Preparation of a Resin-Bound Ruthenium Phosphine Complex and Assessment of Its Use in Transfer Hydrogenation and Hydrocarbon Oxidation

Nicholas E. Leadbeater

Department of Chemistry, King's College London, Strand, London WC2R 2LS United Kingdom

nicholas.leadbeater@kcl.ac.uk

Received October 18, 2000

Introduction

Although there are many advantages in using transition metal complexes in synthesis, the problems of metal extraction and product purification make them less than ideal for use in applications such as synthesis of fine chemicals where contamination of the product with heavy metals is highly undesirable. There is now increasing interest in the development of polymer-bound metal catalysts and reagents for organic synthesis that maintain high activity and selectivity.[1] Advantages of attaching a catalyst to a polymer support include ease of separation from the product mixture at the end of a reaction and the fact that attaching a metal complex to a polymer can reduce the toxicity and air sensitivity of the species considerably. In addition, as the catalyst is easily removed from the reaction mixture by filtration, there is the possibility that it can be reused in subsequent reactions.

In this note, we report the preparation and synthetic versatility of the polymer-supported ruthenium complex **1**. This and other chloro-ruthenium complexes are used frequently in metal-mediated organic synthesis for a diverse range of reactions.[2] In our studies we have focused attention on transfer hydrogenation and hydrocarbon oxidation as representative reactions for comparing the activity of **1** with its nonsupported analogue $RuCl_2(PPh_3)_3$ (**2**). Work has also been focused on the effect of catalyst recycling.

Results and Discussion

Preparation of Polymer-Supported Catalyst 1. The polymer support chosen for immobilization of the ruthenium complex was commercially available "polymer-supported triphenylphosphine" (polystyrene cross-linked with 2% divinylbenzene; 3 mmol P/g resin). The immobilized complex **1** was prepared by stirring **2** with the functionalized resin in dichloromethane overnight during which time the resin beads turned from light brown to dark brown in color (Figure 1). Subsequent filtration, washing, and drying of the polymer gave a black powder, characterized as **1** by comparison of spectroscopic data with that of **2** which is also black in color. The assignment was further confirmed by elemental analysis, this also allowing us to determine the catalyst loading at approximately 0.3 mmol per gram of resin. The polymer bound complex formed is stable in air but for prolonged storage is better stored under an atmosphere of nitrogen in which case no decomposition is noted over the period of three months at room temperature.

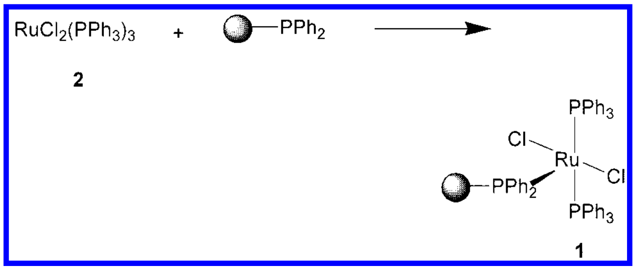


Figure 1. Preparation of polymer-bound catalyst **1.**

Use of 1 as a Catalyst for Transfer Hydrogenation. The ability of ruthenium complexes to dehydrogenate alcohols and deliver the hydrides to a ketone has made them useful as transfer hydrogenation catalysts.[3] However, the majority of methods described require elevated temperatures (150−200 °C). Recently, Bäckvall reported that base has a profound effect in hydrogen transfer catalysis using **2**.[4] The mechanism for the reaction is thought to proceed via initial attack of an alkoxide ion on the Ru complex followed by β-elimination from the alkoxide leading to an anionic ruthenium hydride complex. Following protonation of the anionic species to give a ruthenium dihydride, the reduction of the ketone by this dihydride results in the desired alcohol product. With this mechanism in mind we felt that transfer hydrogenation may be a suitable reaction for adaptation to solid-phase conditions using **1** since the M−P bond between the ruthenium center and the polymer-bound phosphine moiety may stay intact throughout the process thereby limiting the chances of catalyst leaching by direct decomplexation.

We find that, in the presence of a catalytic amount of **1**, the selective hydrogen transfer from propan-2-ol to various ketones occurs rapidly giving the product alcohols in yields comparative to those obtained using 2 as shown in Table 1. For comparative purposes, reported yields for the analogous reactions using **2** are also shown.[4] The substrate-to-catalyst ratio used in the case of the polymer-supported complex (C/S = 0.15%) is slightly higher than in the case of the homogeneous analogue (C/S = 0.10%) in order to compensate for the fact that the polymer beads do not swell totally in the solvent mixture used. Indeed the choice of solvent in which the reaction is performed proves to be very important. The homogeneous reactions are performed using propan-2-ol as the solvent; however, the swelling properties of the resin in the solvent are very low. On the other hand, 1,2-dichloroethane is a good solvent for swelling the resin, but is clearly not suitable

---

(1) For an introduction to the area see: (a) Hartley, F. R. *Supported Metal Complexes: A New Generation of Catalysts*; Reidel: Amsterdam, 1986. (b) Ley, S. V.; Baxendale, I. R.; Bream, R. N.; Jackson, P. S.; Leach, A. G.; Longbottom, D. A.; Nesi, M.; Scott, J. S.; Storer, I.; Taylor, S. J. *J. Chem. Soc., Perkin Trans. 1* **2000**, 3815.

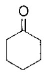
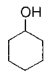
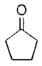
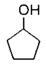
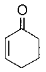
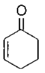
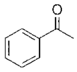
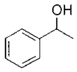
(2) See: Naota, T.; Takaya, H.; Murahashi, S. I. *Chem. Rev.* **1998**, *98*, 2599−2660.

(3) (a) Yamakawa, M.; Ito. H.; Noyori, R. *J. Am Chem. Soc.* **2000**, *122*, 1466−1478. (b) Noyori, R.; Hashiguchi, S. *Acc. Chem. Res.* **1997**, *30*, 97−102

(4) Chowdhary, R. L.; Backvall, J.-E. *J. Chem. Soc., Chem. Commun.* **1991**, 1063−1064.

10.1021/jo001497y

Table 1. The Use of 1 in Transfer Hydrogenation

Substrate	Product	Yield using 1 (%)	Yield using 2 (%)
		83	89
		62	60
		61	71
		40	48

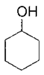
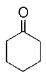
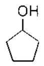
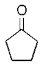
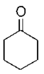
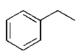
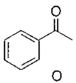
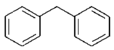
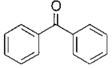
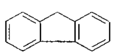
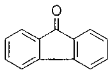
for performing the reaction. Other solvents such as THF and dioxane, when mixed with propan-2-ol, led to significant byproduct formation, and so we find that the reaction is best performed in a mix of 1,2-dichloroethane and propan-2-ol (1:2).

In an attempt to show that **1** can be recycled, the transfer hydrogenation of cyclohexanone to cyclohexanol was repeated four times using the same batch of supported catalyst. The yields remain around 80% clearly illustrating the reusability of the catalyst.

A further objective of our studies was to determine whether the catalysis was due to **1** or to a homogeneous ruthenium complex that comes off the support during the reaction and then returns to the support at the end. To test this, we focused on the transfer hydrogenation of cyclohexanone to cyclohexanol. We filtered off the resin after 30 min of reaction time and allowed the filtrate to react further. The catalyst filtration was performed at the reaction temperature (80 °C) in order to avoid possible recoordination or precipitation of soluble ruthenium upon cooling. We found that, after this hot filtration, little further reaction was observed. This suggests that the catalyst remains on the support at elevated temperatures during the reaction.

Use of 1 as a Catalyst for Oxidation Reactions. The oxygenation of unsaturated C−H bonds with metal complexes is of importance to synthetic chemists. Of the many metal complexes studied, **2** has shown a high catalytic activity when used in conjunction with *tert*-butyl hydroperoxide.[5,6] We find that similar activity is observed when using **1** in these reactions. The oxidation of a range of alcohols and hydrocarbons using *t*-BuOOH and a catalytic amount of **1** gave the desired carbonyl products in comparable yield to when **2** is used,[5,6] as shown in Table 2. Although the catalyst can be reused a number of times, work is ongoing to determine whether the ruthenium complex at the end of the first reaction (and hence that used in subsequent reactions) is the same as that at the beginning of the first reaction. One observation is that, if a sample of catalyst that has been used for the oxidation reaction is subsequently used in the hydride transfer reaction, the observed activity is lower than when a new sample of **1** is used. This indicates that either some of the catalytically active **2** is chemically modified during the oxidation reaction such that it is not active in the hydride transfer reaction. Alternatively, all the **2** is chemically modified during the oxidation reaction, and the resultant ruthenium complex is a catalyst for the hydride transfer reaction but not as good as **1**.

Table 2. The Use of 1 in Hydrocarbon Oxidation

Substrate	Product	Yield using 1 (%)	Yield using 2 (%)
		85	89
		64	60
		45	47
		80	91
		70	75
		89	100

In conclusion, we have shown that attachment of $RuCl_2(PPh_3)_3$ to polymer-supported triphenylphosphine leads to an air stable, versatile immobilized catalyst that is as active as its homogeneous analogue and has the advantage that it can be reused a number of times. Work is currently underway to exploit the activity of other polymer-supported organometallic complexes in metal-mediated organic synthesis.

Experimental Section

General. All chemicals were reagent grade and used as purchased including polymer-supported triphenylphosphine (Fluka, 3 mmol P/g resin). All reactions were performed under an inert atmosphere of dry nitrogen using distilled dried solvents.

Preparation of Polymer-Supported Ruthenium Complex 1. Commercially available polymer-supported triphenylphosphine was first washed several times with THF and then dichloromethane before being dried in vacuo and 100 mg added to a toluene solution of $RuCl_2(PPh_3)_3$ (300 mg, 0.31 mmol). The resultant mixture was agitated overnight during which time the originally light brown polystyrene beads turned deep brown in color. After cooling, the beads were filtered off using a sintered funnel and washed five times with dichloromethane and then twice with hexane before drying in vacuo to give a black powder. Loading of the ruthenium complex on the resin was found to be approximately 0.3 mmol/g resin by elemental analysis (comparison of P, Cl, and Ru content).

General Method for Transfer Hydrogenation Catalyzed by 1. To solid **1** (50 mg) were added degassed propan-2-ol (10 mL) and 1,2-dichloroethane (5 mL). The mixture was heated to reflux and then the ketone (10 mmol) added. The resulting mixture was stirred at reflux for 15 min, and then a solution of NaOH in propan-2-ol (10 mg, in 2 mL) was added dropwise. After a further 1.5 h at reflux, the mixture was cooled, the supported ruthenium complex filtered off, and the product analyzed. Spectroscopic data for the products were compared with those in the literature, showing formation of the appropriate alcohol. Yields of products are shown in Table 1.

Assessment of the Reuse of 1. The reaction of the transfer hydrogenation of cyclohexanone to cyclohexanol catalyzed by **1** was repeated four times using the same batch of polymer-bound catalyst. Between experiments the catalyst was washed with dichloromethane and dried in vacuo before placing it back in the reaction vessel. The microanalysis before and after each

---

(5) Tsuji, Y.; Ohta, T.; Ido, T.; Minbu, H.; Watanabe, Y. *J. Organomet. Chem.* **1984**, *270*, 333−341.

(6) Murahashi, S.-I.; Oda, Y.; Naota, T.; Kuwabara, T. *Tetrahedron Lett.* **1993**, *34*, 1299−1302.

reaction shows that leaching of small quantities of the ruthenium from the support is a problem that needs to be addressed in future work.

General Method for Hydrocarbon Oxidation Catalyzed by 1. To a stirred mixture of hydrocarbon (2 mmol) and **1** (50 mg) in 1,2-dichloroethane/ethyl acetate (7:1) was added a 30% solution of peracetic acid in ethyl acetate (6 mmol in 4 mL) dropwise at reflux over the period of 2 h. After 2 h at reflux, the mixture was cooled, the supported ruthenium complex filtered off, and the product analyzed. Data collected were compared with those in the literature confirming formation of the carbonyl complexes. Yields are shown in Table 2.

Acknowledgment. The Royal Society is thanked for a University Research Fellowship. Zeneca Pharmaceuticals, Pfizer, and Novartis are thanked for financial assistance. Kathryn Scott and Lucy Scott are thanked for assistance in initial experiments.

JO001497Y