperidine catalyst **44** (Scheme 25) and this new methodology has been exploited in the preparation of libraries of caffeic acid derivatives using parallel synthesis.



Scheme 25

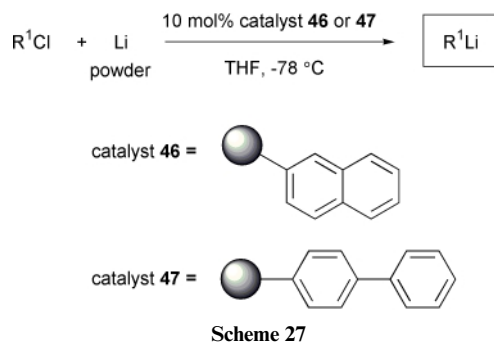
Finally, a new supported catalyst for the cyclisation of 2-haloacetamides has been reported.⁵⁷ The silica-supported *N*-alkyl-2-pyridylmethanimine ligand complexed to copper(I) **45** (Scheme 26) was active in the atom-transfer radical cyclisation of tri-, di- and mono-haloacetamides (despite slower rates than its homogeneous counterpart). However, this activity dropped considerably with reuse due to catalyst deactivation to inactive copper(II).



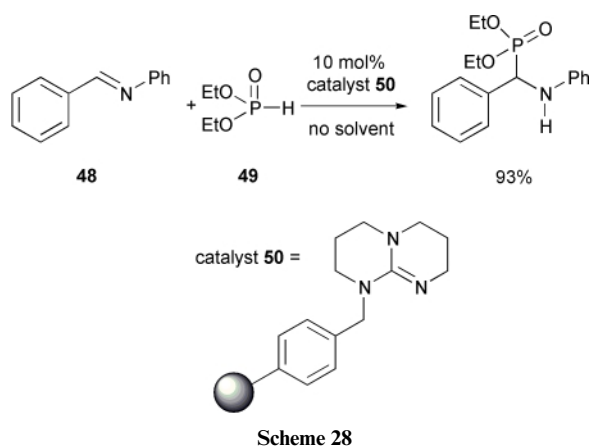
Scheme 26

3.2 C–X bond formation

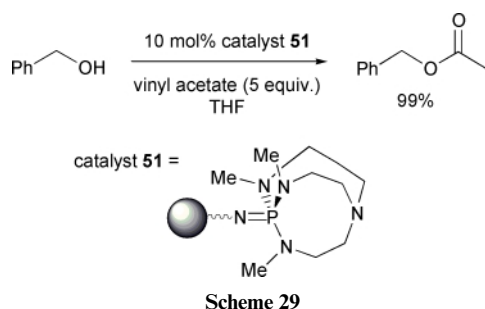
There are only very few reports on supported catalysts for C–X bond formation. The generation of lithiated intermediates ($X = \text{Li}$) is therefore covered in this section, although it eventually could also lead to formation of new C–C bonds. Gomez *et al.*⁵⁸ have reported that their supported electron transfer catalysts **46** and **47** (Scheme 27) promoted the facile lithiation of chlorinated species. The yields obtained were comparable to those of the soluble system, even after recycling 3–4 times.



Simoni and co-workers⁵⁹ have recently evaluated a polymer-supported triazabicyclodecene (P-TBD) base **50** in the nitroaldol (Henry) reaction — which involves addition of nitroalkanes to carbonyl compounds. They have also investigated its use in the addition of dialkyl phosphonates **49** to a range of carbonyl compounds and their derivatives, such as imines **48** (Scheme 28), and found it to be an efficient promoter for both these reactions.

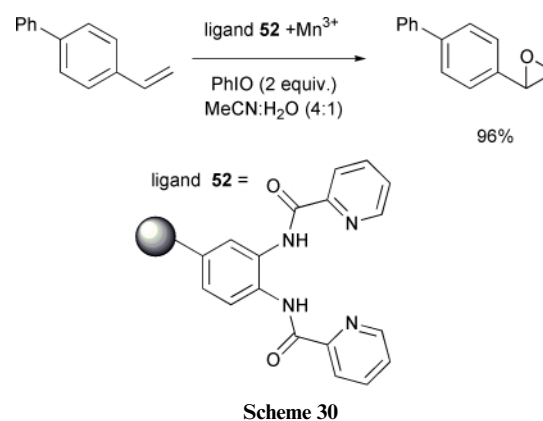


An iminophosphorane base has also been immobilised onto Merrifield resin⁶⁰ **51** and assayed for its effectiveness in catalysing the acylation of alcohols using enol esters (Scheme 29). Selective acylation of primary alcohols is possible as secondary alcohols do not react under these conditions. Furthermore, this approach results in high yields of the desired product under very mild conditions thus allowing for the presence of delicate functionality, often present in the synthesis of natural products.

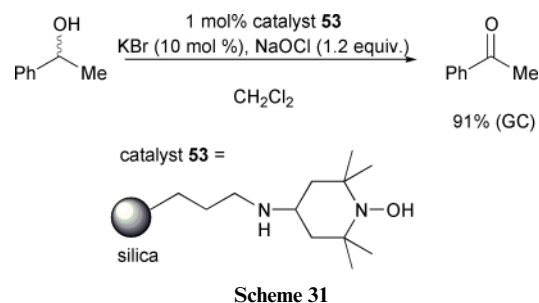


3.3 Oxidation

Sherrington^{61,62} has continued his investigations into polymer-supported molybdenum complexes as alkene epoxidation catalysts. Other studies on oxidation of alkenes (Scheme 30) and alkanes have been carried out by Havranek *et al.*⁶³ who have focused on supported manganese diamide catalysts based on **52**. They used a combinatorial approach towards catalyst optimisation by preparing libraries of related ligands, followed by screening in a parallel fashion. This led to the discovery of a new catalyst with enhanced reaction rates.



A supported version of the TEMPO catalyst used for oxidation of alcohols has been reported.⁶⁴ The silica-bound species **53** (Scheme 31) displayed the same behaviour as the homogeneous catalyst, such as selectivity towards primary alcohol oxidation (*vs.* secondary) and no racemisation of optically active compounds. In addition, it was found that the activity was relatively unchanged after 10 runs. Most of the yields provided were determined by GC.

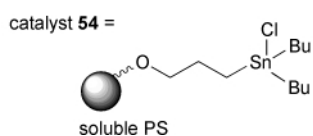
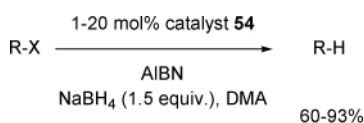


Finally, a palladium complex anchored on an ion-exchange resin has been shown⁶⁵ to catalyse the Baeyer–Villiger oxidation of ketones with hydrogen peroxide. However this catalyst suffered many drawbacks, such as loss of activity.

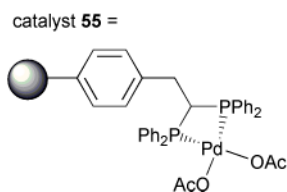
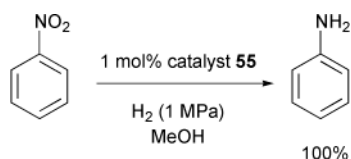
3.4 Reduction

The use of organotin reagents in free radical reactions often leads to complications, such as the problematic removal of the toxic tin residues from the product. Enholm and Schulte⁶⁶ have designed a new tin complex bound to a non-crosslinked polystyrene **54** (Scheme 32) which can be used catalytically in conjunction with sodium borohydride and removed easily from the reaction by precipitation. They have demonstrated the utility of their supported catalyst in the free radical reduction of alkyl halides to the corresponding alkanes.

Finally, Benvenuti *et al.*⁶⁷ have supported a palladium(II) complex onto polystyrene beads modified with a bidentate (bis(diphenylphosphine)) ligand **55** (Scheme 33) and carried out detailed hydrogenation studies. The reduction of nitrobenzene was found to proceed successfully, and the reusability of their catalyst was also demonstrated. Furthermore, the chemo-



Scheme 32



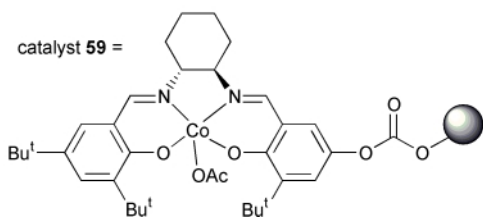
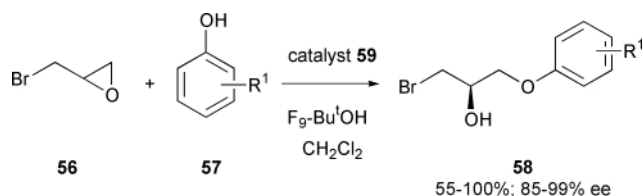
Scheme 33

selective reduction of α,β -unsaturated aldehydes was also achieved under mild conditions.

4 Applications of supported catalysts in multi-step synthesis

The use of supported catalysts and reagents can facilitate the preparation of libraries of pharmacologically active compounds.^{7,9} A review by Kobayashi⁸ has covered in detail the use of supported catalysts in combinatorial chemistry.

For example, Jacobsen^{68,69} applied his previously reported supported Co(salen) catalyst **59** (Scheme 34) to the enantioselective parallel synthesis of 1-aryloxy-2-alcohols **58** by the kinetic resolution of epoxides **56** with phenols **57**. Further derivatisation can be carried out on these valuable intermediates which makes this an extremely useful synthetic procedure. It has been suggested that it will be a valuable tool in the preparation of libraries of a wide range of analogous structures thanks to its generality and suitability for automation.



Scheme 34

5 Conclusion

This review highlights the most significant advances in the development and use of supported catalysts in organic synthesis during the period from April 1999 to March 2000. One of the main areas of growth in this field has been the introduction of novel tailor-made supports to suit different types of catalysts

or reactions. In particular, the use of rigid chiral polymers for supporting asymmetric catalysts has been shown to give superior enantioselectivities in many cases. This observation was recently the focus of a review by Pu.⁷⁰ In fact, the nature of the support has been shown to play an important role in most supported catalyst systems. In general, functional groups present on the support can have a detrimental effect on catalysis if they can compete with the substrate and lead to catalyst deactivation (*e.g.* this is observed for some catalysts anchored on hydroxy-containing silica supports or PEG-containing resins). Another factor under investigation has been the length of the spacer chain between the support and the bound catalyst. In certain cases, there is a delicate balance between mobility and rigidity required.

We have seen therefore a greater diversity of supports available for the preparation of new classes of supported catalysts than just a few years ago. There is still some interest in soluble polymeric supports,⁷¹ however the majority of studies have been on solid supports. The range of catalysts under investigation has also expanded considerably, with major advances in the development of supported asymmetric catalysts for enantioselective reactions.

6 Acknowledgements

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